THE REPUBLIC OF MAURITIUS
MINISTRY OF ENVIRONMENT, SUSTANAIBLE
DEVELOPMENT, DISASTER AND BEACH MANAGEMENT
(MOESDDBM)

THE PROJECT FOR CAPACITY DEVELOPMENT ON COASTAL PROTECTION AND REHABILITATION IN THE REPUBLIC OF MAURITIUS

FINAL REPORT

COASTAL CONSERVATION PLAN

(Volume 2)

June 2015

JAPAN INTERNATIONAL COOPERATION AGENCY

KOKUSAI KOGYO CO., LTD.
NIPPON KOEI CO., LTD.
CENTRAL CONSULTANT INC.
FUTABA INC.

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Locations of 14 Coasts for Preparation of Coastal Conservation Plans

Rate of Currency Translation

1 USD = 35.230 Rs

= 124.11 JPY

100 Rs = 2.760 USD

= 342.56 JPY

Rs: Mauritius Rupee

As of June 1st, 2015

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Abbreviations

Abbreviations	English
AAP	Africa Adaptation Programme
AC	Advisory Committee
AF	Adaptation Fund
AFD	Agence Française de Développement
AFP	Adaptation Fund Programme
BA	Building Act
BLUPG	The Building and Land Use Permit Guide
C/P	Counterpart
CA	Capacity Assessment
CADMAC	Climate Change Adaptation and Disaster Management Committee
CC	Crisis Committee
CCD	Climate Change Division
CD	Capacity Development
CEB	The Central Electricity Board
CONDC	The Cyclone and Other Natural Disasters Committee
CONDS	Cyclone and Other Natural Disasters Scheme
CSO	Central Statistics Office
CWA	The Central Water Authority
DEM	Digital Elevation Model
DRR	Disaster Risk Reduction
EU	European Union
F/S	Feasibility Study
FAS	First Aid Service
Fs	Safety Factor/Factor of Safety
GDP	Gross Domestic Product
GIS	Government Information Service
GIS	Geographic Information System
GL	Ground Level
HFA	Hyogo Framework for Action
HWL	High Water Level
HWM	High Water Mark
IC/R	Inception Report
ICZM	Integrated Coastal Zone Management
IEC	Information, Education, and Communication
IOC(COI)	Indian Ocean Commission (Commission de l'Océan Indien)
ISO	International Organization for Standardization
JET	JICA Expert Team
JICA	Japan International Cooperation Agency
JICE	Japan International Corporation Center
LGA	Local Government Act, 2003
LMU	Landslide Management Unit
M/M	Minutes of Meeting
Mauritius	The Republic of Mauritius
MBC	Mauritius Broadcasting Corporation

Abbreviations	English
MEHR	Ministry of Education and Human Resources
MGCW	Ministry of Gender Equality, Child Development and Family Welfare
MHL	Ministry of Housing and Lands
MHQL	Ministry of Health and Quality of Life
MLG	Ministry of Local Government & Outer Islands
MMS	Mauritius Meteorological Services
MoESD	Ministry of Environment and Sustainable Development
MOESDDBM*	Ministry of Environment, Sustainable Development, Disaster and Beach Management (*Former MoESD)
MoFED	Ministry of Finance and Economic Development
MPI	Ministry of Public Infrastructure, National Development Unit, Land Transport and Shipping
MSL	Mean Sea Level
MSS	Ministry of Social Security, National Solidarity and Reform Institutions
MTEF	Medium-Term Expenditure Framework
MTL	Ministry of Tourism and Leisure
MTSRT	Ministry of Tertiary Education, Science, Research and Technology
NDOCC	National Disaster and Operations Coordination Centre
NDS	National Development Strategy
NDU	National Development Unit
NGO	Non-Governmental Organization
ODA	Official Development Assistance
OPS	Outline Planning Schemes
P.Fs	Planning/Designed Factor of Safety
P/R	Progress Report
PBB	Programme-Based Budgeting
PDA	Planning and Development Act
PEFA	Public Expenditure and Financial Accountability
PFM	Public Financial Management
PIU	Planning and Implementation Units
PMO	Prime Minister's Office
PMS	Performance Management System
PPG	Planning Policy Guidance
PS	Permanent Secretary
PVC	Polyvinyl Chloride
R/D	Record of Discussion
SC	Steering Committee
TAS	Treasury Accounting System
TCPA	Town and Country Planning Act
The Disasters Scheme	The Cyclone and Other Natural Disasters Scheme
The Project	The Project for Capacity Development on Coastal Protection and Rehabilitation in the Republic of Mauritius
TICAD IV	The Fourth Tokyo International Conference on African Development
UNDP	The United Nations Development Programme
WCDR	World Conference on Disaster Reduction

Chapter 1

Baie de Tombeau

1 Baie du Tombeau

1.1 General

The site is located at the north west coast and receives waves by the cyclone from northwest. The coast is convex of 5 km long. At the south the lagoon is 4km long with 500m of width in front. At the north the coast is rocky and 1km long without reef. At the north end the River du Tombeau flows and formed sandy beach. Houses, bungalows, hotels and a public beach are located along the coast.

The beach is almost stable at present though eroded in old days. At the south two sand bars were formed in the lagoon with an accreted beach. A part of vertical revetments and trees were damaged though it was limited. The bridge to the public beach were damaged and removed recently. Then the accessibility to the public beach becomes difficult.

1.2 Coastal Conditions

1.2.1 Waves and Tides

Main waves are generated by cyclones because the coast faces to the northwest. The tidal range at a spring tide is 0.5m estimated from the observation at Port Louis. The water level in a lagoon has to be considered the storm surge and the wave setup together with the tide.

1.2.2 Beach Condition

The beach is formed at the foot of concave lava plateau as shown in Figure 1.2.1 by coral sand and debris with 500m wide lagoon. Two water courses, Rivulet Terre Rouge and River Tombeau flow out at the both end of the coast and coral reef is absent.

At the north end of Le Goulet, beach and sand bar are formed by the sediment from River du Tombeau, coral sand and debris of cliff erosion.

At the south the vertical walls were constructed within the DBZ (dynamic beach zone) and they were damaged over time by cyclones and storms as shown in the Photo C in the Figure 1.2.2. The remains were scattered in front of the damaged wall. There were also no beaches in front of the vertical walls.

There is presence of a mature tree (Badamier) with exposed roots within the dynamic beach zone in front of leased site of Loretto Institute as shown in the Photo D in the Figure 1.2.2. The roots of the tree were washed by waves and became difficult to support upper parts of the tree. This also disturbs the accumulation of sediment at the beach.

JICA Expert Team modified based on Google Earth (5/16/2014)

Figure 1.2.1 Coast of Baie du Tombeau and Photos Position

Photo A Public Beach and River Mouth at Le Goulet (3/6/2012)

Photo B Pedestrian Bridge Crossing the River Tombeau at Le Goulet (3/6/2012)

Photo C Damages Vertical Wall (3/6/2012)

Photo D Wave Washed Roots of a Tree (3/6/2012)

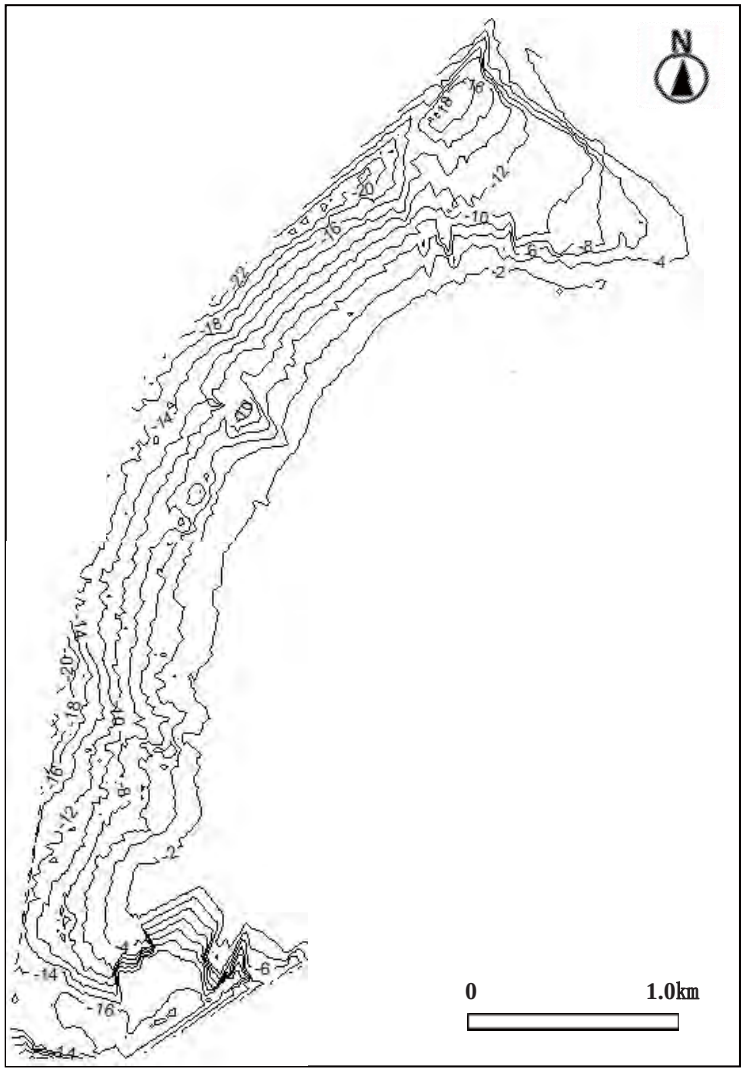
Photo E Accumulated Low Beach at the South (16/7/2014)

Photo F Lagoon Use as Anchorage at the South (16/7/2014)

Source: JICA Expert Team

Figure 1.2.2 Coastal Condition at Baie du Tombeau

The bottom profile was surveyed by MOI and the bathymetric map is shown in Figure 1.2.3. In the lagoon the ground height is above -2m (MSL) and has no big changes. The offshore slope of the reef is about 1/30 until 20m deep.



Source: JICA Expert Team drew from the raw data of MOI

Figure 1.2.3 Bathymetric Map at Baie du Tombeau

1.2.3 Reef Environment

As shown in Figure 1.2.4, the coverage of corals was estimated as 60% and was evaluated as "good" by the evaluation criteria of Japanese Ministry of Environment. The recruitment of juvenile *Acropora* was zero per square meter. Many patch reefs scattered around the monitoring site and branching-type *Acropora* and massive *Porites* were abundant. Number of species was high and diversity was also rich. Also skeleton of branching-type *Acropora* was abundant among patch reefs. Coverage of living corals was high, but many coral diseases were observed, so we need to pay attention to the coral diseases in the future. Transparency was 10 m and siltation was low. In the opposite coast, Le Goulet, living coral coverage was estimated as 15% dominated by massive corals. But, many corals were partly dead due to the siltation on these corals. According to the aerial photographs taken in 1996 and results of its analysis, most of corals seemed to be alive at back reefs and shore reefs in the north of the lagoon. However, at

present most of the living corals seemed to be decreasing.

Source: JICA Expert Team modified based on Google Earth

Figure 1.2.4 Coral Condition at Baie du Tombeau and Le Goulet

The investigation results on water quality and impacts to coral in the lagoon at Baie du Tombeau are shown in Table 1.2.1. According to the results of water quality monitoring by AFRC, the considerably-high concentrations for NO_3, PO_4 and COD ($NO_3$and $PO_4$with higher than 0.2 mg/L and COD higher than 2 mg/L) were detected and deteriorated from 2001 to 2003. However recently, very high concentration has been no longer detected. Chlorophyll a in the vicinity of the coast is significantly high (1.74 ug/L) and at a level that corals can hardly live (the coverage of living coral is less than 10%). It is in eutrophication state. The coast is a densely populated areas (population density: 1,964 /km^2) and sewerage system is almost operated. However, still a considerable number of households are using AP (absorption pit) or ST (septic tank). As the cause of the eutrophication, the effects of drainage from the houses not connected to the sewerage system are considered.

Table 1.2.1 Investigation Results on Water Quality and Impact to Water Quality in Lagoon

Check items		Conditions
Water quality	Chlorophyll a (ug/L)	1.74(*)
	Turbidity (NTU)	-
	NO_3-N (mg/L)	-
	PO_4-P (mg/L)	-
Population density behind coast(per km^2)		1,964
Sewerage disposal behind coast	Status of development of sewerage facilities behind coast	Sewerage Systems (Trunk Sewer), Absorption Pit, Septic Tank,
	Present condition of sewerage disposal from houses (Sewerage system, Septic tank, Pending arrangement, etc.)	Baie du Tombeau VCA: SS: 3422, AP: 414, ST: 82
	Present condition of sewerage disposal from hotels and restaurants (Sewerage system, Septic tank, Pending arrangement, etc.)	Hotels >75 rooms uses onsite treatment plants. Restaurant uses septic tanks.
	Development plan of sewerage system for houses and hotels behind	Sewerage Systems Completed in Year 2010.

	coast				
Impact of pollution from sugarcane	Incidence of red-soil runoff from land side	Yes. River Mouth. Reef Dist. 1.7 km			
	Existence of sugarcane field behind coast. If there is it, area of the field behind coast.	Yes. Area: 118 Ha			
Relation between living coral and water quality**	Coral coverage	Chlorophyll a (ug/L)	Turbidity (NTU)	NO_3-N (mg/L)	PO_4-P (mg/L)
	>50%	<0.2	<0.5	<0.012	<0.007
	20-50%	0.2-0.6	0.5-1.3	0.012-0.051	0.007-0.016
	10-20%	0.6-0.9	1.3-1.9	0.051-0.081	0.016-0.023
	<10%	>0.9	>1.9	>0.081	>0.023

*: Observation for water quality was conducted close to shore.
**: This relation was obtained by the water quality survey in this study. Refer to Table 2.6. 3 in Vol.1.
SS: Sewerage Systems, Ap: Absorption Pit, ST: Septic Tank, PL: Pit latrine
Source: JICA Expert Team

The lagoon monitoring report 2014 explains the sewage condition of the area as follows. The village has an estimated resident population of 13,616 comprising 3,752 households (CSO, 2012). Private bungalows are found all along its coast with 6 operating textile industries (EPZ, 2010) and three small hotels, namely Corotel (Belle Rive Hotel:21 rooms), Les Cocotiers (48 rooms) and Pension Arc en Ciel (25 rooms) with a total of 94 rooms.

Untreated sewage including industrial effluent from Port Louis and Roche Bois was being discharged at a sewage outfall approximately one metre off the shoreline at Mer Rouge near the Portico till the end of 2001.

In February 2002, the new sewage outfall came into operation at Baie du Tombeau. It caters for wastewater from Port Louis North, Fanfaron, Plaine Verte, Abercrombie, Cite la Cure, Cite Roche Bois, Cite Mer Rouge, Cite Ste Croix, Camp Florida and Camp Florida NHDC, Morcellement Coprim, Morcellement Cocheyle, Morcellement Swan, Elizabeth Ville, Morcellement La Concorde, Riche Terre Industrial Zone and Baie du Tombeau coastal road.

As at December 2010, out of 3,752 households, 3,145 were connected to the sewer network. No household connection was made in 2011. Twenty (20) house connections were made in Baie du Tombeau in 2012 and 19 in 2013 making a total of 3,184 connections.

The wastewater from the mentioned regions, before being discharged through the sea outfall, undergoes only preliminary treatment at the Baie du Tombeau wastewater treatment plant. The outfall discharges wastewater beyond the reef at a depth of about 35 m and at a distance of 950 m from the reef and 1,407m from the High Water Mark at Pointe Roche Noires (WMA, 2003).

There have been general improvement in the water quality at Baie du Tombeau, except at Rivulet Terre Rouge (BTB1) and Nassau Bay (BTB2) where frequent high levels of total and fecal coliforms have been observed from 2010 to 2013 as compared to 2009. Both the stations BTB1, situated at the mouth of Rivulet Terre Rouge and station BTB2, the Nassau Bay about 100m from mouth of Rivulet Terre Rouge, are influenced by contamination from run-off following heavy rainfall.

It is to be noted that the sewerage from part of the houses found within the catchment area of Rivulet Terre Rouge would be treated under the sewerage project Phase III as from 2017 subject to availability of funds and consideration could be given to include in the project area at

least all the houses lying along Rivulet Terre Rouge (MEPU, 2011).

1.2.4 Coast Use

The beach use is not popular because the material is sand with rubble. There is only one public beach in this coast at Le Goulet and the rest of the coast at Baie du Tombeau is leased sites or privately owned sites. The public beach located at Le Goulet is used by local people.

The calm area behind sand bars is used for anchoring of fishing and leisure boats. The road runs along the coast with bungalows and hotels on the seaward side. It is possible that the beach use will become popular after the office and housing development under construction at the north plateau. The coastal condition and problems are summarized as shown in Table 1.2.2.

Table 1.2.2 Condition of Baie du Tombeau

Basic investigation No.	No. 1 (Sediment Cell No.1)	PB No.	No. 1
Coast name	Baie du Tombeau (Lorrette)、Le Goulet		
Natural and topographic characteristics	Sea state	Cyclonic waves are arriving from the north.	
	Topography	Convex coast with about 500m-wide lagoon Most of the west side is a gravel beach, while the north side is a sand beach.	
Environmental characteristics	Coral reef	Coral reef coverage near the beach is around 60%. According to the results of coral reef monitoring by AFRC, coral reef coverage around the reef edge is on a declining trend from 2000 to 2010.	
	Water quality	Transparency is about 10m and siltation is low. Though the water quality (COD, PO_4) was deteriorated from 2001 to 2003, the current water quality is relatively good.	
Coastal transformation characteristics	Disaster and structures	The seawall was partially destroyed and trees fell down. This is not directly caused by erosion, but by the fact that the renter (personnel) has used the coast without securing buffer zone.	
	Coastal transformation	According to the results of topographic interpretation by aerial photos, the shoreline is retreating at a rate of 0.1m/year at maximum at the northern part and at the south part, there is accumulation of sand at a rate of 0.3m/year. No wide-scaled coastal erosion is observed. However, the foundation of the pedestrian bridge crossing the river-mouth at north side of beach (Le Goulet) is exposed, and the river-mouth sandbar is varying.	
Coastal utilization characteristics	Beach utilization	Though beach is public beach, beach utilization itself is restricted. The hinterland is a small-scaled cottage area.	
General assessment		The coral reef is in good condition with a low eroding speed, and no development is planned for the hinterland. In light of these facts, the necessity of creating a protection program is considered not so high. More priority should be given to individual measures such as forest management and river-mouth processing rather than countermeasures against coastal erosion in the whole area under the project.	

Source: JICA Expert Team

1.3 Coastal Process

1.3.1 Shoreline Change

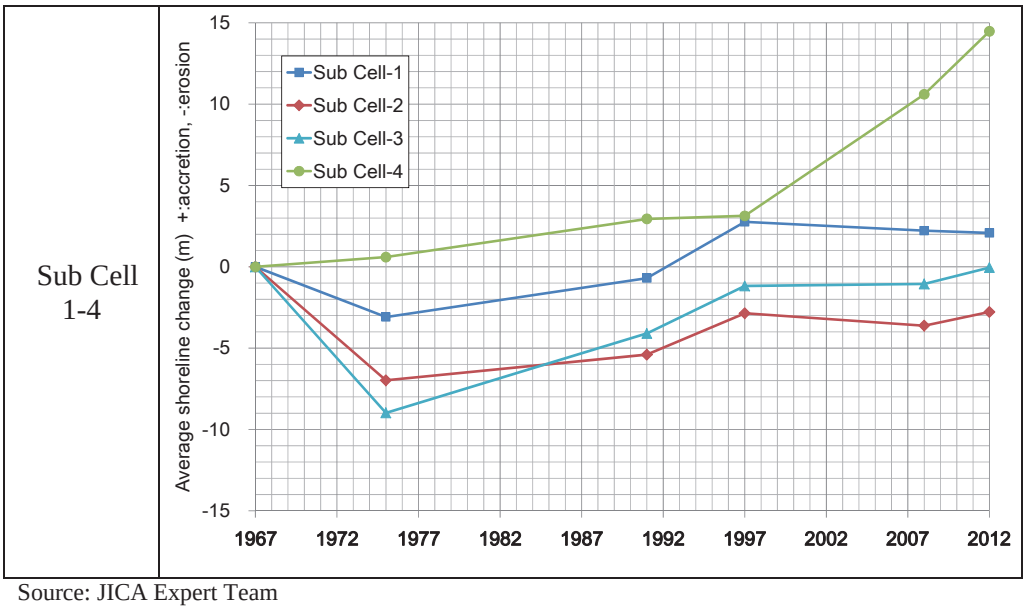
The studied area of shoreline change divided into 4 sub cells by aerial photograph is shown in Figure 1.3.1. The long term changes are erosion at the sub cell No.2 and accretion at No.4 with stable at No.1 and No.3.

The shoreline changes of each sub cell are shown in Figure 1.3.2. The shorelines were eroded except sub cell No.1 from 1967 to 1975. After that the whole shoreline shows a tendency of accretion. The sub cell No.2 is still eroded from 1967 however it is not serious. The sub cell No.1 at the south shows 15m accretion from 1967 and 10m after 1997.

The sediment budget at each sub cell is shown in Figure 1.3.3 and Figure 1.3.4. The beach in a whole is accreted and the volume reached about 20,000m^3 from 1967. The accretion No.4 is large compared to the other sub cells.

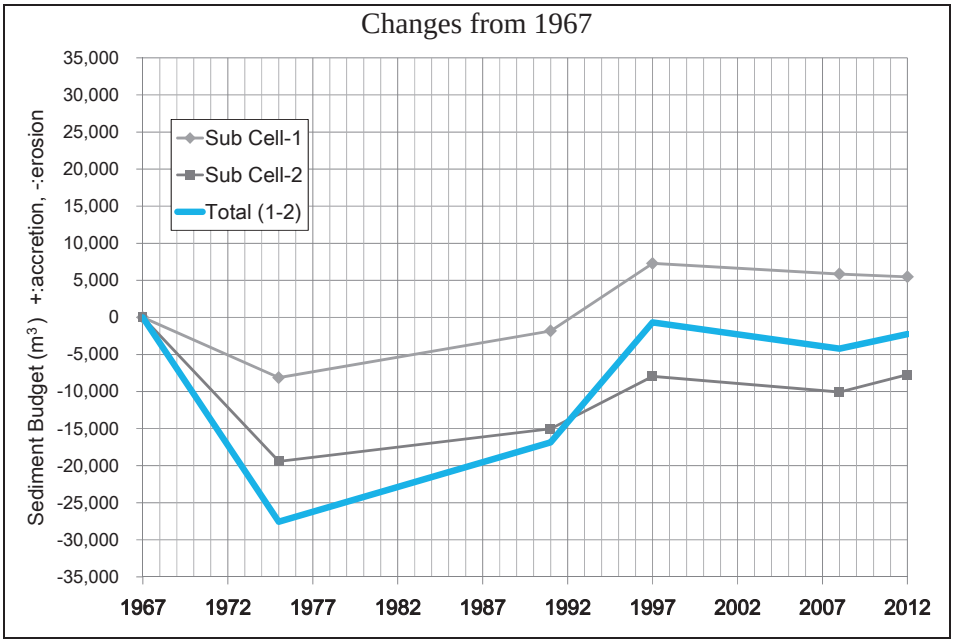
(Source: JICA Expert Team modified based on the material from MHL)

Figure 1.3.1 Location of Sub Cell and Erosion at Baie du Tombeau



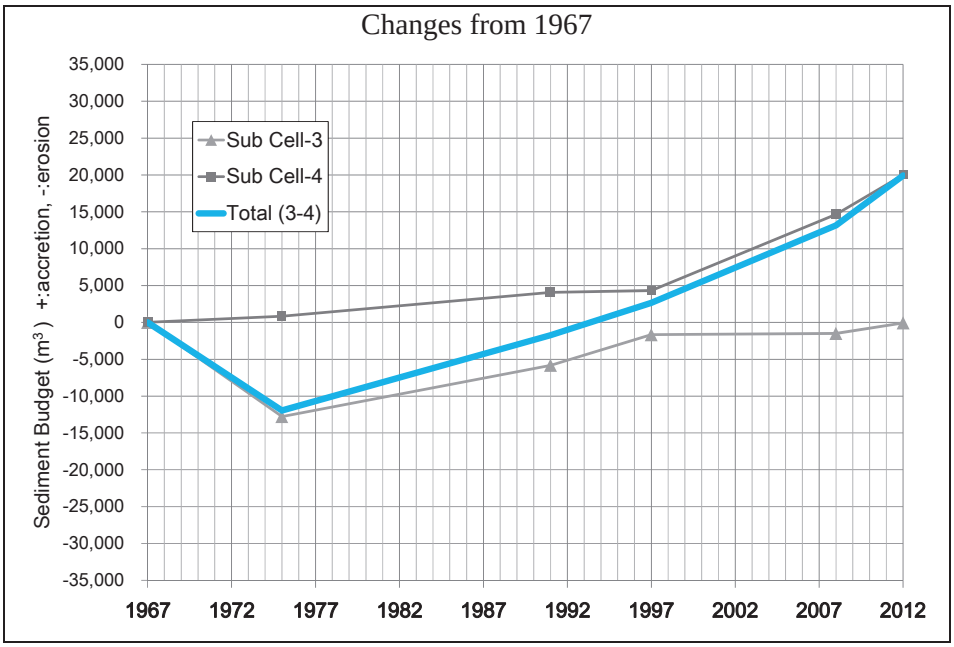
Source: JICA Expert Team

Figure 1.3.2 Shoreline Changes (Sediment Cell No.1)



Source: JICA Expert Team

Figure 1.3.3 Sediment Budget at Baie du Tombeau (Sediment Cell No.1, Sub Cell-1-2)



Source: JICA Expert Team

Figure 1.3.4 Sediment Budget at Baie du Tombeau (Sediment Cell No.1, Sub Cell-3-4)

1.3.2 Sediment Transport

The beach is formed of coral sand and rubble. They are produced at the reef edge by high waves and transported by reef current to the beach. Some parts are deposited and the others are transported by longshore current. A part of the coral rubble deposits because of strong waves and currents in the lagoon. Here after 1991 the rubble deposited at two sites in the south lagoon and increasingly formed sand bars. On the main landward side of the bar the sand is accreting on the beach by the weak waves and currents.

The formation of one of the sand bars located at the south on the Figure 1.2.1 is shown in Figure 1.3.5. The sediment transported from offshore increases the area of the sand bar. In 1991 the sand bar was not existed and increased to the area of 26,000m^2 in 2011. The volume becomes about 50,000m^3 if the deposited height is assumed to be 2m.

The sand bar is acting as a breakwater and is breaking the wave energy leading to accumulation of sand on the landward side of bar. Erosion can also be seen on both sides of the accumulation area, though the amount is small.

Sand Bar Area 10,000 m^2 (2003) | Sand Bar Area 12,600 m^2 (2006)

Sand Bar Area 22,800 m^2 (2008) | Sand Bar Area 26,100 m^2 (2011)

Source: JICA Expert Team modified based on Google Earth

Figure 1.3.5 Temporal Change of Sand Bar in the Lagoon of Baie du Tombeau

The sand bars are increasing and made of coral cobble. Then cobble can be used for beach nourishment and prevention of scouring in front of vertical revetment. In this case the amount of dredging should be smaller than the increase of the sand bars by monitoring to keep the shape. Also the environmental impact assessment is necessary. The sand bar contributes to stabilize the beach. If the shape is changed, it brings the beach changes of erosion and accretion. The removing of coral coble also impact on the ecosystem in the lagoon. The coral coble in the lagoon is important resources. Then it is necessary to consider sustainably for the use of coble.

At the north of the coast the River du Tombeau flow out at Le Goulet. Mineral sand is mainly deposited from the river at the flood and the adjacent beach by waves. The sand bar at the river mouth changes by floods and waves as shown in Figure 1.3.6. The pedestrian bridge between Baie du Tombeau and Le Goulet was damaged at the abutment by the flood of March 2013. Now the both sides of the bridge were broken for the safety and became impassable. The access

from Baie du Tombeau to the public beach is one of the problems.

Source: JICA Expert Team modified based on Google Earth

Figure 1.3.6 Change of Sand Bar and Beach at the River Mouth of Le Goulet, Pedestrian Bridge Damaged at March 2013

1.4 Coastal Conservation Plan

1.4.1 Problems and Related Factors

Most of the beach is accreting except for a part which is eroded, though the scale is small. The revetment and trees located within the dynamic beach zone were partly damaged by wave action. The pedestrian bridge from La Goulet to the public beach was damaged by flood of 2013 and has been removed in 2014. Those problems will be solved in a short term and partly.

If the condition of the past is continued, the sand bars at the south of the lagoon will increase and the beach will accrete at the landward side of the sand bar and erode at the both side. The increase of sand bar brings the accumulation of sediment in a whole reef and partial erosion of the beach. The dynamic change of the beach is within the setback and it seems not to be big problems.

At the north part of the lagoon the transparency was 10m and the coral coverage was 60%. However the transparency from the middle to the south is not good and the sedimentation of silt seems to be large in general. Coral and seagrass were existing from 1994 to 1996 at the

north and they are decreased at present. It is possible the supply of coral sand and the effect of wave dissipation will decreased in future.

The future climate change impacts the decrease of sediment supply to the beach by the degradation of coral with beach erosion. The degradation seems not to cause the erosion immediately however in a long term the impact will appear. The sea level rise and intensified cyclone causes wave run-up problems. The impact will be limited in a low land area because the beach has plateau in the rear in this country. It is difficult to specify the low land because of the lack of accurate topographical map. Then it is necessary to prepare risk map by the better topographical information and to regulate the land use.

1.4.2 Short Term Action

First as the basic policy is to keep the setback line for the dynamic beach. A part of coast has problems and it is better to response individually because the problems are limited in a whole. The damage of revetment will be solved improving to make the slope gentle or to put riprap at the foot because the vertical one tends to bring scouring in front. The falling tree is cut down if it is old and difficult support by the root.

One of the measures for improving the reef environment is the monitoring of water quality with high accuracy to understand the condition of eutrophication. First the impact of activities in the reef related to the conservation of coral reef and seagrass should be investigated. The existing guidelines and regulations should be reviewed in line with new findings on coral reef water quality. Continuous monitoring is being undertaken by MOESDDBM, Ministry of Fisheries, Ministry of Health, and WMA.

The bridge at the mouth of Le Goulet seems to be reconstructed because it is one of the accesses to the public beach. At the mouth the beach changes largely by the wave action and flooding. The abutment of the bridge should be located at the position where no impact of beach changes. If it is not possible to relocate the structures, the abutment is designed to be stable against the action of external forces.

The existing abutment was located in the changing area as shown in Figure 1.3.6 and the dimension was large with receiving impacts of scouring and flow force. Then the abutment was damaged. The scouring depth usually becomes the same scale of the abutment which was about 5m. This brought the corruption of the abutment. The BA will reconstruct the bridge.

Training walls were proposed by residents/hotel owners at Le Goulet to control the flood flow of River Tombeau as measures to minimise accumulation of sand at the mouth of the river. They are not suitable because of the scouring caused by the flood if the width is not wide and the impact on the adjacent beach of erosion and accretion caused by the obstruction of sediment movement. It is necessary to investigate the phenomena and functions of the river mouth. At Le Goulet there are no coral reef because of the flood flow from the River du Tombeau. The sand bar at the river mouth forms wetland of the upstream. The siltation in the wetland contribute to the coral growth at the both side beach of the river mouth. If the river mouth is increased for the navigation, the function of siltation is lost and it gives impacts on the coral. Then it is necessary to assess the impact of river mouth improvement and to mitigate the impact by EIA.

The drainage at the public beach of La Goulet was discussed. Since the drainage flows from the plateau and there is no low area, the drained water can be guided smoothly to the sea

based on the topographic survey results without river mouth clogging.

1.4.3 Long Term Action

For the long term action it is necessary to monitor the change of sand bar and related shoreline and the condition of coral as short term action. If the present condition continues, the beach will accrete at the south. However the beach at the accreted area is not high enough to prevent wave run-up caused by cyclones and future sea level rise. Then it is necessary to keep the present setback line and to regulate the construction of structures. Wave run-up or inundation causes problems on the low beach if the shoreline and HWL (high water line) move offshore.

The monitoring will be conducted by the photograph taken from a helicopter. The points of interest are (1) the change of shoreline, (2) the change of sand bar in the lagoon, (3) the condition of coral and seagrass in the lagoon, (4) structures along the coast. Those conditions can be analysed from the aerial photograph georeferenced as GIS data.

The results of the monitoring will be applied for the management of coastal zone. The important is (1) the regulation of structures in the setback line, (2) the setting of setback line according to the change of offshore sand bars, (3) the replantation of coral and seagrass and coastal vegetation. The source for the coral farming to the other area can be taken because the bed material is not fine and the siltation is suppressed.

The coral farming is possible from the monitoring results if water quality is appropriate and the coral coverage is high. In this case, the regulation of water quality is necessary from the development of hinterland for the prevention of water contamination. Also the siltation by the flood water from the River du Tombeau will impact on the water quality. The effect of deposition at the river mouth has to keep even if it is developed to give some possible locations.

The coordination on the monitoring on water quality, state of corals and beach changes will be done by MOESDDBM from the point of ICZM. The results should be distributed widely and MoF, MOI and UM can analyse as their role. The measures can be done by the each organization with the discussions. Those activities become continuous with the consultation of local people.

If the eutrophication becomes clear in the lagoon from the water quality monitoring, the improvement of sewage system by the connection of sewage from private houses as examples.

1.5 Coast Maintenance Plan

1.5.1 Maintenance Plan

The following items should be considered as coastal maintenance plan for the beach.

- The monitoring of the construction of structures in the setback zone is necessary to decrease the impact on the beach and the risk of disasters.
- Corals and rubbles shall not be removed from the shore.
- The dynamic beach zone should be vegetated with veloutiers, grasses, creepers to keep

the sand.

- It is possible to use pebbles in front of vertical walls to minimize effects of waves on the vertical revetments.

- It is necessary to control fishing activities such as large nets in the lagoon.

1.5.2 Validity of Setback Amount

The setback amount for eroded sand beach is configured as summation of the amount of erosion during a certain period, the amount of erosion which is caused by strong wave such as cyclones in that period, and the erosion due to the SLR (sea level rise) is anticipated in future which is described as following.

Amount of setback = Amount of erosion for a long period + Amount of erosion by temporally event (i.e. extreme weather conditions such as cyclones) + Erosion amount due to SLR

There are several proposed equations to estimate the amount of erosion due to the SLR. Among these, the equation proposed by Per Bruun is applied generally. The equation is as follows.

$E=C\times S$,

Where, E: Erosion amount due to the SLR, C: coefficient of beach characteristic and S: amount of SLR.

The rate of the SLR from 1987 to 2011 is about 3.9mm/year in average, and the coefficient of C, which is related with the inverse of sea-bottom slope and transportation area of sediments, is set as 10 by the mean sea-bottom slope in Mauritius. The erosion amount due to the SLR, therefore, is calculated as 1.6 m by multiplying averaged erosion rate of 3.2mm/year, the coefficient of 10, and the period of 50years ($E=10\times 3.9mm/year\times 50years=2m$).

The amount of setback becomes 20m if the period is assumed 50 years, the erosion rate of 0.1m, and temporally erosion at the maximum caused by Cyclone Carol of 13m. (Refer Vol.1 Ch. 2). Then the amount is under the present value of 30m.

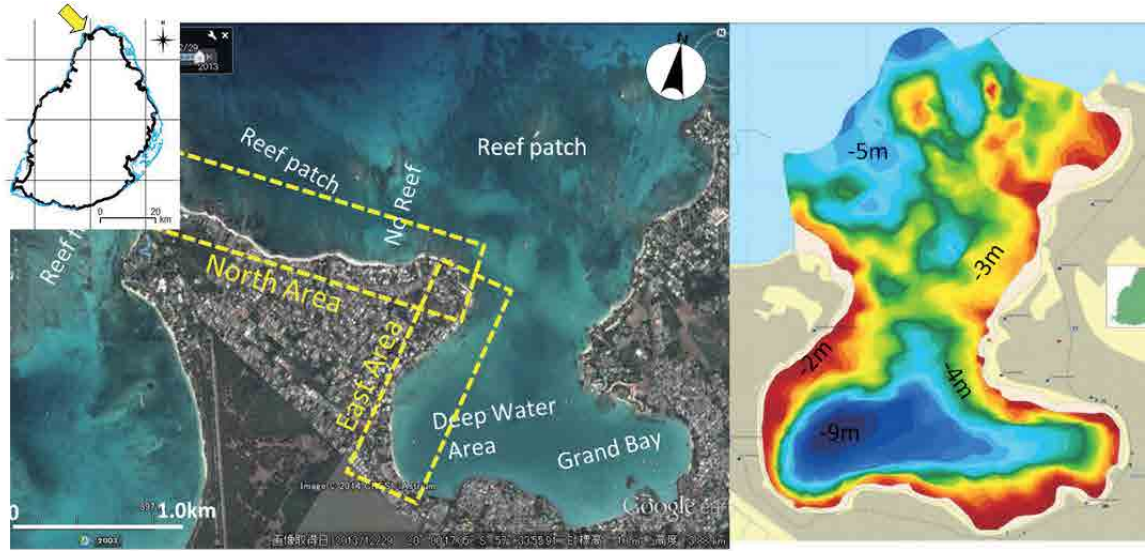
Amount of setback= 0.1*50+13+2=20m

Chapter 2

Pte. aux Cannoniers

2 Pte. aux Cannoniers

2.1 Outline of Coast



Source: Processed by JICA Expert Team based on Google Earth and data from MOI

Figure 2.1.1 Pte. aux Cannoniers Coast

The coast of Pte. aux Cannoniers is divided into two areas. A 2km-long north-facing stretch of east-west coastline and an eastern area, a 1.4 km stretch of north-south coast in Grand Baie ; as shown in Figure 2.1.1.

a. North area

In the western end of the north area there is a coral reef that continues on from Mon Choisy. It is initially about 300m wide and decreases rapidly to the east before finally disappearing. However, coral reefs exist offshore. At the east of the north area there are no coral reefs at the entrance to Grand Baie and it is deeper than other areas. There are hotels in the west and houses and holiday homes occupy all other areas. There is only one public beach at the east end of the north area. The coastline is not uniform because of the presence of a rock reef and offshore topography with white coral sand.

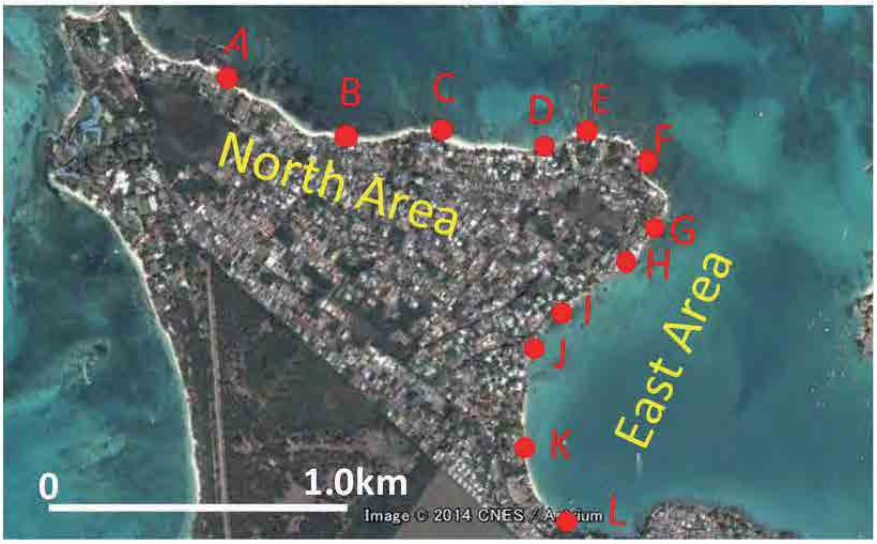
b. East area

The east area is located in the Grand Baie. The north is rock reef zone and the south is sandy beach with limited scattered rock reefs. The inner reaches of the bay is deeper than at the entrance, especially at the west side of wide area, as shown Figure 2.1.1. The coast is used for small hotels, holiday homes and houses. The sandy beach disappears beyond the groyne at the south end and there are no sandy beaches along the inner reaches of the bay.

2.2 Present Condition

2.2.1 Site Reconnaissance

Coast photos taken from the point in Figure 2.2.1 are shown in Figure 2.2.2 at the north area and in Figure 2.2.3 at the east area.



Source: Processed by JICA Expert Team based on Google Earth

Figure 2.2.1 Position of Photos

a. North area

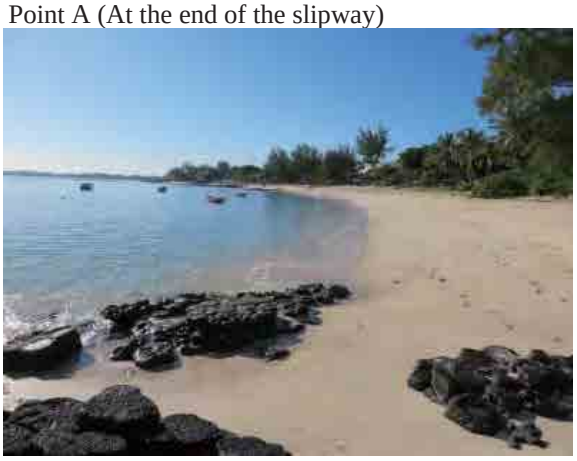
The littoral drift eastward is estimated from the west end toward the vicinity of the central part by the coastline changes of both sides of the ramp at the point A, and the coastlines shapes at the point B and C (refer to Figure 2.3.1). At the points B and C there are wide beaches. The beach sand is coarser compared with the sand of Mon Choisy and many coral gravel is scattered on the beach. The berm is high and the slope is steep from 1:5 to 1:7. The waves are estimated higher than those at Mon Choisy from such beach conditions. The beach is disappeared in front of the vertical revetments at the points D and E. At the point F near the eastern end, there are rock reefs, gravels and accumulation of gravels in the sand traps set by the lessees.

b. East area

The presence of southward littoral drift is clear from the entrance of Grand Baie (at the north) to the bottom of the bay (at the south) by the coastal condition at the east area (point G and H). At the northern end there are small hotels that established groynes by themselves to control the littoral drift to the south with the aim of ensuring a sandy beach in a limited range. The point I, was designated last year as a public beach, however, there is no sand beach in the front part so gabions were installed for land protection. MOESDDBM has already removed the gabions and gravels placed. At point J, is a residential area, there is no sandy beach and the coastal condition is the worst of these areas. And each lessee individually took measures such as small groynes and revetments which lead to the collapsing of littoral drift balance causing the adverse effect to the south. Point K, is 200 m before the southern end groyne and from this point the sand beach appears to form a curved coastline to the south groyne. Ahead from the Point L, which is the groyne at the southern end point, the sandy beach completely has disappeared, and it is the last groyne that is fully stopping the southward sand drift in this area.

Point A (At the end of the slipway)

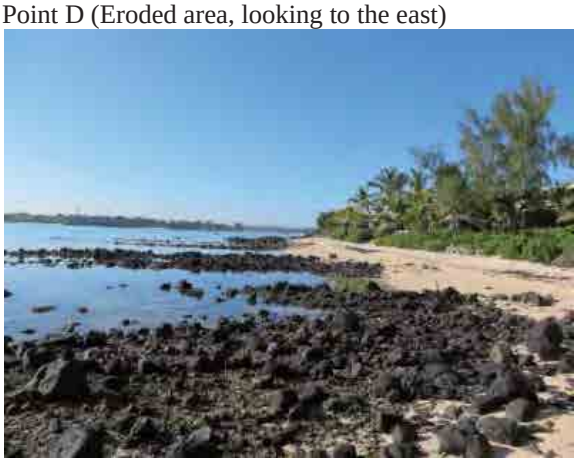
Point B



Point C

Point D (Eroded area, looking to the east)

Point E (Eroded area, looking to the west)



Point F (East end)

Source: JICA Expert Team

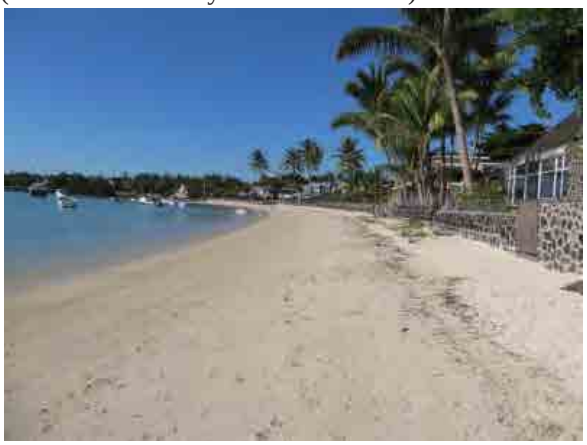
Figure 2.2.2 Coastal Condition at the North of Pt. aux Cannoniers (May 2014)

Point G (Small hotel)

Point H (Small hotel)

Point I (Public Beach)
(Gabion was already removed in 2014)

Point J (Lease area)



Point K (Before the south end groyne)

Point L (Looking from the south end groyne to the north)

Source: JICA Expert Team

Figure 2.2.3 Coastal Condition at the east of Pt. aux Cannoniers (May 2014)

2.2.2 Long Term Coastline Change and Sediment Budget

a. North area

The aerial photos in 1967 and satellite images in 2008 are shown in Figure 2.2.4 at the north

area. Enlarged photos of the eroded area at the east of the north area are shown in Figure 2.2.5. The coastline in 1967 is shown as a blue line and the coastline in 2008 as a red line. The sediment budget at each sub cell from at six points in time between 1967 and 2012 is shown in Figure 2.2.6. The conversion to the sediment budget from the obtained shoreline change was to multiply the height of sediment movement which was assumed 2.5m from the field observation result.

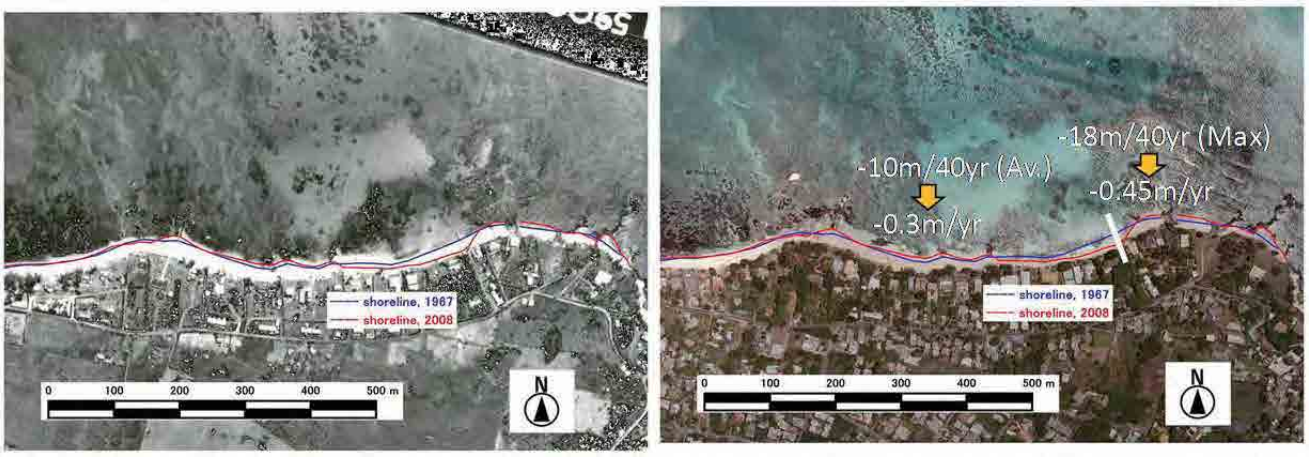
- The erosion at the east sub cell No. 3 of 200 m is significant and the coastline eroded 10 m on average within 45 years with the maximum of 18 m. The beach was eroded from 1975 to 1997 with no large changes as shown in Figure 2.2.6. The causes of the erosions seem to be the high waves by the large cyclones.

- Large cyclones seemed to attack to the north coast of Mauritius from 1975 to 1997 with high waves. The Cyclone Gervaise in 1975, Cyclone Claudette in 1979 and Cyclone Hollanda in 1994, which have occurred in this area, were one in ten year large scale cyclones. These cyclones took the courses as shown in Figure 2.2.7 from north directly to Mauritius and caused high waves at the north coast. Waves came directly to the beach because of the lack of reefs in the front of the northern eroded beach.

- The total sediment loss over 45 years at the eroded sub cell No.3 was about 5,000 m^3 and about 8,000 m^3 during a period of heavy erosion from 1975 to 1991. The other sub cells were stable. At the west end of sub cell No.1 the beach was accreted before 1997 and after that the beach was eroded. The sediment loss volume was about 10,000 m^3 from 1997 to 2012.

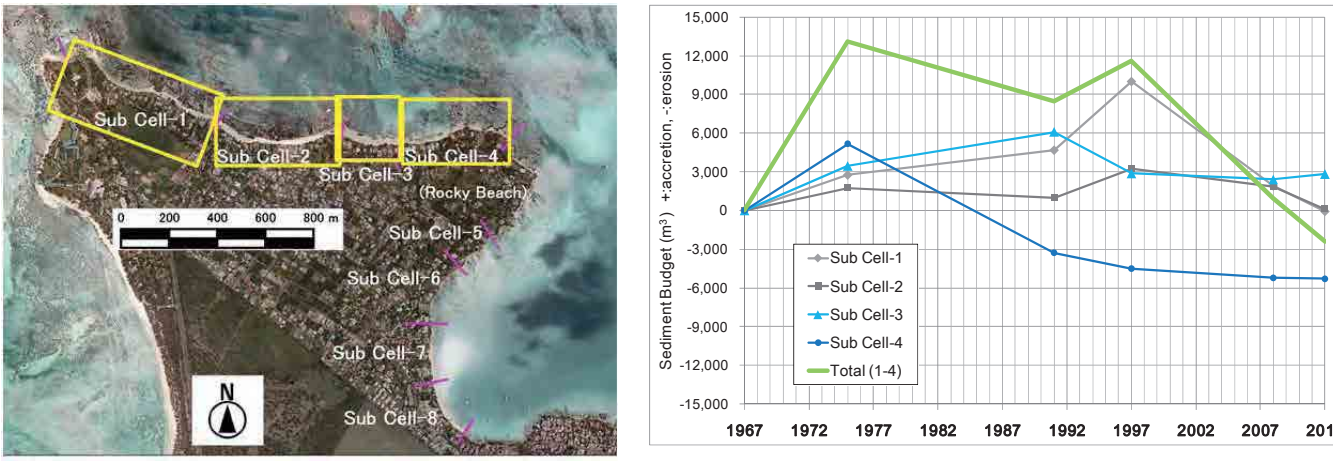
Source: Processed by JICA Expert Team based on Google Earth and the data from MOI

Figure 2.2.4 Comparison of Aerial Photo (North area), (left:1967, right:2008)



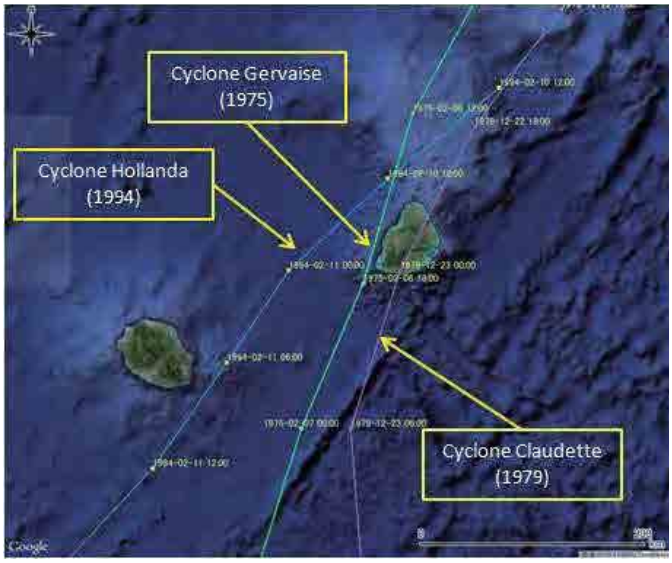
Source: Processed by JICA Expert Team based on the data from MHL and Google Earth

Figure 2.2.5 Comparison of Aerial Photo (Eroded south area), (left:1967, right:2008)



Source: Left; Processed by JICA Expert Team based on the data from MHL and Google Earth, Right; JICA Expert Team

Figure 2.2.6 Sediment Budget at Each Sub Cell



Source: Joint Typhoon Warning Center

Figure 2.2.7 Routes of the Three Cyclones

b. East area

The aerial photo in 1967 and satellite image in 2008 is shown in Figure 2.2.8 at the east area. Enlarged photo of the eroded area at the middle of east area is shown in Figure 2.2.9. The coastline in 1967 is shown as a blue line and the coastline in 2008 as a red line. The sediment budget at each sub cell at six points in time from 1967 to 2012 and the total amount of change are shown in Figure 2.2.10.

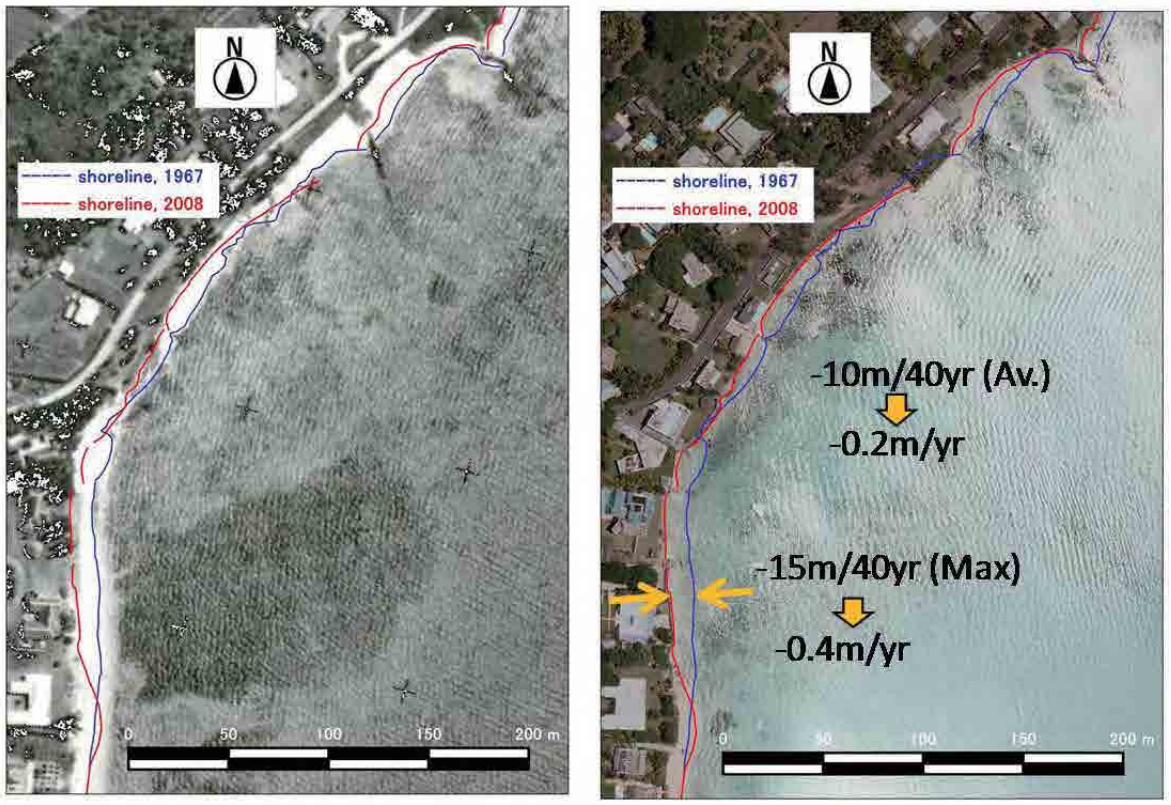
- The coast line has not changed at north rocky area, however, the middle of the curved part shows significant erosion. The most eroded area is sub cell No.6 as shown in Figure 2.2.10. The coastline eroded 15 m at the maximum of 0.4m/y within 45 years. Most of the beach here has already been eroded away and there has been almost no change over the last 10 years.

- The eroded area moves to the south and the sub cell No.7 has eroded over the last 10 years.

- The eroded volume was about 5,000 m^3 over 45 years at sub cell No.6 and the sediment loss of about 7,000 m^3 in the whole of east area was estimated from the changes of sediment budget in Figure 2.2.10.

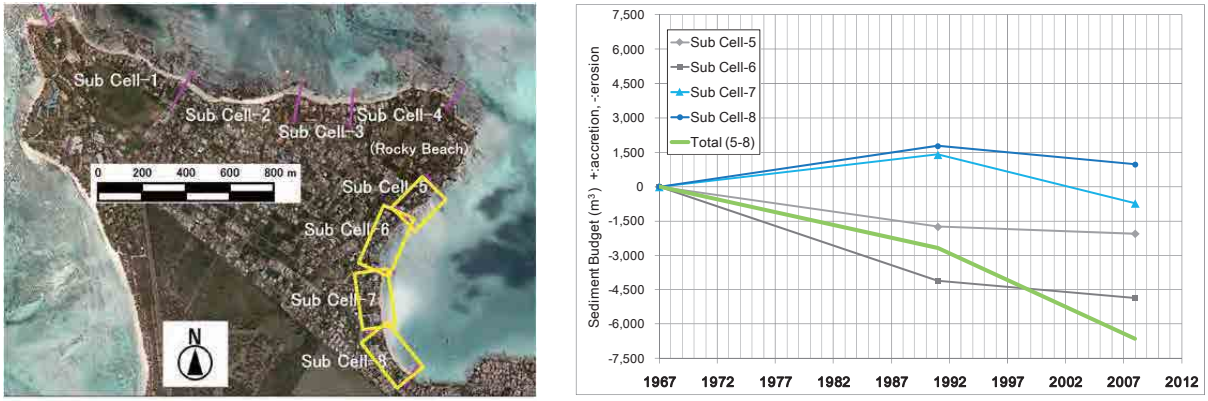
Source: Processed by JICA Expert Team based on the data from MHL

Figure 2.2.8 Comparison of Aerial Photo (East area), (left:1967, right:2008)



Source: Processed by JICA Expert Team based on the data from MHL

Figure 2.2.9 Comparison of Aerial Photo (Eroded east area), (left:1967, right:2008)



Source: Left; Processed by JICA Expert Team based on the data from MHL, Right; JICA Expert Team

Figure 2.2.10 Sediment Budget at Each Sub Cell

2.2.3 Short Term Coastline Change

This coast is out of the scope of the continuous monitoring of the objective coast in this project, and there is no beach profile survey data. However, according to several site investigations which were carried out since the beginning of the Project in 2012, significant changes in the shoreline, formation of a new beach scarp, etc., were not observed. As well as the long term coastline changes presented in 2.2.2, the changes in the shoreline were not significant compared to the changes in Mon Choisy. Furthermore, several rocky heads can be observed at this coastline. And the rocky heads have the function to control the sediment movements. This may be a reason why the change in this coastline is not significant in this coast.

2.2.4 Characteristics of Wave, Water Level, Current, Topography, Bed Material and Reef Environment

a. Characteristics of Meteorological and Hydrological Conditions

The high waves attacks this coast as same as in Mon Choisy mainly from December to March of cyclones season and the offshore predominant direction is estimated from the W to the NW. Moreover, these waves have large impact to the complex reef topography and at some points it is considered the changes of waves direction along in the north area. At the east area in the Grand Baie, the waves are diffracted and decrease its height to several 10 percent compared to the north area with the constant direction of the NE. It is considered that in the east area, the generated winds waves in the bay also affect the littoral drift movement.

b. Coastal Topography and Sediment Material

As it is mentioned above, the coastline at the north area is not smooth due to the impact of the complex offshore topography. There are rock reefs at the end of the north area and the east area. The east area forms a curved coastline from the middle to the bottom of the bay.

The beach sand is white coral. The sediment at the north area is coarser-grained compared with Mon Choisy and many coral gravels are wash up on the beach. The foreshore slope is steep from 1:5 to 1:7. On the other hand the sand in the east area is fine and the slope is gentle of 1:10.

c. Reef Environment and Water Quality

In the north area, the seawater exchange seems to be higher than other lagoon because of the narrow width of coral reefs and scares offshore reefs. However, living corals in the shore reefs in 1996 decreased to only one percent in coverage, mostly corals of *Pocillopora*, by the spot-check survey in 2013. In the patch reefs offshore, living coral coverage was estimated as ca. 30 %, dominated massive *Porites*, by the direct observation using a glass-bottom boat in 2014. However the 30 % in coverage is higher than ca. 15 % of average coverage of living corals in other lagoon, the area of coral community was lower than that in AFRC Chart in 1994 and coral distribution area in 1996. Environmental conditions for corals gradually became worse in these 20 years.

The investigation results on water quality and impacts to water quality in the lagoon at Pte. aux Cannoniers are shown in Table 2.2.1. Chlorophyll a in the lagoon is at a level that it is not well suited as a habitat of coral (the coverage of living coral is from 10 to 20%). In the northern area, where the reef width is narrow, transparency is maintained at a high level because the outside seawater enters near the coast, compared with that in Mon Choisy and Grand Baie located in the west. However, it is considered to be possible that the eutrophication is progressing rapidly, because the hinterland has become a densely populated area with the rapid residential development. Especially, as the cause of eutrophication, the effects of drainage from the houses with Ap (Absorption pit) and St (Septic tank) not connected to the sewer are considered. The water quality in the eastern area, where belongs to the inner bay, is deteriorated and the transparency is extremely low. The coral reefs and living corals have not found even by using the satellite image analysis. Currently, the JICA sewage treatment facility development projects in progress in Grand Baie region (from March 2007 to December 2015). This project aims to promote the environmental preservation by connecting the unconnected areas to an existing sewerage system. Thus, the water quality near Pte. aux Cannoniers is in

eutrophication state slightly, but it is expected that the water quality will be improved by this project in the future.

Table 2.2.1 Investigation Results on Water Quality and Impacts to Water Quality in Lagoon

Check items		Conditions			
Water quality	Chlorophyll a (ug/L)	0.86(*)			
	Turbidity (NTU)	-			
	NO_3-N (mg/L)	-			
	PO_4-P (mg/L)	-			
Population density behind coast(per km^2)		794			
Sewerage disposal behind coast	Status of development of sewerage facilities behind coast	Sewerage Systems (Trunk Sewer), Absorption Pit, Septic Tank, Pit Latrine			
	Present condition of sewerage disposal from houses (Sewerage system, Septic tank, Pending arrangement, etc.)	Grand Baie VCA: SS: 114, AP: 291, ST: 974, PL: 8			
	Present condition of sewerage disposal from hotels and restaurants (Sewerage system, Septic tank, Pending arrangement, etc.)	Hotels >75 rooms uses onsite treatment plants. Restaurant uses septic tanks.			
	Development plan of sewerage system for houses and hotels behind coast	In pipeline for development, Study stage			
Impact of pollution from sugarcane	Incidence of red-soil runoff from land side	None			
	Existence of sugarcane field behind coast. If there is it, area of the field behind coast.	Yes. Area: 678 Ha			
Relation between living coral and water quality**	Coral coverage	Chlorophyll a (ug/L)	Turbidity (NTU)	NO_3-N (mg/L)	PO_4-P (mg/L)
	>50%	<0.2	<0.5	<0.012	<0.007
	20-50%	0.2-0.6	0.5-1.3	0.012-0.051	0.007-0.016
	10-20%	0.6-0.9	1.3-1.9	0.051-0.081	0.016-0.023
	<10%	>0.9	>1.9	>0.081	>0.023

*: Observation for water quality was conducted close to shore.

**: This relation was obtained by the water quality survey in this study. Refer to Table 2.6.3 in Vol.1.

SS: Sewerage Systems, Ap: Absorption Pit, ST: Septic Tank, PL: Pit latrine

Source: JICA Expert Team

2.3 Littoral Drift and Causes of Erosion

2.3.1 Littoral Drift

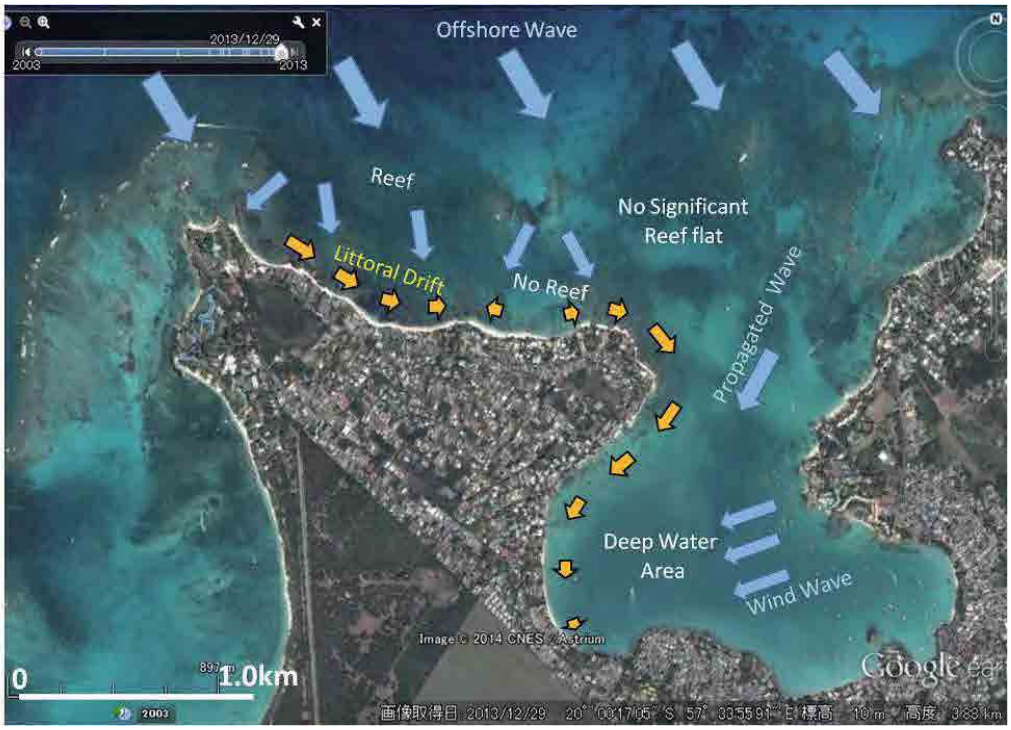
Estimated waves and littoral drift in the coast are shown in Figure 2.3.1.

- The overall sand of the littoral drift, seems to be supplied from the reef and move eastward in general.

- The sediment transport rate at the north area is estimated smaller than at the east area because the direction of waves to the beach is not inclined and there is no highly oblique wave incident on the coast. Possibly the direction of the littoral drift changes according to the existence of reefs or its topography. The sediment budget was balanced in the past. However, the sediment of the sand drift at the west side seems to be decreased after 1997.

- The source of the sand at the east area, the sand drift that moves around from the north side area is considered to be dominant. The erosion at the east end of the north area seems to be conducive to the erosion at the east area. The waves at the east area are smaller than those at north area because of the diffracted waves from the bay entrance. However, the obliquely incident waves on the shoreline cause significant southward littoral drift. The southward littoral drift decreases because the wave height is father reduced in accordance with the forward movement to the inner part of bay. There is no drift across the south bend groyne.

- The sand of 10,000 m^3 was lost within 45 years at the both of north and east areas. There is the possibility that the disappeared sand was moved to the offshore through the deep area of water depth with no coral reefs or through the steep slope part of the bay.



Source: Processed by JICA Expert Team based on Google Earth

Figure 2.3.1 Waves and Littoral Drift Patterns at Pte. aux Cannoniers

2.3.2 Causes of Erosion

The estimated causes of erosion are summarized as follows.

a. Decrease of sediment supply

Recent decrease of sediment supply at the north area from reef is significant. Sediment supply from the north area which previously existed might have decreased leading to erosion of the eastern area.

b. Rapid erosion was caused by cyclones and reduction of recovering capacity

The erosion at the west end of the north area seems to be caused by the deep water and high incident waves from the lack of coral reef. The erosion was not continuous but caused by the high waves at the cyclones. One of the reasons why there is no recovering after the cyclone is the reflected waves and scouring due to presence of vertical revetments within dynamic beach zone.

c. Down drift side erosion caused by the individual structural measures such as groynes by the lessees

The coast is mainly leased land area and has been managed by the lessees. Basically the measures are intended to protect the private land and to preserve the beach. The coast belongs to one continuous sediment cell from the north to the east and the individual measures are highly possible the factors to conduce the erosion in the downstream side of the sand drift from the vicinity of the eastern end of the north area to the east area. Those problems are seen at other leased land areas where the coastal management is left to individuals such as Pte.

d'Esny.

d. Impact due to nautical and fishing activities using large nets on the lagoon

The boat passage was constructed in front of Hotel Cannoniers which are located at the north area in 1990's. From the result of interview survey from the hotel, beach erosion has been occurred since this activity. The fishing using large net was also possibility to carry out. These activities is a possibility to lead the change of wave and current pattern on the lagoon and decrease of corals and seagrass.

2.4 Coastal Conservation Measures

2.4.1 Outline

The current sandy beach is preserved in the main part of the north area, and the beach public area (Public Domain, between HWL and LWM) which is available to anyone has been generally secured. However, the loss of the foreshore among 200 m in the vicinity in east side is hampering the free access to the beach. Also in the east area, already in more than the half of this area the sandy beaches that existed before disappeared and it is difficult to travel to the shoreline due to the grove of existing revetments, groynes, etc..

Planning as short-term (several years) measures for the causes of (2) and (3) and long-term (more than few decades) measures for the causes (1) is required. From the above coastal situation, the northern eroded area (200 m) and the east central part area (about 500 m) are the priority sites to develop measures. MOESDDBM has removed the gabions and put gravels at the public beach of the east area.

2.4.2 Principle of Measures

a. Short Term Measures

The main measures of short-term to be proposed are 1) setback, 2) nourishment, and 3) structures, the combination of those is also considered. The applicability and evaluation to the priority sites is shown in Table 2.4.1. The principles of the measures are as follows.

Northern eroded area

This area is facing to the north and easily could have the impact of cyclones. The accumulation of fresh coral sand is seen on the beach although the sediment supply is decreasing. Even though the coast is in a lease area, the natural landscape and coastal environment are maintained without structures which affect the littoral drift. In considering the conservation measures in the northern eroded area, it is required to keep the current good condition of the coastal environment while implementing these measures. The principles of the measures are as follows.

Table 2.4.1 Overview for Comparison of Alternative Measures

Measure	Setback	Beach Nourishment	Structure
Applicability	Most of the coast has been a leased land and there are no houses which were made in front of the coastline after 1967, except some new hotels in the east area, It is difficult to apply the 30 m setback rule to the eroded area because there is no space at the seaside leased area of the road and also some of buildings were constructed in the dynamic zone. On the other hand, at the time of the renovation of existing vertical revetments, there are several places that are applicable to move the revetment landward to increase the natural recovering of sand. Re-design of existing revetment from vertical impermeable type to gentle slope permeable type is also effective to increase the natural recovering of sand.	Beach nourishment is recommended to keep the natural landscape and access to the beach. At the north area the natural rock reef has function to control littoral drift. To decrease the sand loss after the beach nourishment, the impact of detached breakwaters is small because the direction of the littoral drift is changing locally. But the landscape has to be considered. At the east area it is difficult to make stable beach by beach nourishment only because of the longshore littoral drift to the south. It is recommended the combination with groynes to keep a stable beach. The sand is necessary to get from exterior because there is no accumulated area of prominent sand in the coast. It is possible to use the sand which is transported offshore in the bay.	The use of the structures such as groynes, detached breakwaters and submerged breakwaters is not advisable because it will cause possibly new erosion. At the north area, the measures of detached breakwaters can be applicable to decrease the nourished sand loss because the littoral drift is not even and it is surrounded by rock reefs. At the east area, the arrangement of groynes to make a static stable beach is recommended in order to decrease the loss of nourished sand loss by the longshore littoral drift. Existing vertical revetments sometimes prevent the recovering of sand by the natural action from the offshore because of the direct wave action in some areas. The effects of structures can be improved by performing the combined the change of relocation if there is enough space, and the enhancement to permeable vertical revetments.
Evaluation	To conduct Setback building is difficult but the relocation of existing revetment line is possible.	Recommended measures	At the east area, is recommended to conduct the beach nourishment with groynes to make a static stable beach. The improvement of existing vertical revetments and the relocation of revetment line are proposed.

Source: JICA Expert Team

- Beach Nourishment: Maintenance of the sand is necessary specially when the sand loss has occurred by events such as cyclones
- Detached breakwaters to prevent offshore sediment loss in considering the coastal landscape
- Removing the existing revetment with the measures above

East eroded site

At the coast the eroded area proceeds to the south in decreasing the sediment supply almost from the north area. Each lessee has protected the beach by vertical revetments and groynes

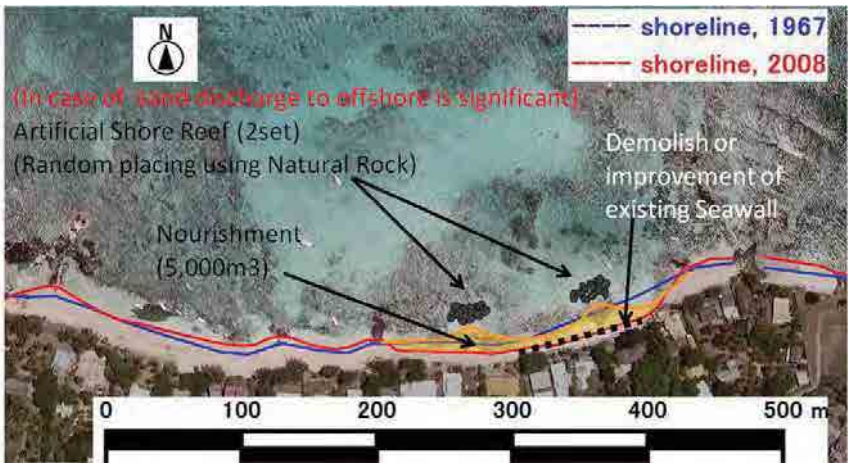
from the north end to the middle in the vanishing continuous beach. The access to the beach is difficult because of the unregulated revetments and groynes by the lessee. The principles of the measures are as follows to protect the lease area and ensure the public access.

- To make a static stable beach with the beach nourishment and groynes
- Improving the existing revetments from impermeable vertical to permeable gentle with setback

b. Long Term Measures

The following measures were proposed as the long-term measures.

- Water improvement to maintain or enhance the coral and seagrass environment
- Setback in the timing of the next lease contract it is recommended in order to minimize the flood risk at the residential area along the coast and to minimize the trouble and cost for the beach maintenance and management in the medium- to long-term.



Source: Processed by JICA Expert Team based on the data from MHL

Figure 2.4.1 Measures at North Eroded Area

2.4.3 Short Term Measures

a. North Eroded Area

The image for short-term measures at the north eroded area is shown in Figure 2.4.1.

a.1 Beach Nourishment with Suitable Sand Grain Size and Color, and Periodical Sand Filling

The coral reef is not so developed at the north area, and the incident waves is not so reduced due to topography condition. Thus, the grain size of sand on the beach is coarser than other coasts and the beach slope is also steeper with 1:5 to 1:8. The employed sand for nourishment shall be basically use the same grain size or bigger size to keep the same beach slope as the present condition. Volume of the nourishment is assumed 5,000 m^3, which is the same with the volume of sand loss of 40 years. The area to do the nourishment is 200 m, where small

rocky shores exist at both ends. Even though the beach profile survey was not undertaken at this area, the berm height was assumed to be approximately 2.5 m to 4 m high. The width of the beach after the nourishment is expected to be 6 to 10 m.

It is not advisable to use sand with different color (means black colored sand) to maintain the present beach environment and landscaping in an aesthetic point of view.

The recommended beach nourishment is a dynamic method without any supplementary coastal structures such as groynes, headland, etc., there is a possibility to cause sand discharge due to the action of strong waves generated by events such as cyclones. Although the littoral drift is expected not to be significant at this area, the sand outflow toward offshore direction is anticipated because of the deepness of the depth in front of the beach. It is difficult to predict the expected sand discharge without any detailed data for beach monitoring. Thus adaptive management shall be considered based on the monitoring results after the beach nourishment.

a.2 Demolish or improvement of existing vertical seawall (by lessee)

The vertical seawall exists just behind the target area. During high water or high wave conditions, the waves hit directly to the seawall accelerating the beach retreat due to scouring. In order to maintain the sand after the beach nourishment, it is recommended to demolish this existing seawall. On the other hand, there is a possibility not to undertake the proposed beach nourishment at this area due to few reasons such as problems of sand procurement. In such cases, it is necessary to consider that each private lessee will continue to improve the current situation. The following improvements which will be carried out in the level of private lessees are recommended (Figure 2.4.2).

- Improvement of existing seawall from impermeable vertical to permeable gentle revetment and the relocation of revetment position landward as much as possible and planting of vegetation for stabilizing the backshore

- Filling of gravels in front of revetment in case of accumulation or stabilization of sand in front of the improved revetment if necessary. It is recommended to use a similar or the same color as the existing sand (white colored stone) taking into account the image and landscaping of this beach.

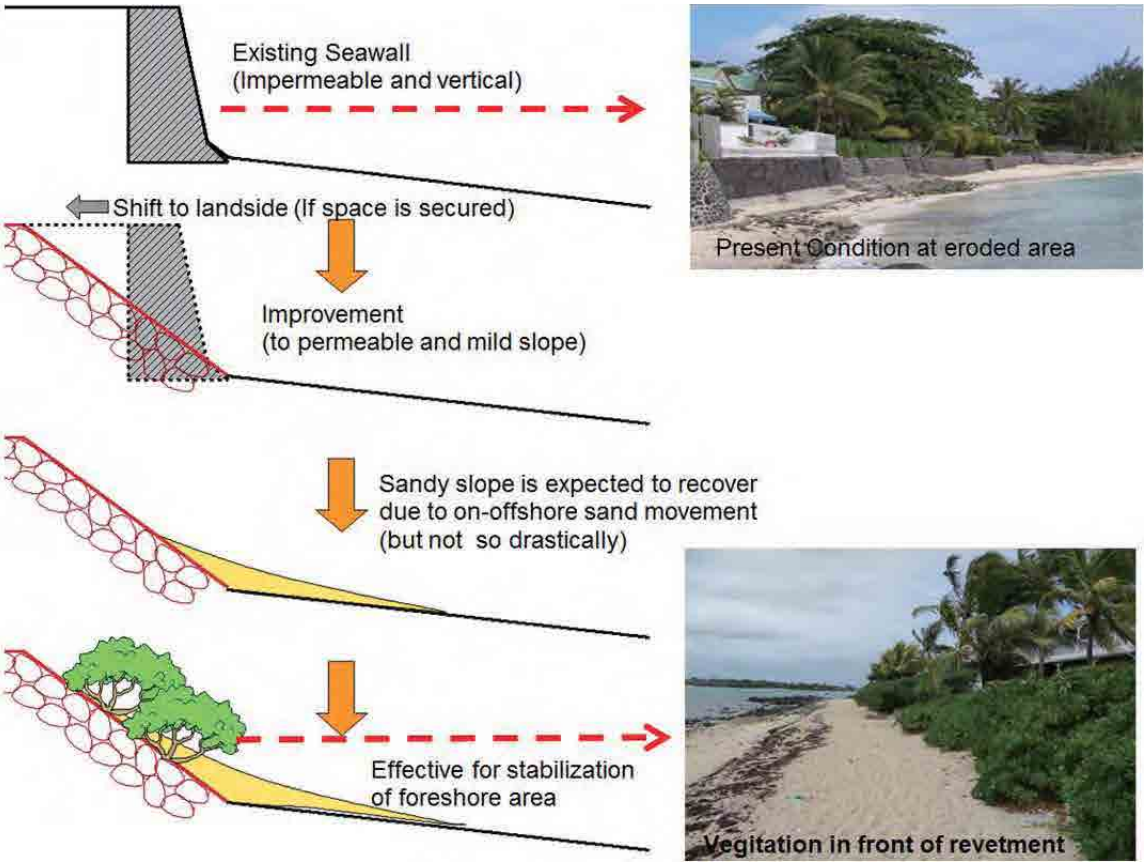
a.3 Artificial Shore Reef

The setting of artificial shore reef is not recommended as essential countermeasure from the beginning. In case that sand discharge to the offshore is identified to be significant based on the monitoring result, and a proper countermeasure is required to reduce the sand outflow to the offshore, it will be taken in account as one of the alternatives. If it is necessary, the planning and design shall be finalized based on not only technical approach but also on public consultation to the residents taking into account the landscaping and beach use. At least, the artificial shore reef should be harmonized with the existing rock reefs to keep present landscape of the coast with the same gray natural rocks and random placements. The bigger scale of length and width makes large trapping effect of sand. On the other hand, this will also makes artificial image on landscape view point as an adverse effect. Thus, it is important to make design taking into account both functional and landscaping points of view.

The dimension of the artificial shore reef which shows in Table 2.4.3 is just as one of

examples. The size or armor rock was assumed 400 to 800kg/unit based on the predicted incident wave condition, but further detail estimation is required based on quantitative wave analysis.

In case that sand discharge to the offshore is identified not to be significant but prefer to take some adaptation measures, the trial of coral transplantation is one of the alternatives to reduce the sand discharge to the offshore.



Source: JICA Expert Team

Figure 2.4.2 Improvement of Existing Seawall for Each Lessee

b. East Eroded Area

The image for short-term measures at east eroded area is shown in Figure 2.4.3.

Source: Processed by JICA Expert Team based on the data from MHL

Figure 2.4.3 Short Term Measures at East Eroded Area

b.1 Beach Nourishment

Used sand shall be basically use the same grain size or bigger size, and same color as present condition. The required volume for the beach nourishment in order to recover the sandy beach as before is assumed 10,000m^3, which is same with the sand loss of 40 years. Assuming the project length is approximately 500m and berm height is 2.5m, it is expected to recover the sandy beach with 8 m width.

On the other hand, the most important consideration is from where nourished sand will be procured. Following to the present regulation, the nourished sand shall be basically procured from the sand quarry site on land. However if so, the project cost becomes too high and it might be difficult to implement it. It is strongly required to find the new potential source of sand nearby. According to the study for littoral movement in this area, southward transported sand might be accumulated at some area in Grand Baie through the steep bottom slope in the bay. Based on this, there is a possibility to find sand potential source in the bay even though the grain size of sand might be fine. Further investigation is required to look for the sand potential source near the site to perform the sustainable beach management taking into account the project and maintenance cost.

As the partial protection measures in order to protect just in front of specific area, the fill of rock sand or pebbles with black color is one of the alternative to protect the land or facilities. However, the impact on landscaping and environment due to scattering to surrounding area shall be carefully verified.

b.2 Groyne Arrangement

The groynes will be arranged to trap the nourished sand to the downstream side of the littoral drift based on the estimated coastline after the beach nourishment. The coastline is estimated from the same coastline angle where the sand is maintained with existing groynes. The interval is determined to be 100 m in considering the impact on landscape and the beach use. Depending on the results the interval is decided. The groynes are curved at the head to decrease the erosion at the downstream side of the littoral drift and to increase visual effects. The

suitable length to prevent sand loss on the downstream side of the littoral drift will be determined by the monitoring after the beach nourishment in a period of time. The suitable length is determined by the adaptive management based on the monitoring results. In this case the groynes are installed in a straight line at first and after that the recommended final length is decided by the monitoring results as stepwise construction. The south area from G6 shown in Figure 2.4.4 has some possibilities of erosion from the present coastline due to the construction of groynes at upstream side. Regarding to this, it is planned to determinate the necessity of the additional groynes while watching the beach condition.

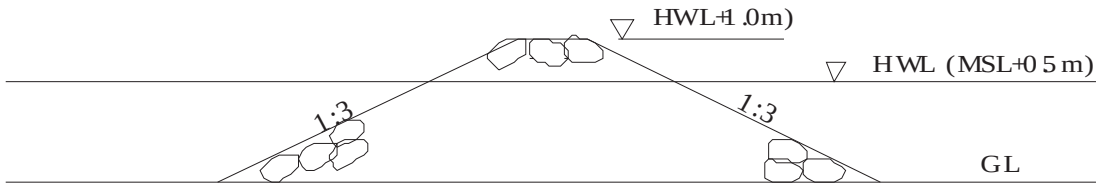
Based on description above, an example of a study of groynes length and width is shown in Table 2.4.2. However, this is intended to merely show the concept, the details are necessary to be finalized by the detailed design.

Table 2.4.2 Details of Groynes

Groyne No.	1		2		3		4		5		6	
Length (m)	12		16		22		17		25		16	
Interval (m)		80		105		110		90		90		

Source: JICA Expert Team

It is necessary to set the appropriate crown height as well as length and width of groynes to capture sufficient sand sediment in the downstream of littoral drift. In this case, 1.0 m is set, considering the waves height in the HWL of 0.5 m above MSL. The slope of the groynes will be finalized in considering the beach use, construction cost. Public consultation with lessees is required before construction. Here, it is taken as 1:3 of inclination for the use of the slope to facilitate the beach access as shown in Figure 2.4.4. The size of armor stone is assumed to take 400 to 800 kg/unit considering presumed wave condition at this coast.



Source: JICA Expert Team

Figure 2.4.4 Image of Groynes (for reference)

b.3 Improvement of Existing Revetments

The improvement of existing vertical revetments to permeable gentle revetments is proposed to decrease the sand volume before the beach nourishment and to improve the stability of the beach after the beach nourishment. It is expected to make the beach stable by moving back the revetment lines to the land side if there is enough space.

c. Summary of Short-Term Measures and Rough Construction Cost Estimates

The recommended short-term shore protection measures for the north and east eroded areas and its rough construction costs are presented in Table 2.4.3 and 2.4.4.

Table 2.4.3 Summary of Recommended Short-Term Measures and Rough Cost Estimate at the North Eroded Area

Item	Contents
Target Area	Eroded North Area of about 200 m
Measures	Beach nourishment + periodical sand filling as maintenance, and removing or improvement of existing seawalls (If sand discharge to the offshore is significant, add construction of artificial shore reef or other measures)
Specification for Nourishment	Volume: 5,000 m^3, estimated sand loss of 40 years with 8 to 10 m beach width Size: 0.3 to 0.6 mm in D50, the same or courser than existing sand Quality: white coral sand, the same as the existing sand
Specification for Artificial Shore Reef (as example)	Two units, 10 to 15 m long, from 3 m to 5 m wide and crown height of 1.0 m above HWL, armor size is assumed 400 to 800 kg/unit
Rough Construction Cost (as reference)	Beach nourishment: 7.5 million MUR (assuming 1,500MUR/m^3) 3) Two artificial shore reefs: 0.4 million MUR (assuming volume is 265m^3/unit, 800 MUR/m^3) 3)

Source: JICA Expert Team

Table 2.4.4 Summary of Recommended Short-Term Measures and Rough Cost Estimate at the East Eroded Area

Item	Contents
Target Area	Eroded East Area of about 480 m
Measures	Static stabilized method by applying beach nourishment with groynes, and improvement of existing seawalls
Structures	Six groynes, 12 to 25 m long, 1 m wide and crown height of 1.0m above HWL、armor size is assumed 400 to 800 kg/unit
Beach Nourishment	Volume: 10,000 m^3, estimated sand loss of 40 years Size: 0.3 to 0.6 mm in D50, the same or courser than existing one Quality: white coral sand, the same as the existing sand
Rough Construction Cost (as reference)	Nourishment: 15 million MUR (assuming 1,500MUR/m^3) 3) Six groynes: 3.4 million MUR, length 130 m (assuming 26,000 MUR/m)

Source: JICA Expert Team

2.4.4 Long-Term Measures

a. Improvement Measure on Water Quality Based on Monitoring Results

The detailed eutrophication conditions in the coast are not clear. The quantitative data on the causal relationship with the reef environment is missing. Therefore, it is necessary to conduct the water quality monitoring with high precision analysis and the survey to understand the actual situation of the pollution load through the groundwater from the small river. Based on these monitoring results, it is reccomended to promote the connection of sewerage to the houses and villas not connected to the sewerage as for the long-term countermeasures.

b. Setback in Timing of Next Lease Contract and Re-planning of Land Use at Coastal Area

Most of leased properties in this coastal area does not have a 30m setback from the HWM. Most of these leased properties exist before 2004 and in accordance with existing provisions at that time; they respected a 15m setback from the HWM. Also, the beach retreated due to erosion. Each lessee has their right based on the lease contact which was updated in 2008 and it is not realistic to impose the setback rule to existing lessees in this time. Only the opportunity to impose the setback with 30m distance from HWM is the next renewal of lease contract, which will be planned in 2068. In that timing, it is recommended to perform the re-panning of land use at coastal area in this region including relocation of coastal road.

2.5 Beach Operation and Maintenance Plan

2.5.1 Improvement Plan against Present Beach Management Issues

In regard to the Beach Maintenance and Land Utilization for Pte. aux Cannoniers, the present issues and the improvement plan are described in Chapter 5 in the Volume 1. The issues and the improvement plan for the system and implementation which common to the most of the target beaches are described in Chapter 5 as well. This section shows improvement plan against present beach management issues of the beach as follows.

a. Beach cleaning issues

- Enhancement of awareness of beach cleaning to lessees by using leaflet, etc.
- Periodic inspection by local authority
- To establish a new beach cleaning system and/or add responsibility of beach cleaning in lease agreement

b. Existing facilities issues

- Modification of revetment from vertical type to sloping permeable type with plantation
- Demolition and modification of groynes depending on effective

2.5.2 Beach Management Plan for Coastal Conservation Plan

In this section, several concerns on management for beach conservation are specified. The Beach Conservation Plan of Pte. aux Cannoniers recommends a dynamic beach nourishment or an artificial reef as an offshore prevention facility in some cases are recommended for the erosion area in North as well as beach nourishment, construction of groyne and improvement of revetment for the Eastern area.

The plan says that it is necessary to purchase sand from the two sand quarries on land because there is no utilizable sand at existing beach. Therefore, it should be considered how to procure white sand with cheaper price for the Beach Operation and Maintenance. Possible ideas are as follows;

1) Utilization of sand dredging at accumulated area,

2) Utilization of seabed sand in the offshore out of reefs

3) Utilization of accumulated sand in the lagoons.

As for the case of 1), it has been already planned to utilize the dredging sand from accumulated areas. A comprehensive sand management in close coordination and cooperation with relevant organizations are required to reuse the accumulating sand.

As for 2), the seabed survey led by MOI in the offshore potential area was started. Further survey is expected and its outcomes should be opened. In order to take seabed sand, a dredging work on sea with a special ship is necessary, and the whole cost of the Beach Maintenance will be increased accordingly. Therefore, the implementation plan for the Beach Maintenance should be prepared in place.

As for 3), there is no sand extraction works in lagoons, since a sand extraction in lagoons for a business purpose has been banned in 2001. In the meantime, a large amount of sand has been found in the lagoons. Through the study on possibility of sand extraction in lagoons and environmental impact assessment, further consideration and discussion including a review of the law will be required in the Mauritian Government. The details of such sand management are described in Chapter 5.3 or later in the Volume 1.

Basically, the tenants of the beach in the lease-land area are responsible for the beach maintenance. But the comprehensive measures based on a continuity of sediment transport are drastically different from the various countermeasures that have been taken by individuals. Therefore, the responsibility for the implementation and cost of beach maintenance should be discussed between the public and the private sectors.

An improvement of revetment, as usual, should be conducted by tenants as long as it protects private lands. But their various improvement works may affect the whole system of sediment transport even MOESDDBM evaluate and approve each individual plan based on EIA prior to their implementation. In such case, they may have lack of sense on whole beach conservation. So each individual plans should be evaluated in accordance with the comprehensive beach conservation plan developed by the Government. In addition, the Government needs to explain about the impact, implementation and cost of the improvement works and maintenance for the tenants based on the comprehensive beach conservation plan.

For the groyne, the beach monitoring led by the Mauritian Government will be required in order to measure remaining sand continuously. Based on the monitoring results, further countermeasures can be considered accordingly.

2.5.3 Validity of Setback Amount

The setback amount for eroded sand beach is configured as summation of the amount of erosion during a certain period and the amount of erosion which is caused by strong wave such as cyclones in that period, which is described as following.

Amount of setback = Amount of erosion for a long period + Amount of erosion by temporally event (i.e. extreme weather conditions such as cyclones)

In addition, the erosion due to the SLR (sea level rise) is anticipated in future. There are several proposed equations to estimate the amount of erosion due to the SLR. Among these, the equation proposed by Per Bruun is applied generally. The equation is as follows.

E=C×S,

Where, E: Erosion amount due to the SLR, C: coefficient of beach characteristic and S: amount of SLR. Therefore, the amount of setback needed is described as follows.

Amount of setback = Erosion amount for a long period + Erosion amount by extreme weather conditions + Erosion amount due to SLR

The rate of the SLR from 1987 to 2011 is about 3.2mm/year in average, and the coefficient of C, which is related with the inverse of sea-bottom slope and transportation area of sediments, is set as 10 by the mean sea-bottom slope in Mauritius. The erosion amount due to the SLR, therefore, is calculated as 1.6 m by multiplying averaged erosion rate of 3.2mm/year, the coefficient of 10, and the period of 50years (E=10×3.2mm/year×50years=2m).

2.6 Issues on Implementation

2.6.1 Necessity of a Detailed Design and Residents Consensus Formation

The plans shown in this report has been outlined based on the limited information and data. In order to plan and decide the locations and specifications, the detailed design process has to be conducted such as beach topographic survey (mapping), sediment transport monitoring, wave characteristics and clarification of other external factors. Since the target beach is located in the lease-land area, the participation of the residents during the planning process is inevitable.

2.6.2 Necessity of Comprehensive EIA for One Sediment Cell

One of the issues at lease area such as Pte. aux Cannoniers is that the protection measures have been basically undertaken individually by each lessee. On the other hand, the coastal area has its own sediment cell which was formed by own geographical and hydrographical condition. If the protection measure is conducted only under considering the protection of their property and facilities, there is no considerations to the effect on surrounding coastal zone, and such lack of consideration induce further coastal problems. Therefore, even if the same coastal management system might be continued, it is recommended to improve the current EIA system, not to focus only to protect the individual area but to consider the comprehensive area for one continuous coastal area with same sediment cell.

2.6.3 Establishment of Implementation Structure

The lessees are responsible for beach maintenance in the lease-land area according to their lease agreement. But the proposed conservation measures for beach nourishment and artificial reef(s) contribute not only to the individual tenants' areas but also to the whole beach. Additionally, the estimated construction costs for proposed measures will be surely increased than that for the current individual protection measures which are undertaken by each lessee. After considering the results of the pilot study with a non-physical measure project in Pte. d'Esny, the responsibility for the implementation and costs of the beach maintenance should be discussed between the public and the private sectors.

2.6.4 Securing Sand for Beach Nourishment

There is no accumulated area with recyclable sand at this beach. So it is required to transport sand in from outside the area. Around 15,000m^3 of sand for the beach nourishment is necessary in northern and eastern areas. In addition, sand supply for maintenance is also necessary. Therefore, securing sand for these should be ensured. A total of 12,000 m^3 of sand that has

been eroded from the beach so far had been possibly accumulated around the beach. This sand may be moved to the deep part of the bay. So it can be assumed that there is an adequate quality and quantity of sands in the deep seabed. After a following survey for the seabed and an environmental impact assessment for the beach, the utilization of seabed sand will be considered based on the quantitative data.

As the partial protection measures in order to protect just in front of specific area, the fill of rock sand or pebbles with black color is one of the alternative to protect the land or facilities. However, the impact on landscaping and environment due to scattering to surrounding area shall be carefully verified.

2.6.5 Adaptive Management based on the Beach Monitoring Results

In northern area facing the open sea, sand supply sediment transport is affected by the cyclones. Therefore, stable seashore will not be sustainable even if any countermeasures are applied. As a result, an adaptive management should be required by the continuous monitoring of the beach depending on the situation.

In the eastern area, as said above, the final shape and structure of the groynes to stabilize sand should be optimized at each stage of construction in accordance with the beach monitoring results, namely flexible management, which is considered valid and important.

Chapter 3

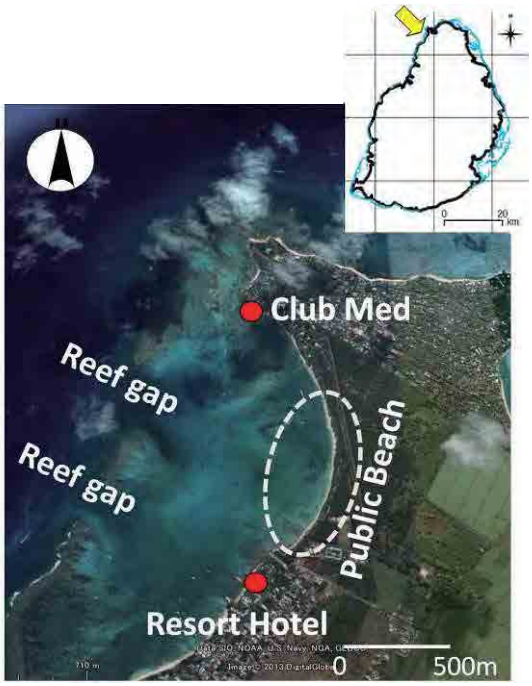
Mon Choisy

3 Mon Choisy

3.1 Beach Condition

Mon Choisy is a coral reef beach that is 2 km long; it is fronted by a coral reef that is 1 km wide and at a depth of 1 to 2 meters, as shown in Figure 3.1.1. A resort hotel exists at the south tip of the beach, and there is a 1.5km long public beach, which is the biggest public beach in the northern area of Mauritius. The hinterland is utilized as a public camping area. Many foreign tourists and local people visit this public area. There are no artificial coastal structures on the public beach and the natural beach has been maintained.

The beach at northern side of the public beach is utilized as a private area of the high grade hotel (Club Med La Pointe aux Cannoniers). The configuration of the beach changed at this area from concave shape at south area to convex shape to north area. The basalt rocks of black color and gravels are found in the north of this coastline.



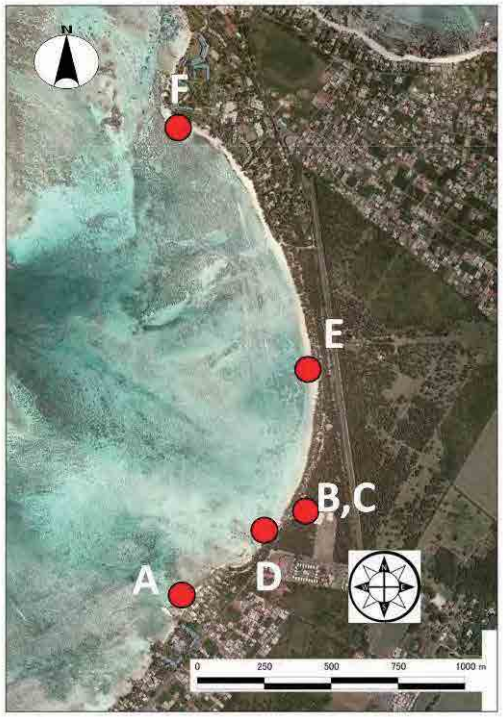
Source: Processed by JICA Expert Team based on Google Earth.

Figure 3.1.1 Mon Choisy Beach

3.2 Understanding of Current Condition

3.2.1 Results of Site Investigation

Figure 3.2.1 shows the location of photographs taken in January 2013, and each photograph is shown in Figure 3.2.2. The revetment and groynes were constructed during 1975 to 1991 at point A. The photos of the camping area located at northern side are shown in point B and C. The beach scarp with approximately 350m length was observed at the southern side of the public beach as shown in point D. The height of the scarp was roughly 2m. The scarp gradually disappeared toward the north and the sandy beach with mild slope exists at north side of the public beach as shown in point E. Point F shows the private beach of Club Med. According to the old aerial photograph, the vertical seawall in front of the hotel area was constructed during 1991 to 1997. The small groyne was constructed at north side of the seawall before 1967.



Source: Processed by JICA Expert Team based on satellite image obtained from MHL.

Figure 3.2.1 Location of Photo

Point A (Groyne in front of the hotel at south area)

Point B (Camping area behind the public beach)

Point C (Camping area behind the public beach)

Point D (Scarp at south side of the public beach)

Point E (North side of the public beach)

Point F (in front of Club Med)

Source: JICA Expert Team

Figure 3.2.2 Beach Condition at Mon Choisy (January 2013)

The beach conservation measure has been required at the public beach located at the south coast. Significant beach scarps have been frequently formed recently and they are disturbing beach utilization. Based on the comparison of the shoreline between previous and present and the result of site investigation, the beach has been retreating, (-0.3m/year in average). To rehabilitate the beach, 3,800m^3 beach nourishment was carried out by MOESDDBM at 600m alongshore in 2010 to 2011. Seventy five trees were also cut. However, after strong waves

during storm season in 2012, most of the nourishment sand has been scattered and the beach has returned to almost the same condition as previously, as shown in Figure 3.2.3.

Source: JICA Expert Team

Figure 3.2.3 Change of Profile at the South of Public Beach

MOESDDBM has informed the JICA Expert Team that they plan to conduct additional beach nourishment. However, there is a possibility of sand loss again. The optimum method of beach conservation is required. The area has been selected as a project site by the Adaptation Fund Board (AFB), and there is a plan to conduct coastal conservation measures to protect public beaches from erosion starting in 2015.

Based on the evidence that a seawall was constructed in the 1990's in front of Club Med Hotel at the north area, the beach might have been eroded at that time. However, the significant difference indicating changes in the shoreline was not observed by comparison of aerial photographs.

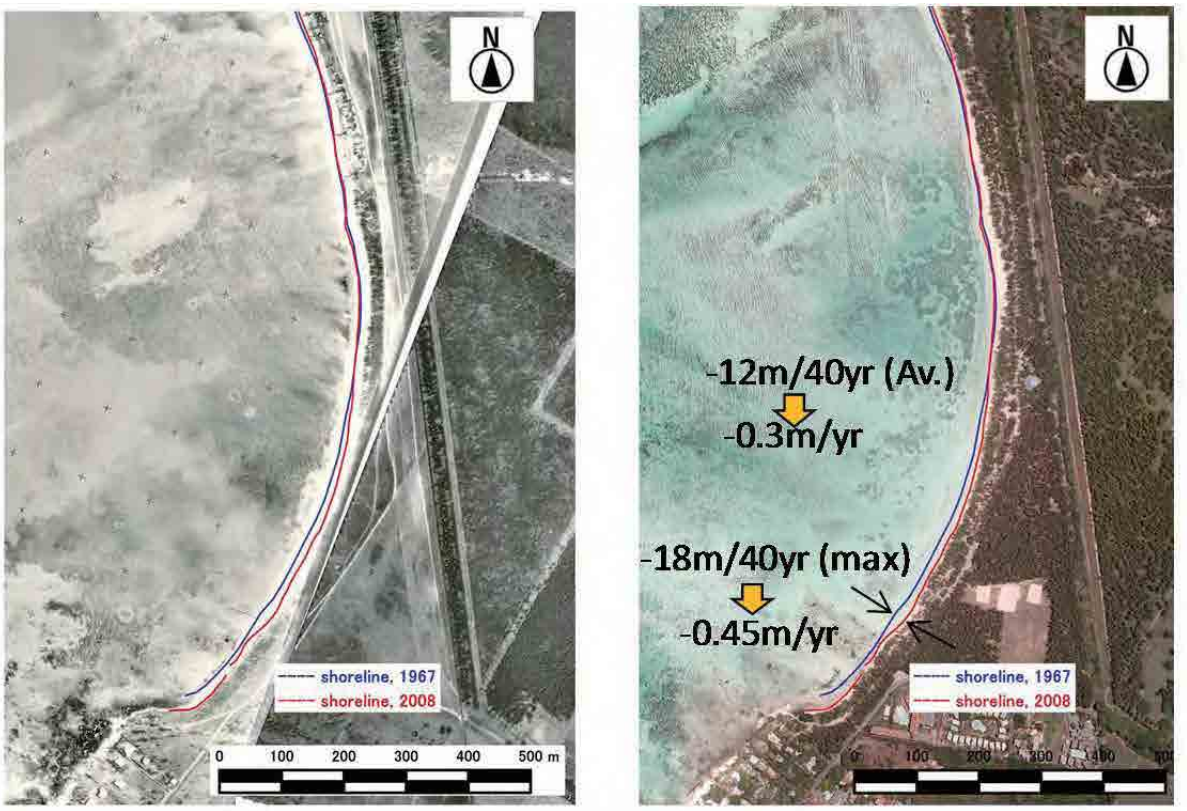
3.2.2 Long Term Shoreline Change

Figure 3.2.4 shows vertical aerial and satellite photographs taken in 1975 and 2008 and Figure 3.2.5 shows an enlargement of the eroded area. The position of the shoreline in 1975 is described by a blue line and in 2008 by a red line. Figure 3.2.6 shows the sediment budget for six periods from 1967 to 2012. The volume was calculated from the result of area change. The value of 2.5m as the average height of sediment movement at coral beaches in Mauritius was assumed for calculating the volume from the area of change.

- The shoreline at south of the public beach (sub cell No.7) was eroded 12m on average and 18m at the maximum within 45 years from 1967. The erosion seems to be continuing at present. The rate of erosion is 0.3m/y on average and 0.45m/yr at the maximum. The sediment budget at sub cell No.7 is about -20,000m^3 (loss).
- Significant changes of shoreline cannot be observed at sub cell No.5. Also the sediment budget at sub cell No.6 is slight increased even though some changes were observed. The sand budget in total is -20,000m^3 for 40 years and this beach is categorized as "totally eroded beach".

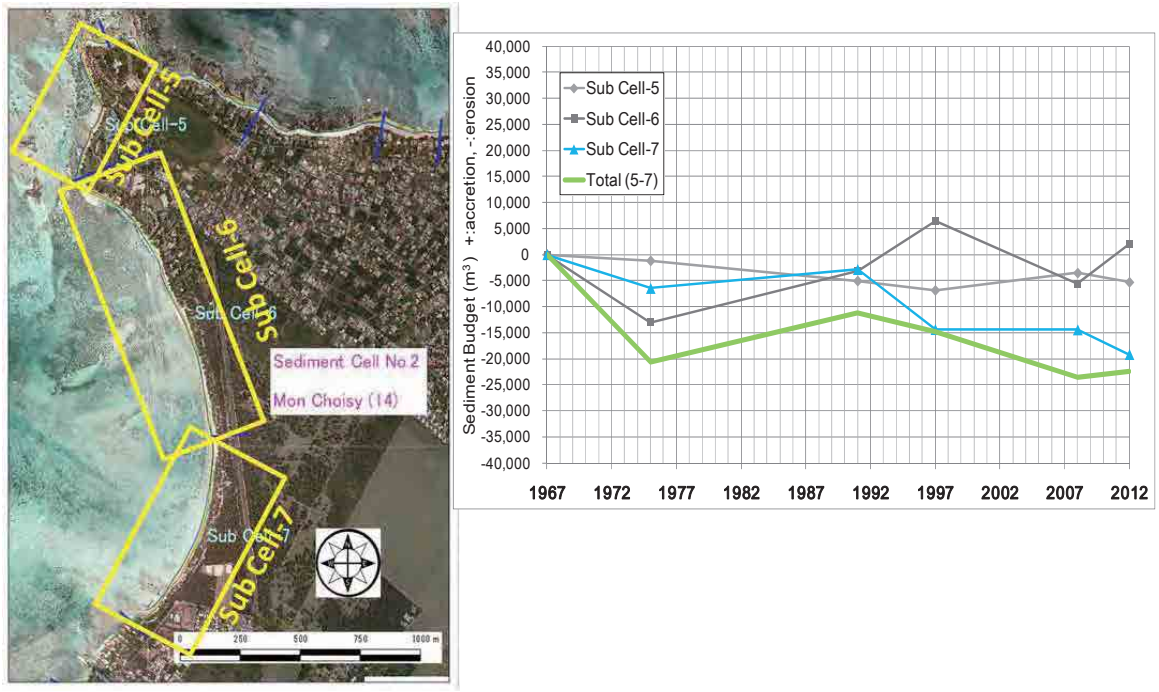
Source: Processed by JICA Expert Team based on aerial photo and satellite image obtained from MHL

Figure 3.2.4 Comparison of Aerial Photo (Whole area), left:1967, right: 2008



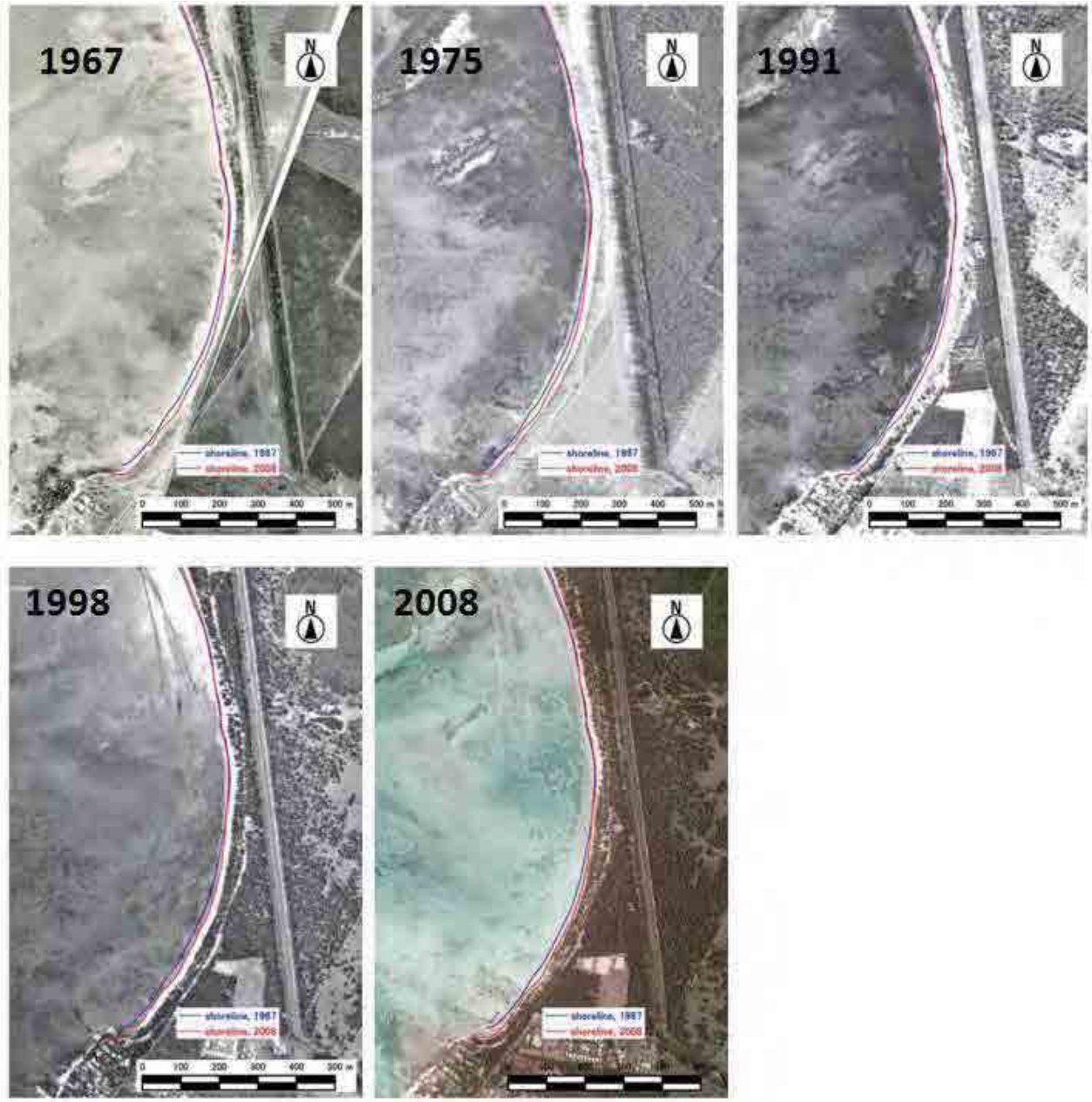
Source: Processed by JICA Expert Team based on aerial photo and satellite image obtained from MHL

Figure 3.2.5 Comparison of Aerial Photo (Eroded south area),left: 1967, right:2008



Source: left: Processed by JICA Expert Team based on aerial photo and satellite image obtained from MHL,
right: JICA Expert Team

Figure 3.2.6 Sediment Budget at Each Sub Cell



Source: Processed by JICA Expert Team based on aerial photo and satellite image obtained from MHL

Figure 3.2.7 Change in Condition of Coral Reef from 1967 to 2008

Figure 3.2.7 shows the change in condition of coral reef from 1967 to 2008. It is identified that the light and shade pattern on coral reef decreased from 1998 to 2008. The shade part on the coral reef is identified as sea grass area based on the previous field observation.

3.2.3 Short Term Shoreline Change (Results of continuous monitoring)

In Mauritius, no continuous and systematic beach profile monitoring had been conducted, and few quantitative data supporting short term coastal change were available.

Mon Choisy is a target area for continuous monitoring proposed in this project. As the data will be accumulated from now on, the quantitative data on short term coastal change in this coast will also be accumulated. The beach profile monitoring survey has been conducted about every 3 months since December 2013 under this project, setting 8 measuring lines along the coastline

about 2km long. Figure 3.2.9 presents the results from about one year monitoring at the 6 representative points in Figure 3.2.8 (Monitoring result for all monitoring line are presented in the supporting data).

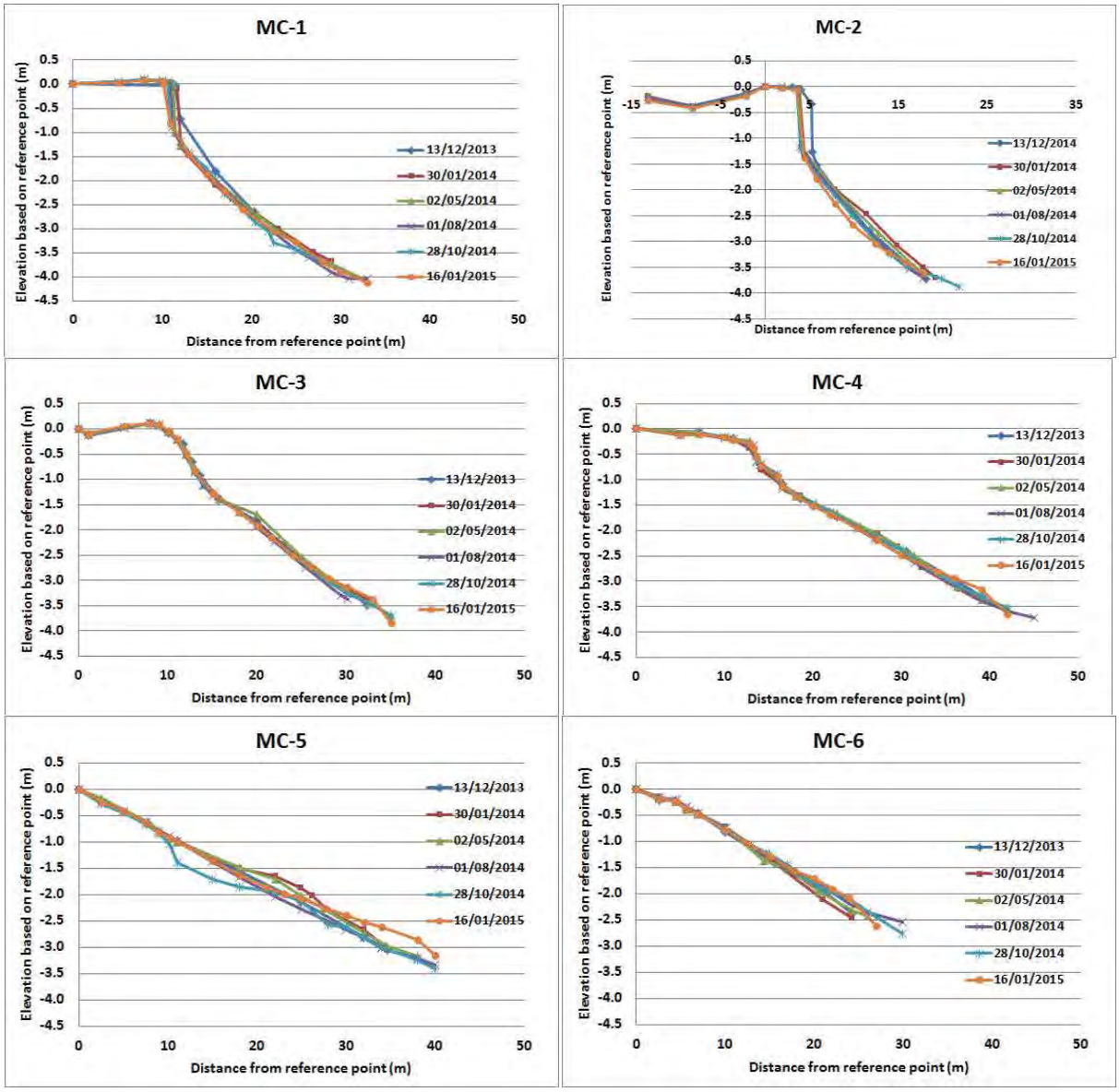
The findings from the monitoring results are as stated below:

- Highly noticeable changes are not found at Points L1 and L2 in the south area, where a scarp of about 1.5m height is permanently formed and an about 1m retreat of scarp has been caused during the recent one year period.
- At Point L5, the change at each time of measurement is remarkable, compared to those at other points. The direction of coastline has changed at this point. This point presents a convex shape (deposition tendency) a little bit, as seen in Figure 3.2.8. It is inferred that the location of deposition area might have been moving according to seasonal variation of wave incidence direction.

Source: Adapted from Google map by JICA Expert Team

Figure 3.2.8 Location Map of Coastal Survey

- No noticeable change in beach profile is found at other points.



Source: MOESDDBM and JICA Expert Team

Figure 3.2.9 Results of Continuous Coastal Monitoring Survey at 6 Representative Sites

3.2.4 Characteristics of Wave, Water Level, Current, Topography, Bed Material and Reef Environment

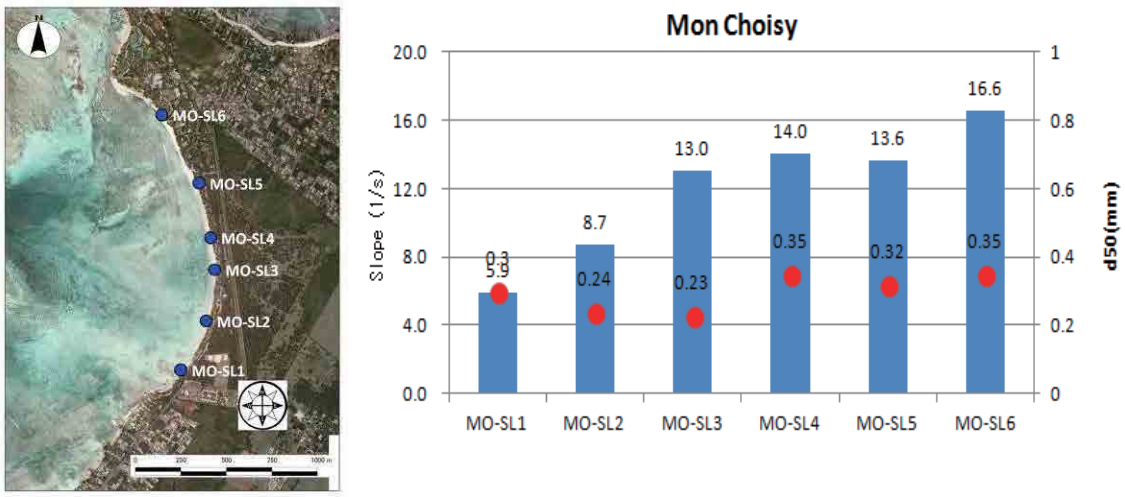
a. Characteristics of Meteorological and Hydrological Conditions

The strong waves commonly hit the coast during the cyclone season from December to March. The dominant wave direction is from E to NW even though it depends on the route of each cyclone. However, the impact of the waves on the shore is significantly decreased by the existence of coral reef with approximately 1km width. The wave to the shore changes not only the variation of offshore wave characteristics but also the change of tide condition. The significant beach change will occur if the incident waves and tidal level are high. The beach scarp at the south part of the public beach is usually formed during cyclone season.

b. Coastal Topography and Sediment Material

Two significant reef gaps exist offshore of the coast, and this will have a great influence on the beach topography. Especially, the forming of concave configuration of the beach at the public beach will be related to the existence of the reef gap (Figure 3.1.1).

The sand at Mon Choisy is coral origin with light color. Figure 3.2.10 shows the distribution of median size (D50) and foreshore slope alongshore. The median size is from 0.24 to 0.36mm. The foreshore slope is steeper at the public beach with the slope of 1:6 to 1:8 and becomes mild toward the north with the slope of 1:14 to 1:16.



Source: Left; Processed by JICA Expert Team based on satellite image obtained from MHL.
Right; Processed by JICA Expert Team.

Figure 3.2.10 Foreshore Slope and Average Grain Size

c. Reef Environment and Water Quality

Seagrass bed of *Syringodium* covered offshore of public beach and no coral community appeared in the seagrass bed in these twenty years. Open sand bottom is seen in the seagrass bed. Siltation was heavy and transparency was only 1 m. By the direct observation using a grass-bottom boat on September 29, 2014, coral community in the north area died out and macro-algae and soft corals grew thick on the skeleton of coral. Shore reef and back reef were covered with living corals in the lagoon from the south tip of Mon Choisy to Trou aux Biches by the aerial photographs and its result of analysis in 1996. Most of the coral seemed to be alive on the shore reefs in 1996, but no living coral is observed at present. Area of living coral in this lagoon apparently decreases and coverage of living coral also seems to decrease in these 18 years because of partly death in the area of living corals. Outbreak of *A. planci* was recorded in the lagoon of Trou aux Biches from 2011 to 2012. Coral reefs in the lagoon of Mon Choisy also seems to be attacked by *A. planci* at the same time. Also, there was a possibility to die by coral-breaching phenomena partly. Large net fishing is carried out in the lagoon and it is anxious about that such activities affect on the living corals, especially juvenile corals in the lagoon.

The investigation results on water quality and impacts to coral in the lagoon at Mon Choisy are shown in Table 3.2.1 Chlorophyll a close to the shore is extremely high and at a level that it is not well suited as a habitat of coral (the coverage of living coral is less than 10%).

Currently, it is significantly in eutrophication state. Although this coast is the sewerage construction plan area, most of households are using AP (absorption pit) or ST (septic tank). As the cause of eutrophication at the coast, the effects of drainage from behind the houses, villas and hotels are considered. Currently, although the water quality monitoring have been conducted, the detailed eutrophication conditions in the lagoon are not clear due to the low analysis accuracy, etc..

Table 3.2.1 Investigation Results on Water Quality and Impact to Water Quality in Lagoon

Check items		Conditions			
Water quality	Chlorophyll a (ug/L)	1.60(*)			
	Turbidity (NTU)	-			
	NO_3-N (mg/L)	-			
	PO_4-P (mg/L)	-			
Population density behind coast(per km^2)					
Sewerage disposal behind coast	Status of development of sewerage facilities behind coast	Sewerage Systems (Trunk Sewer), Absorption Pit, Septic Tank, Pit Latrine			
	Present condition of sewerage disposal from houses (Sewerage system, Septic tank, Pending arrangement, etc.)	Grand Baie VCA: SS: 114, AP: 291, ST: 974, PL: 8			
	Present condition of sewerage disposal from hotels and restaurants (Sewerage system, Septic tank, Pending arrangement, etc.)	Hotels >75 rooms uses onsite treatment plants. Restaurant uses septic tanks.			
	Development plan of sewerage system for houses and hotels behind coast	In pipeline for development, Study stage			
Impact of pollution from sugarcane	Incidence of red-soil runoff from land side	None			
	Existence of sugarcane field behind coast. If there is it, area of the field behind coast.	Yes. Area: 678 Ha			
Relation between living coral and water quality**	Coral coverage	Chlorophyll a (ug/L)	Turbidity (NTU)	NO_3-N (mg/L)	PO_4-P (mg/L)
	>50%	<0.2	<0.5	<0.012	<0.007
	20-50%	0.2-0.6	0.5-1.3	0.012-0.051	0.007-0.016
	10-20%	0.6-0.9	1.3-1.9	0.051-0.081	0.016-0.023
	<10%	>0.9	>1.9	>0.081	>0.023

*: Observation for water quality was conducted close to shore.

**: This relation was obtained by the water quality survey in this study. Refer to Table 2.6.3 in Vol.1.

SS: Sewerage Systems, Ap: Absorption Pit, ST: Septic Tank, PL: Pit latrine

Source: MOESDDBM and JICA Expert Team

3.3 Littoral Drift and Cause of Erosion

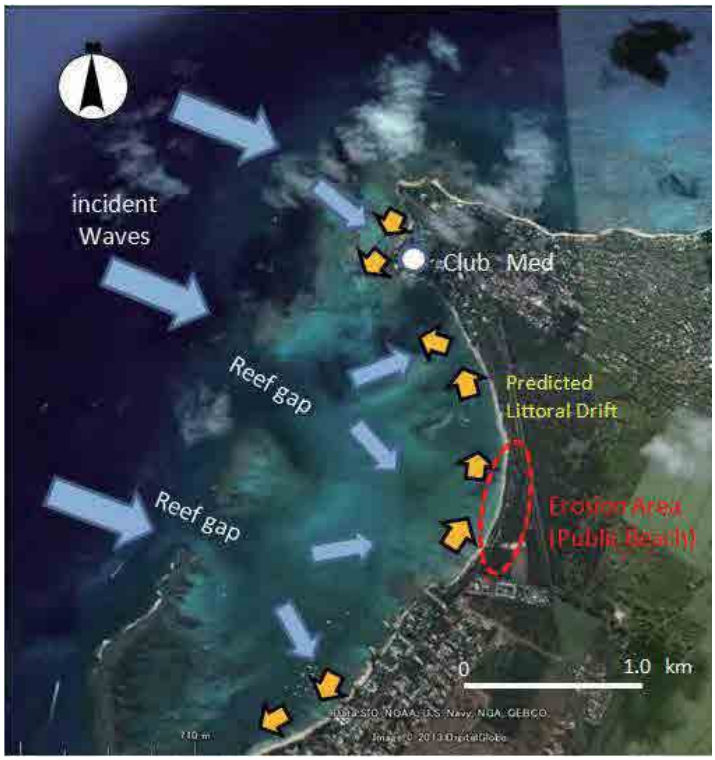
3.3.1 Littoral Drift

As the inclination of the foreshore in Mon Choisy is shown in Figure 3.3.1, the northward littoral drift was expected. The direction of sand movement was also estimated by the line pattern shown on the coral reef. The beach erosion at the south was identified based on the long term shoreline change. However beach accretion that might be expected to balance the sand loss due to erosion was not identified. The coastline at the north area (north of Club Med)

changes suddenly and forms convex rocky area. In an interview with a hotel worker it was reported that the nourished sand for maintenance is being transported and deposited at the south. At the north headland from this point, the direction of the longshore transport changes from the north to the south because of the existence of sudden changes of topography and reef gaps.

From these results, the littoral drift at Mon Choisy was estimated as follows from Figure 3.3.1.

- The littoral drift was estimated to the north because the erosion at the south and the beach slope becomes gentle to the north. Though the transport rate is small.
- There was no area of accretion identified in the north that corresponds to the erosion in the south. This means some quantity of the transported sand might be moved to the offshore through the reef gap.
- Two possibilities are thought for the potential sand source at Mon Choisy in the past as; 1) sand produced by corals on the reef, 2) sand inflow from south area. For 1), taking into account the current coral condition, it is not considered to be a source of sand. For 2), there was a possibility to flow in from south area to the north before the construction of two groynes at the south part in 1975 to 1991. However, no sand inflow is now expected after the construction of these groynes. This means the sand inflow in current condition is too low.



Source: Processed by JICA Expert Team based on Google Earth

Figure 3.3.1 Wave and Littoral Drift Pattern at Mon Choisy

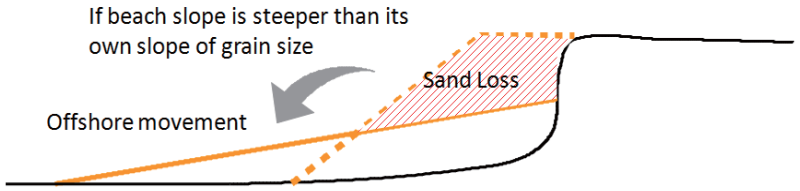
3.3.2 Cause of Erosion

The coastal problem in Mon Choisy is the continuous coastal erosion which has been occurring at the public beach of south area. Also, the sand nourishment, which was undertaken as an erosion countermeasure in 2011, seems not to be very effective. The condition for the existence of slight northward littoral drift is no change since before. There was sand inflow from south side and from offshore side through the coral reef in previous to balance the sediment budget. However due to deterioration of water quality condition and resulting damage for corals, the sediment balance might be changed and totally decreased. Further, the sea grass area existed in the vicinity of the shore previously, and this might have an impact on reducing the wave action to reach to the shore. However, the sea grass area is

not identified at present and this change in condition on the reef may cause acceleration of sand movement near the shore area.

In addition, the following factors might be thought to be impacted to coastal erosion, which are removal and degradation of coral and seagrass due to nautical and fishing activities, removal of corals, seagrass, algae and tree leaves from the lagoon and beach for beach clean-up activities.

According to the obtained information for the remedy to nourish sand with 3,800m^3, which was undertaken by MOESDDBM in 2011, the excavated sand on land for hotel construction (3,200m^3) and the land side sand (300m^3) were employed as nourishment sand. This means the nourished sand has a possibility to be finer than exiting sand on the shore. If the foreshore slope was steeper than the natural slope gradient that is stable for that grain size, some of the sand will be shifted toward offshore to keep its own slope as shown in Figure 3.3.2.



Source: JICA Expert Team

Figure 3.3.2 Offshore Sand Movement In Case of Employing of Fine Sand

3.4 Coastal Conservation Measures

3.4.1 Outline

It is not expected that the supply of coral originated sand will increase naturally in a short period in this coast. Therefore, the physical approach such as artificial nourishment (with supplementary structures, if surely required) and/or a setback is the only considerable short term measures. However, it is very important to highly consider the beach use and landscaping as well as coral reef environment as there is a high priority resort area at north area in Mauritius.

Further, the decrease of sand supply due to deterioration of water quality and coral reef condition was presumed as one of the main causes of erosion. Thus, it is also necessary to consider recovering of sand supply due to improvement of reef environmental conditions as a long term measure.

Source: JICA Expert Team

Figure 3.4.1 Area for Measures

3.4.2 Principle of Measures

a. Short Term Measures

Three methods can be considered as short term measures: 1) nourishment, 2) setback and 3) structural measures (only construction of

groynes, revetment, artificial reef, etc.). The outline, applicability and evaluation are described in the Table 3.4.1.

Table 3.4.1 Comparison of Alternative Measures at the Public Beach

Measures	Setback	Nourishment	Structures
Outline	Plan to leave the beach as natural condition. To set setback line for the future beach erosion as buffer zone. Construction of facilities, buildings are restricted in the area.	Nourish sand to the eroded area. Sometimes groynes or submerged breakwaters are used to keep the sand.	To construct artificial breakwaters to control waves and currents that cause littoral drift.
Applicability	The hinterland is utilized as camping area and seems still enough space. The present natural landscaping can be secured. On the other hand, the space of hinterland might gradually decrease.	- Considering the present beach utilization and required landscaping, nourishment is the most adequate method without structures. On the other hand, sand loss after the nourishment is one of the issues. - There is no possibility of sand recycling at this beach, because the sand accumulation area was not identified. Therefore, nourishment materials will be purchased from quarry site on land, which will be an issue of cost increase.	- Considering the present beach utilization and advantage of this beach, it is requested not to employ the artificial structures as much as possible. - Basically, it is not expected to increase sand inflow to the beach. This means, if the target area can be protected by construction of structures, adverse effect (new beach erosion) might occur in surrounding areas.
Evaluation	Second option (especially, if the nourishment is difficult to conduct)	Recommended	Not recommended

Source: JICA Expert Team

The regular nourishment is proposed to maintain the beach for the principle measures without artificial structures as shown in the following.

- The main attraction of the beach is the maintenance of natural scenery without structures.
- It is important to consider the beach use by the many foreign tourists and local people as it is a major resort area at north of Mauritius.
- Coastal structures such as groynes or detached breakwaters to keep nourished sand may cause erosion at the down drift side because of the northward longshore sediment transport, as previously suggested.

From the consideration the principle of coastal conservation is recommended to keep natural landscape without structures and to maintain the beach with regular sand nourishment.

b. Long Term Measures

The improvement of water quality and the control of tourism use on the coral reef were recommended as the long term measures in order to improve the coral and sea grass condition and to enhance the long term sand supply from the reef. Zoning on the lagoon is immediately required in corroboration with Ministry of Tourism.

3.4.3 Short Term Measures

a. Conditions on Short Term Measures

Conditions on short term measures are presented as follows.

- The target area for short term measures is a 450m-long section of the south part of the public beach as shown in Figure 3.4.1.
- Beach retreat at this area was estimated as 12m in average and 18m in maximum over 40 years based on long term shoreline change analysis. Also it seems that the retreat is continuing at present. If the beach width will be increased significantly, this will induce further unstable condition and sand discharge after the nourishment will be significant. Therefore, the target of short term measures is to keep the present position of the shoreline.
- From the above point of view, initial volume for the nourishment will be a sufficient amount so as to solve the existing beach scarp which is always observed at this area. As the result of continuous beach profile survey, it is assumed that the slope at scarp part is 1:5, average foreshore slope is 1:8 and berm height is 4.0m. Based on this assumption, the total volume for initial beach nourishment for 450m was estimated as 11,000m^3.
- According to the analysis for long term sediment budget, the average of yearly sand loss was estimated as 500m^3/year. From the result, periodical sand nourishment as the maintenance work is assumed to carry out every two years and the volume for sand nourishment is assumed 1,000m^3/ 2 years.
- The nourishment materials will be purchased from a quarry site on land. (Assuming 1,500MUR/m^3 for material cost)

b. Method for Reduction of Nourished Sand Loss

It is important to predict the movement of sand and degree of sand loss after the nourishment for the planning and maintenance. The measures to reduce the loss of nourished sand are required to decrease maintenance cost.

b.1 Selection of proper sediment size and beach slope

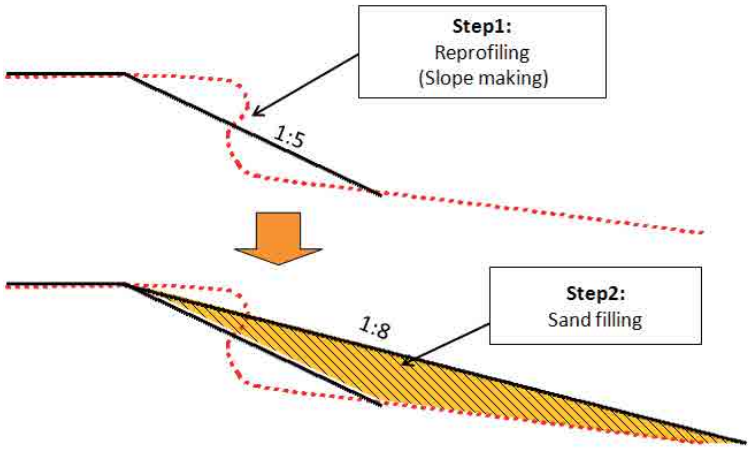
Sediment moves offshore at times of high waves and onshore at low waves with alongshore drift occurring gradually. One of the measures to decrease the sediment loss is as much as possible to prevent offshore movement.

The slope gradient of a beach in equilibrium depends on the wave conditions and the grain size of the sand. The beach slope is 1:6 to 1:8 and the medium size of sand is about 0.25mm at

the south of the public beach. If the nourished sand is smaller than the existing ones, the sand moves offshore regardless of the longshore movement as presented in Figure 3.3.2. It is important to select proper sand size and corresponding beach slope for the onshore and offshore movement together with alongshore movement in the planning of nourishment. The nourished sand can be selected as courser than the existing ones for the stability of the beach though the principle is to use the same size as the existing beach. The selection of sand size has to consider the beach use because it affects the usability and amenity. Also it is strongly recommended not to use different colored sand on such tourism beaches formed by coral sand in order to keep the present image of coral beach as tourism area.

b.2 Beach reprofiling to control beach scarp

Recently there has been a more than 1.5m high beach scarp constantly present at the eroded area. It is hindering access by people wanting to use the beach. Sometimes it prevents recovering of natural beach by the onshore sediment movement (accretion) if the scarp is hard and vertical like a vertical revetment. Thus, it is better to undertake the beach reprofiling before nourishment in advance if the scarp has been already formed. The effect of beach reprofiling is not clear and needs to be evaluated from the monitoring results after reprofiling. The image of beach reprofiling and nourishment is shown in Figure 3.4.2.



Source: JICA Expert Team

Figure 3.4.2 Measures of Beach Reprofiling and Nourishment

c. Cutting a part of trees in the dynamic zone

There are stumps of casuarinas trees at the beach cusp in the south eroded area as shown in Figure 3.4.3. The stumps work as a wall to prevent on-off sediment movement and the recovering of sand on the beach at calm period. The cutting or replanting of trees which cause trouble will contribute the stability of the beach.

Source: JICA Expert Team

Figure 3.4.3 Trees at Foreshore

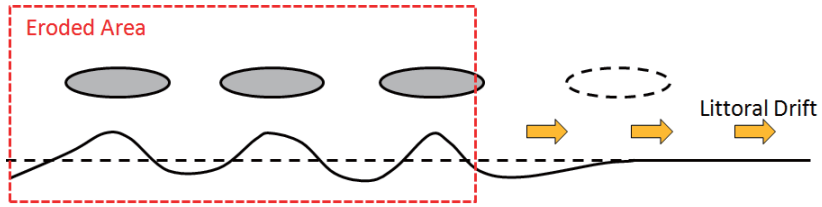
d. Adverse effect to down drift area due to hard structure measures

One of the measures to reduce sand loss of nourishment is the construction of structures such as groynes or detached

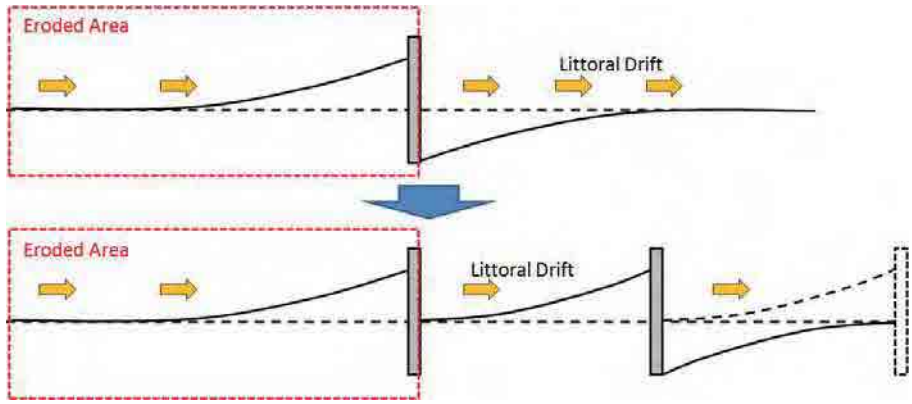
breakwaters to stabilize the beach. The measures give following results.

- Groynes, detached breakwaters or artificial reefs are effective at the eroded south area to stabilize the beach. However the total sand volume does not change basically as shown in Figure 3.4.4. The eroded area becomes stable and the down drift area will be eroded. Then it is necessary to make arrangement plan of structures to the whole sediment cell for the static stability.
- Once a structure is constructed, the impact will be caused at the north. Continuous construction of structures becomes necessary to solve the erosion. This brings the degradation of natural scenery and beach use.

Then the construction of structures should be avoided as much as possible.



(1) Detached Breakwater



(2) Groyne

Source: JICA Expert Team

Figure 3.4.4 Impact of Structures to Down Drift Side

e. Summary of Proposed Short Term Measures

The proposed measures for short term coastal conservation are summarized in Table 3.4.2.

Table 3.4.2 Proposed Short Term Measures at Mon Choisy

Item	Explanation
Area	450 m-long public beach in the south of Mon Choisy
Measures	Continuous dynamic nourishment with proper sand size and beach reprofiling
Sand	D50: more than 0.25mm (the same size as present one or more) White coral sand (shall be strongly considered)
Volume	Initial nourishment: 11,000m^3 Periodical maintenance: 1,000m^3/2 years
Cost	Initial nourishment: 16.5 million MUR (1,500MUR/m^3 was assumed) Periodical maintenance: 1.5 million MUR (1,500MUR/m^3 was assumed)

Source: JICA Expert Team

3.4.4 Long Term Measures

a. Improvement of water quality control based on monitoring result

The detailed eutrophication conditions in the coast are not clear. The quantitative data on the causal relationship with the reef environment is missing. Therefore, it is necessary to conduct the water quality monitoring with high precision analysis and the survey to understand the actual situation of the pollution load through the groundwater from the small river. Based on these monitoring results, it is reccomended to promote the connection of sewerage to the houses and villas not connected to the sewerage as for the long-term countermeasures.

b. Coral plantation in back reefs and establishment of marine protected area (MPA)

Seagrass beds of *Syringodium* covered one third of lagoon just offshore of the public beach (Daby, 2003). Transparency was very bad and siltation was very high. The value of Cha was also high, so here is not adequate for coral habitat, while, living corals were observed in the back reef at one time. From these facts, coral plantation has a possibility at the back reefs under present conditions of water quality, for recovering coral community as the source of coral sand. In the lagoon off Trou aux Biches, neighboring Mon Choisy, Coral communities dominated by tabular and branching *Acropora* were made sure. JICA Experts propose that broken fragments and fragments of living corals are used for donors to be planted in the back reefs. And, we propose also that the back reefs planted corals are established as MPA or the area demarcated as voluntary marine conservation area and planted corals must be monitored in survival rate and growth (Figure 3.4.5).

c. Conservation of seagrass bed by the control of utilization just offshore of public beach

Seagrass beds have functions to decrease wave force and to stabilize fine sediments of the bottom. We propose the conservation of seagrass beds for keeping these functions. For this purpose, we need to control the cruising of pressure-boats and anchoring just offshore of the beach. To make sure the effect of the controls, pilot measure is required at first.

Source: JICA Expert Team

Figure 3.4.5 Proposal of MPA for Corals and Seagrass beds in Mon Choisy Lagoon

3.5 Beach Operation and Maintenance Plan

3.5.1 Improvement plan against present beach management issues

In regard to the Beach Maintenance and Land Utilization for Pte. aux Cannoniers, the present issues and the improvement plan are described in Chapter 5 in the Volume 1. The issues and the improvement plan for the system and implementation which common to the most of the target beaches are described in Chapter 5 as well. This section shows improvement plan against present beach management issues of the beach as follows.

a. Plantation issues on the beach

- To set up suitable arrangement and composition of beach vegetation
- Selection of suitable species of plantation (native species as much as possible)

b. Formation of scarp issues

- Enhancement of monitoring system under cooperation with institutions concerned
- Management of plantation on the beach

c. Vehicle access issues into public beach

- Step-by-step upgrading of parking space in the whole Mauritius
- Installation of sign and information board, shrubs and flower trees as boundary

d. Beach cleaning issues

- Enhancement of awareness of beach cleaning to lessees by using leaflet, etc.
- Periodic inspection by local authority
- To establish a new beach cleaning system and/or add responsibility of beach cleaning in lease agreement

e. Existing coastal facility issues

- Modification of revetment from vertical type to sloping permeable type with plantation
- Demolition and modification of groynes depending on effective

3.5.2 Beach management plan for coastal conservation plan

In this section, several concerns on management for beach conservation are specified. The Beach Conservation Plan of Mon Choisy recommends beach nourishment with appropriate grain size and beach forming.

Due to the wide erosion, there are no areas where have accumulated sand for reuse at this public beach. So it is necessary to purchase sand from the two sand quarries on land, then the cost will be increased accordingly. As a result, the validity of the conservation plan may be re-evaluated. Therefore, it should be considered by the Mauritian Government how to procure white sand with cheaper price for the Beach Operation and Maintenance. Possible ideas are as follows;

1) Utilization of sand dredging at accumulated area,

2) Utilization of seabed sand in the offshore out of reefs

3) Utilization of accumulated sand in the lagoons.

As for the case of 1), it has been already planned to utilize the dredging sand from channels. A comprehensive sand management in close coordination and cooperation with relevant organizations are required to reuse the accumulating sand.

As for 2), the seabed survey led by MOI in the offshore potential area was started. Further survey is expected and its outcomes should be opened. In order to take seabed sand, a dredging work on sea with a special ship is necessary, and the whole cost of the Beach Maintenance will be increased accordingly. Therefore, the implementation plan for the Beach Maintenance should be prepared in place.

As for 3), there is no sand extraction works in lagoons, since a sand extraction in lagoons for a business purpose has been banned in 2000. In the meantime, a large amount of sand has been found in the lagoons. Through the study on possibility of sand extraction in lagoons and environmental impact assessment, further consideration and discussion including a review of the law will be required in the Mauritian Government.

The details of such sand management are described in Chapter 5.3 or later in the Volume 1.

3.5.3 Validity of Setback Amount

The setback amount for eroded sand beach is configured as summation of the amount of erosion during a certain period and the amount of erosion which is caused by strong wave such as cyclones in that period, which is described as following.

Amount of setback = Amount of erosion for a long period + Amount of erosion by temporally event (i.e. extreme weather conditions such as cyclones)

In addition, the erosion due to the SLR (sea level rise) is anticipated in future. There are several proposed equations to estimate the amount of erosion due to the SLR. Among these, the equation proposed by Per Bruun is applied generally. The equation is as follows.

$E=C\times S$,

Where, E: Erosion amount due to the SLR, C: coefficient of beach characteristic and S: amount of SLR. Therefore, the amount of setback needed is described as follows.

Amount of setback = Erosion amount for a long period + Erosion amount by extreme weather conditions + Erosion amount due to SLR

The rate of the SLR from 1987 to 2011 is about 3.2mm/year in average, and the coefficient of C, which is related with the inverse of sea-bottom slope and transportation area of sediments, is set as 10 by the mean sea-bottom slope in Mauritius. The erosion amount due to the SLR, therefore, is calculated as 1.6 m by multiplying averaged erosion rate of 3.2mm/year, the coefficient of 10, and the period of 50years ($E=10\times3.2mm/year\times50years=2m$).

3.6 Issues on Implementation

3.6.1 Sand Resources for Nourishment

The sand for beach nourishment has to be obtained from outside of the coast because there is no accumulated area and it is difficult to get the sand for sand recycling. At present coral sand can be obtained from only one quarry at Maconde of southwest coast near Le Morne and the available volume is limited. It is necessary to find a new site (sites). At Mon Choisy there is possibility of obtaining sand from an offshore area where sand is deposited from the reef gap. MOI confirmed in 2013 the deposited area through a seabed survey. A detailed survey is

necessary to formulate a plan for utilizing the offshore deposited sand for beach nourishment. This is one option for securing sand needed for beach nourishment in Mauritius.

3.6.2 Adaptive Management based on the Monitoring

The proposed measures are sand nourishment without structures. The loss of sand by cyclones is inevitable. In order to maintain the beach in good condition it is necessary to apply the adaptive management system based on the monitoring.

3.6.3 Undertaking of Water Quality Monitoring and Experimental Pilot Project for Coral and Sea grass Transplantation

Coral transplantation and conservation of seaweed beds proposed as long-term countermeasures have not yet reached the implementation level. The regular monitoring to evaluate the water quality variations and habitat conditions quantitatively that becomes the basis for the countermeasures are absolutely missing. The sustainable monitoring for water quality and coral is required. And also, in order to implement the project steadily, it is necessary to conduct the test construction (pilot project) to clarify the impact the countermeasures can be expected to have.

Chapter 4

Bras d'Eau

4 Bras d'Eau

4.1 General

The beach is located in a bay between two headlands at the northeast of Mauritius. Cyclone waves come from northeast and east. Also waves generated by trade winds come from southeast and south. The beaches are found between basalt headlands at the north of the bay. Reef is formed at the east entrance of the bay. However reef is not developed at the west of the bay because of the fresh water inflow.

Along the coast, hotels, bungalows and public beaches are located. The change of beach as erosion and accretion is relatively large and the sediment budget shows deposition tendency. Behind of the eroded there are no important facilities and structures. The problems of disasters are not serious and the urgency of countermeasures are low.

4.2 Coastal Conditions

4.2.1 Waves and Tides

The coast located at the east of Mauritius and the north of a bay and receives waves from east and southeast. Main waves are generated by southeast monsoon and cyclones partly. The tidal range at a spring tide is 0.86m estimated from the observation at Blue Bay and others. (ref. Vol.1 Ch.2) The water level in a lagoon has to be considered the storm surge and the wave setup together with the tide.

4.2.2 Beach Condition

The coast is located at the north of the bay which has opening to the east with 2km wide lagoon as shown in Figure 4.2.1. There is mangrove and no –coral patches at the west part of the bay because of the fresh water inflow. The beaches are of coral sand divided head lands of basalt.

Source: JICA Expert Team modified based on the material from MHL

Figure 4.2.1 Coastal Condition of Bras d 'Eau and Photo Position

At the east hotels are located with wide beach. There are several headlands. There is a beach with a revetment of lease area and without sand at the west. At the west of the beach small groynes with natural rock and a public toilet is located. At the west end there is a mangrove island and sand is accumulated behind it. Those conditions are shown in Figure 4.2.2.

Photo A: Beach and Revetment in front of the Hotel at the East

Photo B: Beach and Revetment in front of Lease Area at the East

Photo C: Erosion and Damages of Mangrove

Photo D: Public Toilet

Photo E: Beach in front of the Public Toilet

Photo F: Accumulated Area and Mangrove at the West

Source: JICA Expert Team

Figure 4.2.2 Coastal Condition at Bras d 'Eau

4.2.3 Reef Environment

According to the direct observation, coral coverage was zero and most part of offshore at Bras d'Eau were covered by the seagrass bed of *Halodule* sp. as shown in Figure 4.2.3. Juvenile *Acropora* sp. was also zero, so there is no possibility of natural regeneration. Green algae were seen along the coastline. Siltation was not seen, but transparency was only 2m. Mangrove trees were seen with dead trees in the lagoon. Seagrass bed was also seen in the aerial photograph

taken in 1996.

Source: JICA Expert Team modified based on Google Earth

Figure 4.2.3 Coral Condition at Bras d'Eau by Spot Check Method

The investigation results on water quality and impacts to coral in the lagoon at Bras d'Eau are shown in Table 4.2.1. Salinity in vicinity of the coast is low (less than 30‰) under the influence of river in the closed-off section of bay. Chlorophyll a in the vicinity of the coast is 0.86 ug/L and at a level that it is not well suited as a habitat of coral (the coverage of living coral is from 10 to 20%). Turbidity is 1.13 NTU and generally good level that the coverage of living coral is from 20 to 50%. As the cause of a somewhat higher chlorophyll a, the effects of input flow from the river are considered. There is no sewerage system in the area and wastewater is mostly disposed of through absorption pits from the houses.

Table 4.2.1 Investigation Results on Water Quality and Impacts to Water Quality in Lagoon

Check items		Conditions
Water quality	Chlorophyll a (ug/L)	0.86(*)
	Turbidity (NTU)	1.13(*)
	NO_3-N (mg/L)	
	PO_4-P (mg/L)	
Population density behind coast(per km^2)		299
Sewerage disposal behind coast	Status of development of sewerage facilities behind coast	Absorption Pit, Septic Tank, Pit Latrine
	Present condition of sewerage disposal from houses (Sewerage system, Septic tank, Pending arrangement, etc.)	P. de Flacq VCA SS: NIL, AP: 2389, ST: 21, PL:119
	Present condition of sewerage disposal from hotels and restaurants (Sewerage system, Septic tank, Pending arrangement, etc.)	Hotels >75 rooms uses onsite treatment plants. Restaurant uses septic tanks.
	Development plan of sewerage system for houses and hotels behind coast	NIL
llu tio n fro	Incidence of red-soil runoff from land side	None

	Existence of sugarcane field behind coast. If there is it, area of the field behind coast.	None			
Relation between living coral and water quality**	Coral coverage	Chlorophyll a (ug/L)	Turbidity (NTU)	NO_3-N (mg/L)	PO_4-P (mg/L)
	>50%	<0.2	<0.5	<0.012	<0.007
	20-50%	0.2-0.6	0.5-1.3	0.012-0.051	0.007-0.016
	10-20%	0.6-0.9	1.3-1.9	0.051-0.081	0.016-0.023
	<10%	>0.9	>1.9	>0.081	>0.023

*: Observation for water quality was conducted close to shore.

**: This relation was obtained by the water quality survey in this study. Refer to Table 2.6.3 in Vol.1.

SS: Sewerage Systems, Ap: Absorption Pit, ST: Septic Tank, PL: Pit latrine

Source: JICA Expert Team

4.2.4 Coast Use

Bungalows and hotels are located at the entrance of the bay and public beach at the bottom with parking area and a public toilet.

The coast condition is shown in Table 4.2.2.

Table 4.2.2 Condition of Bras d'Eau

Basic investigation No.	No. 7 (Sediment Cell No.4)	PB No.	No.35
Coast name	Bras d'Eau		
Natural and topographic characteristics	Sea state	Affected by waves from the east	
	Topography	Sandy beach with 1km to 2km wide lagoon on the front, and located at the bottom of the bay	
Environmental characteristics	Coral reef	The west of the bay is affected by fresh water, which is unsuitable for coral habitat, seaweeds flourish and suitable for mangrove. Coral reef coverage near beach is 0%. Near the edge of the reef, it is around 30%.	
	Water quality	Transparency is 2m at the back of the bay, and 20m near the edge of the reef. The water quality is in eutrophication slightly under the influence of river in the hinterland. The offshore water quality is relatively good.	
Coastal transformation characteristics	Disaster and structures	Beach reprofiling was performed for the scarp. Vertical revetments are located in a part of the beach	
	Coastal transformation	According to the results of topographic interpretation by aerial photos, the erosion with maximum rate of 0.3m/year and the sedimentation with maximum rate of 0.8m year were observed at partial shoreline. The accretion of shoreline arise from not only the alongshore sediment transport but also cross-shore transport.	
Coastal utilization characteristics	Beach utilization	Utilized as PB (public beach). Public toilet and parking area is located. There is a coastal forest behind.	
General assessment		Erosion and beach scarp were seen in front of the public toilet at the public beach. It is caused by maintenance problems.	

Source: JICA Expert Team

4.3 Coastal Process

4.3.1 Coastal Change

a. Shoreline Change

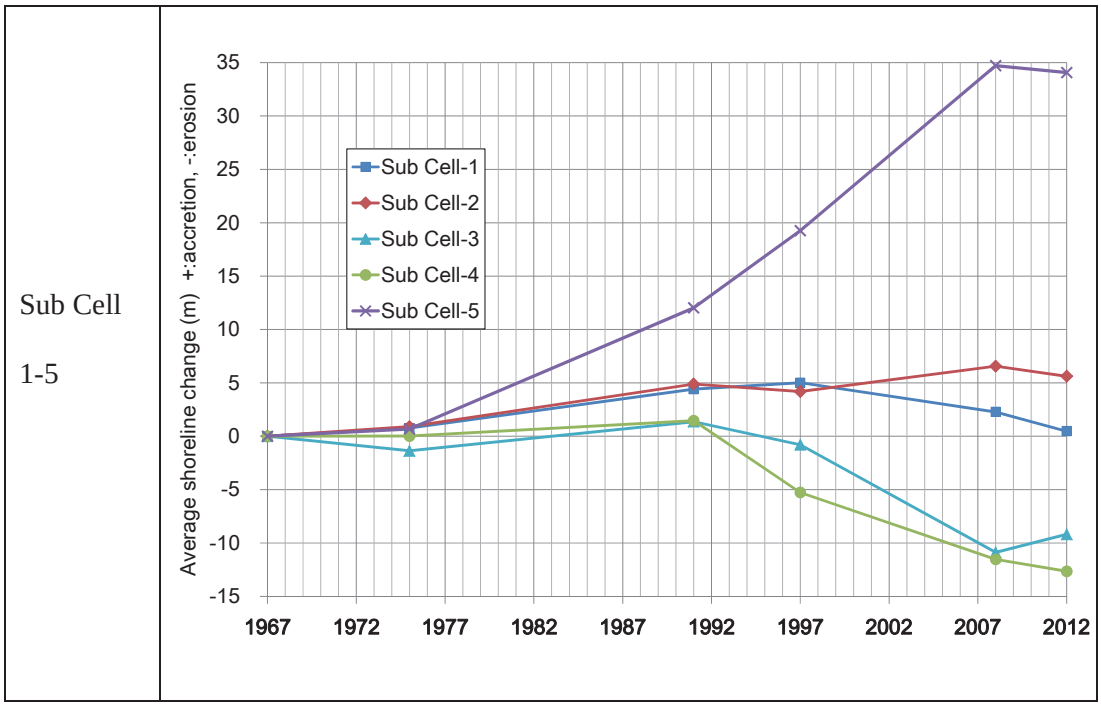
The shoreline condition of erosion and accretion studied by the aerial photograph is shown in Figure 4.3.1. The coast is divided into 5 sub cells. The long term changes are stable at sub cell No.1, accretion at No.2, erosion at No.3 and No.4 and accretion at No.5.

The temporal change of shoreline is shown in Figure 4.3.2. At the sub cell No.5 the coastline is accreting 35m continuously as the rate of 0.8m/y within 45 years from 1967 to 2012. The increase is predominant in 1991 after. The accreted volume becomes more than 10,000m^3. The other sub cells of No.3 and No.4 show the erosion of about 10m. After 1991 the erosion of No.3 and No.4 corresponds to the accretion of No.5. The sediment budget shows no large change.

The public toilet is located at the sub cell No.4 and will be in danger if the trend continues. The beach scarp was seen after the cyclone of January 2014. The monitoring data by MOESDDBM shows the erosion in front of the public toilet and accretion at the bay bottom from November 2013 to January 2014.

Source: JICA Expert Team

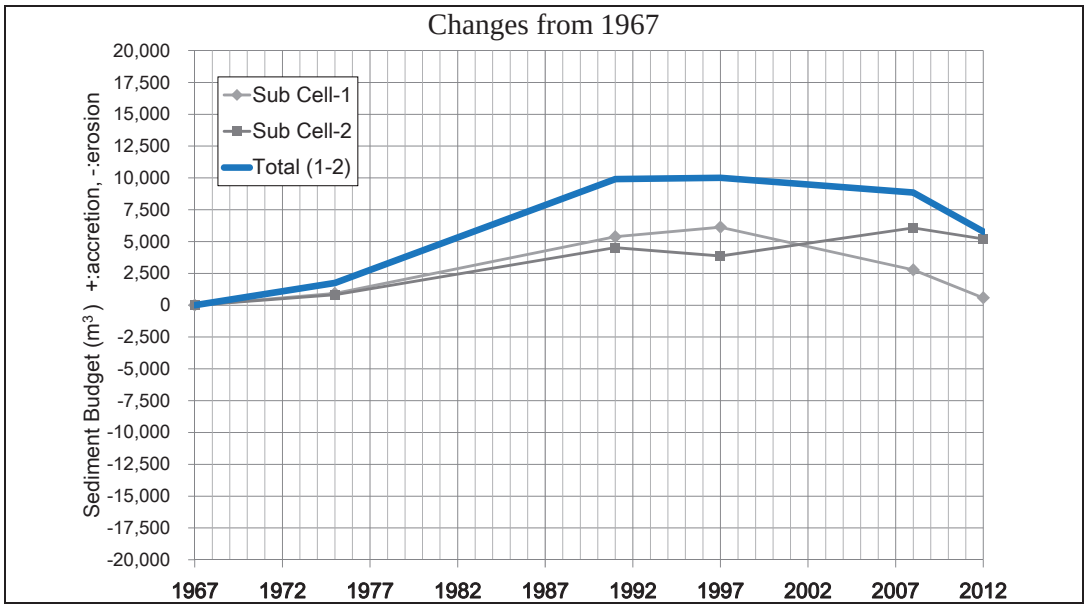
Figure 4.3.1 Study Area and Results of Shoreline Change at Bras d'Eau



Source: JICA Expert Team

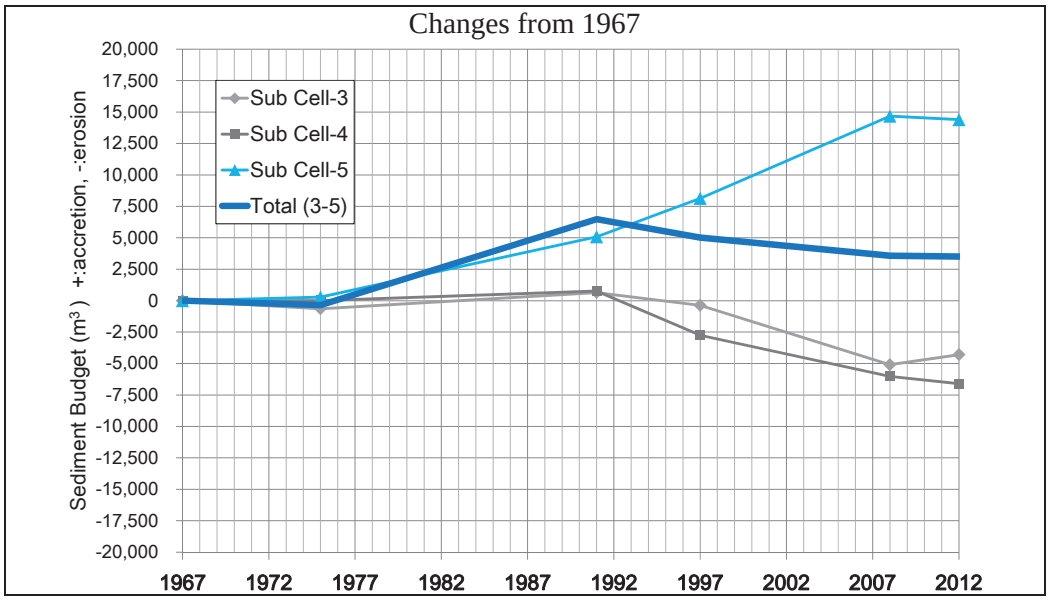
Figure 4.3.2 Shoreline Change at Bras d'Eau

The sediment budget is shown in Figure 4.3.3 and Figure 4.3.4. The total is accretion of 10,000m^3 from 1967. From 1967 to 1991 the beach shows the tendency of stable or erosion though the change is not large.



Source: JICA Expert Team

Figure 4.3.3 Sediment Budget (Sediment Cell No.4, Sub Cell-1-2)



Source: JICA Expert Team

Figure 4.3.4 Sediment Budget (Sediment Cell No.4, Sub Cell-3-5)

b. Beach Monitoring

The beach has been monitored regularly to know the beach profile changes. Four transects were set along the coast from west to east as BD-1、BD-2、BD-3、BD-4 as shown in Figure 4.3.5. The beach was measures at about 3months interval.

Source: JICA Expert Team

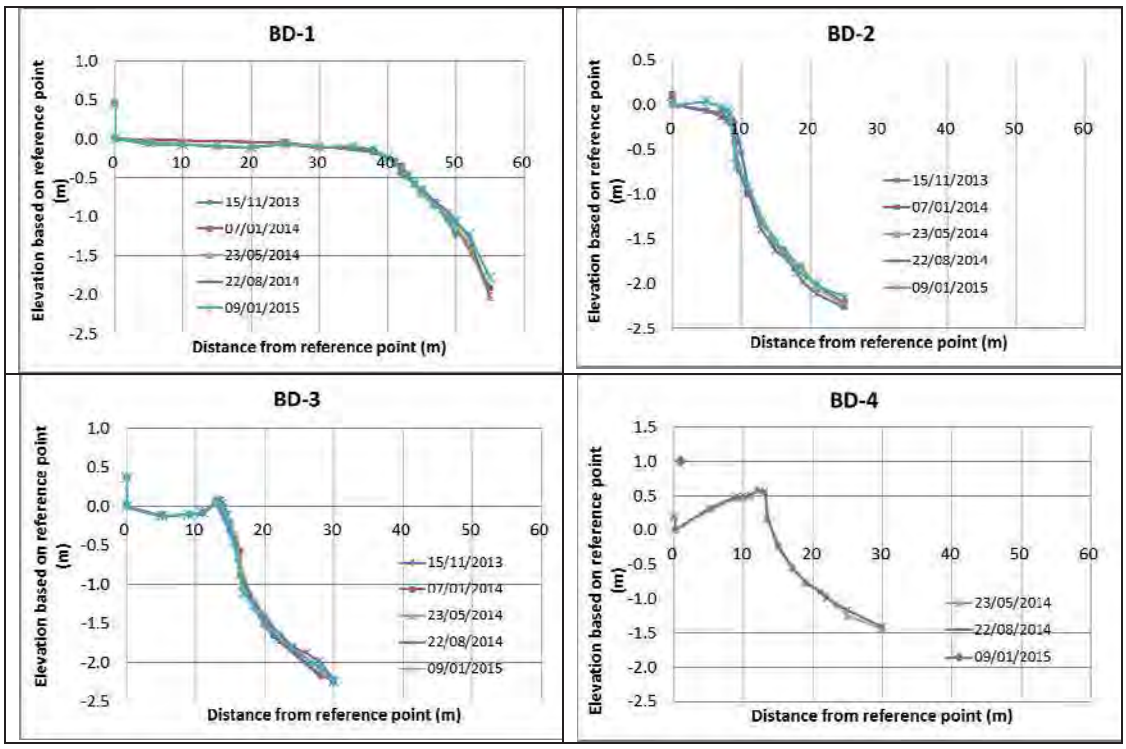
Figure 4.3.5 Arrangement of Transect for Beach Monitoring

The monitoring results of 5 times from November 2013 to January 2015 are shown in Figure 4.3.6. The BD-1 is located in the accreted site of long term and BD=2, BD-3, and BD-4 is located in the eroded site. The profile at accreted site is gentle and steep at eroded site. The elevation is relative height and not the ground level above MSL.

The temporal changes of sectional area from the area at November 2013 as a baseline are shown in Figure 4.3.7. Here, the characteristics are the seasonal change and the difference between the long-term and recent changes. The beach at BD-1 and BD-2 shows accretion from November 2013 to September 2014, erosion after that and recovered at April 2015. On the centrally the beach at BD-2 shows erosion from November 2013 to September 2014,

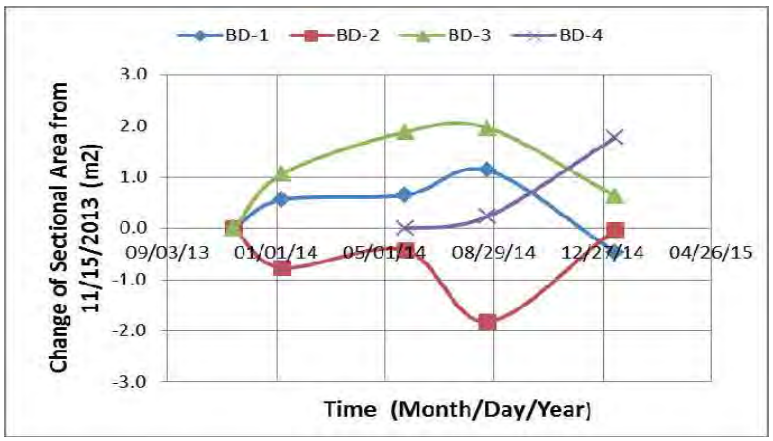
accretion after that and recovered at April 2015. At BD-3 the beach was eroded for long term but it is accreted during the monitoring period.

The changes seems to be related to the seasonal change of wave conditions and the changes of mangrove and seagrass in front of the beach. It is necessary to continue the monitoring because of the observation period is short to understand those changes.



Source: JICA Expert Team

Figure 4.3.6 Beach Monitoring Results at Bras d'Eau



Source: JICA Expert Team

Figure 4.3.7 Temporal Changes of Sectional Area at Bras d'Eau

4.3.2 Sediment Transport

Basically the sediment moves to the west from the entrance to the bottom of the bay. In front of the beach shallow areas are formed by mangroves, rock reef of basalt, and corals and sea grasses. The condition of the lagoon is studied in front of the eroded and accreted beach.

The condition of the lagoon from 1975 is shown from Figure 4.3.8 to Figure 4.3.11 Mangroves and corals are seen compared to the Figure 4.3.11 of satellite image of 2008 in the wide area in front of the beach. There is no seagrass in the image of 2008 with a small shadows to be rock reef in front of the eroded beach of sub cell No.4. On the contrary the shadows of mangroves, seagrasses or rock reef is seen on the other photos. It is difficult to specify the shadows because of the lack of information. It is estimated from present conditions that they are mangroves near the beach and seagrasses offshore. Those shadows were extensive in 1991 and disappeared gradually thereafter.

The mangrove and seagrass usually dissipate waves and currents and decrease the rate of sediment transport. The loss of these seems to cause the increase of the transport rate and erosion. The eroded material transported and deposited at the down drift side of sub cell No.5.

If the sediment supply decreases from offshore, the beach up drift is eroded at the coast with longshore drift. In the coast the sub cell of No.1 and No.2 is stable and the sub cell of No.3 and No.4 of down drift side is eroded with the accreted sub cell of No.5. Then the loss of seagrass in front of the sub cell No.3 and No.4 caused the erosion and accretion.

Sometimes the change of seasonal change of wave condition causes the same kind of situation. However the beach is located at the bottom of the bay and is difficult to receive the change of wave directions.

Source: JICA Expert Team modified based on the material from MHL

Figure 4.3.8 Aerial Photo (1975) of Beach and Reef at Bras d'Eau

Source: JICA Expert Team modified based on the material from MHL

Figure 4.3.9 Aerial Photo (1991) of Beach and Reef at Bras d'Eau

Source: JICA Expert Team modified based on the material from MHL

Figure 4.3.10 Aerial Photo (1997) of Beach and Reef at Bras d'Eau

Source: JICA Expert Team modified based on the material from MHL

Figure 4.3.11 Satellite Image (2008) of Beach and Reef at Bras d'Eau

4.4 Coastal Conservation Plan

4.4.1 Problems and Related Factors

The coast shows the tendency of accretion in the whole. However the beach has been eroded at the public beach and there is a risk of flooding at low land area. The causes of erosion are the loss of mangrove and seagrass in front of the beach and those have to be conserved and rehabilitated. Also the beach maintenance has some problems.

a. Erosion in front of the public beach

The public beach has been eroded in front of the public toilet which was built in 2004. The beach scarp by the cyclone causes problems of beach use. The vertical revetment at a part of the coast also causes some impacts such as scouring in front and erosion of adjacent beach. There are possibilities of damages at the public beach and the toilet by cyclones if no action is taken.

b. Inundation at low land area

The ground level of the accreted beach is low because the action of waves is small at the west of the bay. Then inundation of the road and public beach is one of the problems at high tides and heavy rains. Also the ground water possibly causes the increase of erosion together with the wave action at the cyclone from the wetland behind the beach.

c. Degradation of mangrove, seagrass and coral

The causes of erosion are the loss of mangrove and seagrass in front of the beach. For the long term there are possibilities of the loss of existing mangrove and seagrass, the inundation of sea level rise, and the deterioration of coral caused by the increase of sea surface temperature. The deterioration of coral brings the decrease of the sediment supply and the wave dissipation effect. It is necessary to prepare from now because those are difficult to

correspond in a short term.

d. Beach maintenance

The proposed measures are the beach reprofiling or sand nourishment if eroded as short term ones. The long term ones are the relocation of the toilet and the plantation of mangrove and seagrass.

4.4.2 Short Term Action

The beach reprofiling is inexpensive but needs maintenance with monitoring. The relocation of the toilet block to the parking area or the other side of the road would improve safety of beach users. Then the relocation is recommended because erosion is occurring in front of the toilet block putting the structure at risk during storm surges and cyclones. The public can use the toilet conveniently if it is moved near the parking area. From the consideration the beach reprofiling with monitoring is reasonable for a moment and the relocation of the toilet will be adopted according to the erosion as long term measures. These will be managed by the Beach Authority.

The reprofiling can be done according to the generation and the magnitude of beach scarp by beach monitoring results especially after the cyclone. If the erosion becomes severe the nourishment is one of the alternatives by using the deposited sand at sub cell No.5 as recycling of sand.

The nourishment is estimated by the past shoreline changes in average. The area is about 100m long in front of the public toilet. The volume becomes about $2m^2/m*5years*100m=1,000\ m^3$ of sand. The sand will be taken about 200m down drift side of accreted area. The volume can be adjusted by the loss of sand by cyclone and the long term erosion.

The improvement of vertical revetment is recommended to make gentle revetment for avoiding the scouring in front and will be done by the lessee. If possible it is recommended to remove the revetment and implement setback because it decreases future risk.

The impact of ground water to the erosion will be decided after the observation and investigation of the basic conditions. Those are the relation between ground water seepage on the beach and the erosion, the impact after the lowering of ground water level around the wetland. The organization managed the wetland is suitable to conduct those activities as one of the basic information for the wetland management. The ground water lowering is tested as one of the erosion measures. However the applicability is not clear at the moment. (http://www.coastalconference.com/2013/papers2013/Alessio%20Mariani.pdf) The impact of ground water on the erosion seems not to be main factors because they appear at the both area of erosion and accretion.

The inundation problem at low land can be solved by the improvement of drainage facilities for the road and parking area as usual ones. For the flooding at the cyclone the land use regulation and flood warning is suitable because it is rare. The drains will be installed behind the accumulated area based on the detailed topographic survey. Those are done by MPI as the organization of drainage management.

The change of beach seems to be affected by the corals, sea grasses and mangroves in the

lagoon. It is necessary to monitor the conditions by satellite data with the ground truth and to analyse the causes of beach changes. The activities will be done by MOESDDBM, Beach Authority, MHL and Ministry of Fisheries because it includes the management of coastal area. The MoF is suitable to investigate the change of mangroves and related activities.

The monitoring will be conducted by the photograph taken from a helicopter. The points of interest are (1) the change of shoreline, (2) the change of mangrove in the lagoon, (3) the condition of seagrass and coral in the lagoon, (4) structures along the coast. Those conditions will be monitored continuously.

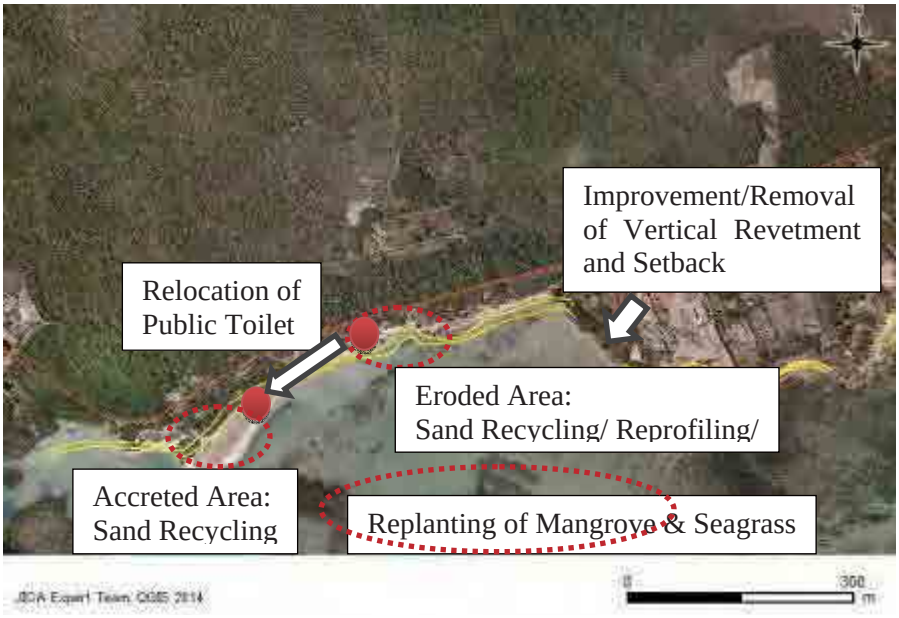
4.4.3 Long Term Action

In the long term the monitoring can be done for the possibility of wave run-up and flooding in low land area and the impact of ground water on the coastal erosion. Those are caused by cyclone or heavy rain. The first step is the measurement of the topography below the ground height of 5m for the map. Then the flooded and run-up area will be estimated by the hearing of local people or the direct measurement after cyclone or heavy rain. The accumulation of those data can be used to make risk map and land use plan to decrease those risks.

For the ground water, after the seepage of ground water is observed at the low tide several times, it is better to start the measurement of ground water level in wells by water level gauges across the beach. Also the water level will be measured at the wetland behind the beach. Those data can be used to estimate the movement of ground water. However, the control of ground water is difficult in general.

The long term measures proposed are the plantation of mangrove and seagrass. MoF is conducting mangrove plantation at the other site already and can applied the results to the coast. For the seagrass plantation, the existing species and their ecological environment have to be monitored. These data can be used to select the suitable species and area for the plantation. Also the site of plantation can be obtained from the past aerial photographs. At present the seagrass exists at the east area. The plantation of mangrove and seagrass may be carried out on a pilot basis.

From the effects of those measures the relocation of the public toilet can be done. The items and location of measures for the short term are shown in Figure 4.4.1.



Source: JICA Expert Team modified based on the material from MHL

Figure 4.4.1 Arrangement of Measures at Bras d'Eau

4.5 Coast Maintenance Plan

4.5.1 Maintenance Problems

Scarps and fallen trees are seen at a part of the public beach and become an obstacle to the use of the beach. A lot of algae is drifted down to the beach and accumulated as shown in Figure 4.5.1. The algae is collected with sand and carried to the disposal site by Beach Authority. It seems that cleaning activity has affected the beach erosion slightly. However, there is the possibility that sand will be lost if it continues for long period.

Beach Scarp in front of the Public Beach

Accumulated Algae on the Beach

Sand in the Collected Algae

Source: JICA Expert Team

Figure 4.5.1 Beach Scarp and Algae on the Beach at Bras d'Eau

4.5.2 Maintenance Plan

The following items should be considered as coastal maintenance plan for the beach.

- Collected driftage should be buried on the beach above HWM. Then, they should be dried in the sun for a few days or buried in the sand at scarps or around trees located on the sand dune. In so doing, the nutrient load in the sand dune would increase there by favoring growth of

bushes, trees and grasses.

- Collected leaves, if buried in the sand would improve the soil and contribute to humus formation. This humus would improve moisture content of the soil and also nutrient load, thereby promoting growth of plants on the sand dune.

- During cleaning of beaches, care should be taken not to remove grasses from the dune. Exposed roots should as far as practicable be covered with sand and grassed.

- To set up suitable frequency of beach profiling survey and analysis.

4.5.3 Validity of Setback Amount

The setback amount for eroded sand beach is configured as summation of the amount of erosion during a certain period, the amount of erosion which is caused by strong wave such as cyclones in that period, and the erosion due to the SLR (sea level rise) is anticipated in future which is described as following.

Amount of setback = Amount of erosion for a long period + Amount of erosion by temporally event (i.e. extreme weather conditions such as cyclones) + Erosion amount due to SLR

There are several proposed equations to estimate the amount of erosion due to the SLR. Among these, the equation proposed by Per Brune is applied generally. The equation is as follows.

E=C×S, where, E: erosion amount due to the SLR, C: coefficient of beach characteristic and S: amount of SLR.

The rate of the SLR from 1987 to 2011 is about 3.9mm/year in average, and the coefficient of C, which is related with the inverse of sea-bottom slope and transportation area of sediments, is set as 10 by the mean sea-bottom slope in Mauritius. The erosion amount due to the SLR, therefore, is calculated as 1.6 m by multiplying averaged erosion rate of 3.2mm/year, the coefficient of 10, and the period of 50years (E=10×3.9mm/year×50years=2m).

The amount of setback becomes 20m if the period is assumed 50 years, the erosion rate of 0.3m, and temporally erosion at the maximum caused by Cyclone Carol of 13m. (Refer Vol.1 Ch. 2). The amount is the same as the present value of 30m. Then it is necessary to monitor the beach profile changes and better to revise the new amount of the setback based on the analysis.

Amount of setback= 0.3*50+13+2=30m

Chapter 5

Q.Cocos Veg and
T.d'Eau Douce

5 Q. Cocos Vge and T. d'Eau Douce

5.1 General

The coast is located at the north part of a bay formed between two headlands at the northeast of Mauritius. The waves come from the east and transport sediment from the reef to the bottom of the bay where sand is deposited. The vertical revetments and groynes constructed for erosion measures cause sometimes a part of erosion. Hotels and public beaches are located along the beach. The coral is not developed because of the inflow of fresh water at the bay bottom.

5.2 Coastal Conditions

5.2.1 Waves and Tides

The coast is located at the northeast of Mauritius and north of a bay. It receives waves from east and southeast. Main waves are generated by southeast trade wind and partly cyclones. The tidal range at a spring tide is 0.86m estimated from the observation at Blue Bay and others. (ref. Vol.1 Ch.2) The water level in a lagoon has to be considered the storm surge and the wave setup together with the tide.

5.2.2 Beach Condition

The coast is located at the north of a bay near T. d'Eau Douce town and the coral reef is not developed because of the fresh water inflow. At the bay entrance the lagoon is 800m wide with a pass. The beaches are of coral sand divided head lands of basalt.

The study area and the coastal conditions are shown in Figure 5.2.1 and related photos are shown in Figure 5.2.2.

Source: JICA Expert Team modified based on the material from MHL

Figure 5.2.1 Coastal Condition of Bras d 'Eau and Photo Position

The study area is about 2km long from the entrance of the bay divided into sub cell No.11 to No.15. The sub cell No.11 and No.12 are sandy beach with hotels. The sub cell No.13 at the west of head land was eroded and revetments and detached breakwaters are constructed. At the west short groynes are constructed as shown in Photo C of Figure 5.2.2. At the west end of the coast the public beach is located and the beach is accreted.

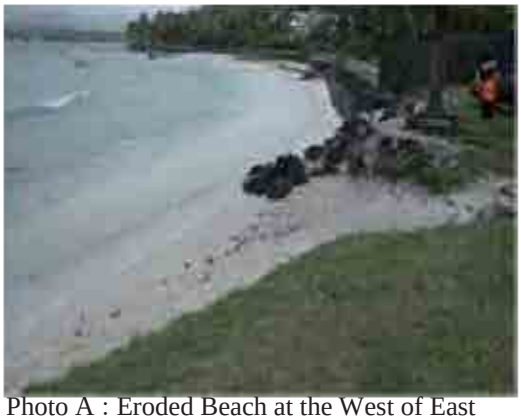


Photo A : Eroded Beach at the West of East Headland in June 2012

Photo B : Revetment and Detached Breakwater on front of the East Hotel in June 2012

Photo C : Arrangement of Groynes

Photo D : Sand Accumulation at the West Beach

Source: JICA Expert Team

Figure 5.2.2 Coastal Condition of T. d'Eau Douce

The public beach at Trou d'Eau Douce Quatre Cocos Vge is subject to erosion. Following surveys carried out by JICA in 2013 and 2014, it was found that the site was eroding. Long term analysis of shoreline carried out under the JICA project also confirmed that the site was under erosive forces.

The MOESDDBM has carried out beach reprofiling at Trou d'Eau Douce, Quatre Cocos Vge in November 2012. However, during cyclone Dumile in January 2013, all the sand placed eroded away. Consequently the MOESDDBM placed small rock of diameter 15–25cm in November 2013. Following cyclone events of January and February 2014, it was found that the pebbles were still in place. The process is shown in Figure 5.2.3.

As a follow up of the project, the following works were undertaken on November 2014:

- The stretch of 50m as from the boundary wall of the public beach has been refurbished with pebbles at a height of 2m and width of 10m towards the sea (slope 1:5). Pebbles of 32-40mm diameter will be used which will be topped up with 15-25mm of pebbles.

- A wooden hand rail of 80m long as from public access has been built to restrict vehicular access across the public space. It was proposed that provision would be made for an access of approximately 2m in case of any emergency. It was also proposed that a signage for parking will be fixed near the wooden hand rail.

- Some 100 Bougainvillea, 30 Veloutier d'Argent, 30 Ste Marie and 15 Pongamia trees was planted in the area between the hand rail and the high water mark within the public space.

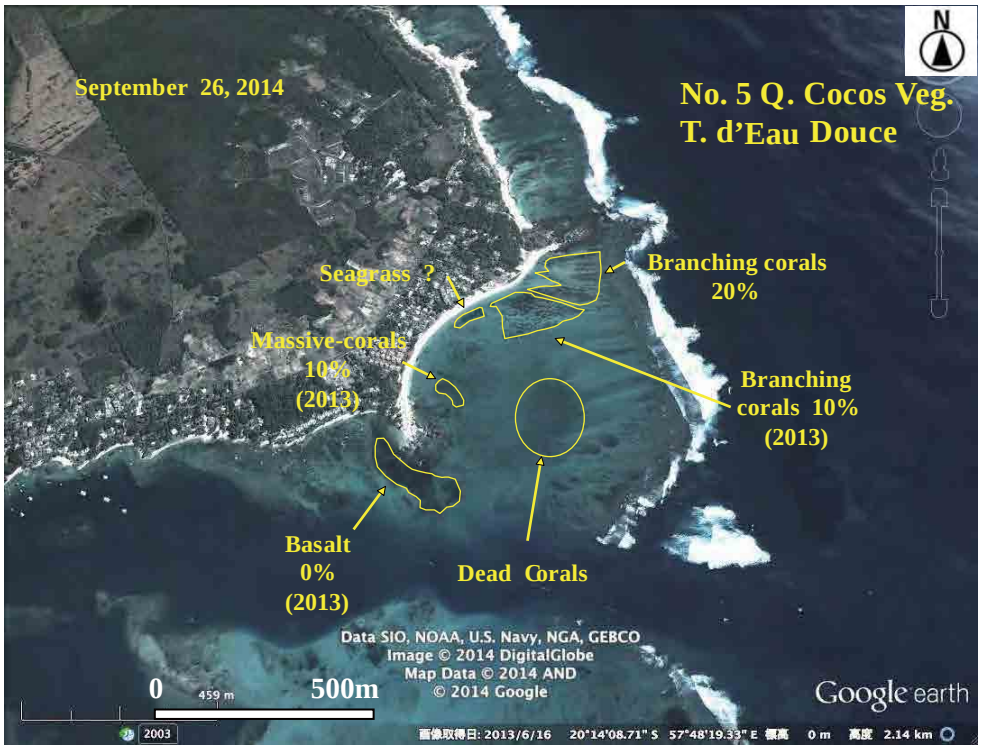
- Grasses would also be grown across the public space to stabilise the dune.

	
February 2012 before reprofiling with sand	November 2012 during beach reprofiling with sand
	
20 December 2013 before reprofiling with pebbles	27 December 2013 after reprofiling with pebbles
	
January 2015	Placement of pine poles to prevent vehicular access on the dynamic beach zone

Figure 5.2.3 Beach Reprofiling at Public Beach

5.2.3 Reef Environment

Living coral was not so abundant and its coverage was from 10 to 20 % as shown in Figure 5.2.4. However patch reefs dominated by branching *Acropora sp.* were seen at the north offshore of public beach. Surrounding areas of the patch reefs were covered by sand. Patch reefs covered same area also in the aerial photos taken in 1996. While, shore reefs dominated by massive corals were seen at the north offshore of public beach and its coverage of corals was only 10% with no juvenile *Acropora sp.*. Seagrass bed of *Halophila sp.* was observed in sandy bottom. *Padina* sp. was also observed on the skeleton of branching *Acropora sp.*. Transparency was 10 m and siltation was not seen. Skeleton of tabular and branching *Acropora sp.* accumulated at the central bottom of lagoon.



Source: JICA Expert Team modified based on Google Earth

Figure 5.2.4 Coral Condition at Q. Cocos Vge Surveyed by Grass Boat

The investigation results on water quality and impacts to coral in the lagoon at Q. Cocos Vge and T. d'Eau Douce are shown in Table 5.2.1. Transparency is 5 to 10m and siltation is low. Under the influence of the marsh in the closed-off section of bay, salinity in vicinity of the coast is 28-34‰ and lower than that in in offshore water (34-35‰). Chlorophyll a, turbidity and PO_4 of nutrient salts are respectively 0.50 ug/L, 1.06 NTU and 0.015 mg/L on an average and generally good level as habitat of coral (the coverage of living coral is from 20 to 50%). However, NO_3 is 0.08 mg/L on an average and at a level that it is not well suited as a habitat of coral (the coverage of living coral is from 10 to 20%). This coast is an underdeveloped district of sewerage system. The most wastewaters are flowing into the coast through absorption pit and septic tank from the houses.

Table 5.2.1 Investigation Results on Water Quality and Impacts to Water Quality in Lagoon

Check items		Conditions			
Water quality	Chlorophyll a (ug/L)	0.22-0.97(#) (Ave. 0.50)			
	Turbidity (NTU)	0.40-3.37(#) (Ave. 1.06)			
	NO_3-N (mg/L)	<0.03-0.17(#) (Ave. 0.08)			
	PO_4-P (mg/L)	<0.005-0.04(#) (Ave. 0.015)			
Population density behind coast(per km^2)		552			
Sewerage disposal behind coast	Status of development of sewerage facilities behind coast	Absorption Pit, Septic Tank, Pit Latrine			
	Present condition of sewerage disposal from houses (Sewerage system, Septic tank, Pending arrangement, etc.)	T. D' Douce VCA SS: NIL, AP: 1470, ST: 115, PL: 28			
	Present condition of sewerage disposal from hotels and restaurants (Sewerage system, Septic tank, Pending arrangement, etc.)	Hotels >75 rooms uses onsite treatment plants. Restaurant uses septic tanks.			
	Development plan of sewerage system for houses and hotels behind coast	Septic tanks, Absorption pits			
Impact of pollution from sugarcane	Incidence of red-soil runoff from land side	Yes. River Mouth Lagoon Width: 2.4 Km			
	Existence of sugarcane field behind coast. If there is it, area of the field behind coast.	Yes. Area: 10,854 Ha			
Relation between living coral and water quality**	Coral coverage	Chlorophyll a (ug/L)	Turbidity (NTU)	NO_3-N (mg/L)	PO_4-P (mg/L)
	>50%	<0.2	<0.5	<0.012	<0.007
	20-50%	0.2-0.6	0.5-1.3	0.012-0.051	0.007-0.016
	10-20%	0.6-0.9	1.3-1.9	0.051-0.081	0.016-0.023
	<10%	>0.9	>1.9	>0.081	>0.023

#: Observation for water quality and coral reef was conducted from the shore to the reef edge.
**: This relation was obtained by the water quality survey in this study. Refer to Table 2.6.3 in Vol.1.
SS: Sewerage Systems, Ap: Absorption Pit, ST: Septic Tank, PL: Pit latrine
Source: JICA Expert Team

5.2.4 Coast Use

At the entrance of the bay, hotels are located and along the coast two public beaches are located, one near the head land and the other at the bottom.

The coastal conditions are summarized in Table 5.2.2.

Table 5.2.2 Condition of T. d'Eau Douce

Basic investigation No.	No. 8 (Sediment Cell No.5)	PB No.	No.37-46
Coast name	Trou d'Eau Douce Quatre Cocos Vge		
Natural and topographic characteristics	Sea state	Affected by waves from the east	
	Topography	Sand beach with around 500m to check-wide lagoon on the front	
Environmental characteristics	Coral reef	At T. d'Eau Douce, coral reef coverage varies widely depending on point, in a range of 1 to 99%. According to the results of coral reef monitoring by AFRC, coral reef	

		coverage around the reef edge from 2000 to 2010 is stable at both coasts. The coral reef coverage near beach at T. d'Eau Douce has been decline from 70% to 15%.
	Water quality	At T. d'Eau Douce, transparency is 3 to 5m and siltation is decreasing as coral coverage is increasing. Nutrients (NO3, PO4) are higher than other lagoons and the effects of input flow from the closed-off section of bay are considered from the survey. Nutrients are higher than other lagoons and the effects of pollution load from the hinterland such as fields considered.
Coastal transformation characteristics	Disaster and structures	Beach reprofiling was implemented in 2012 (sand nourishment), 2013-2014(flexible revetment) (in, 1km) Installation of gabions and groynes was implemented in La Tropical.
	Coastal transformation	According to the results of topographic interpretation by aerial photos, the beach at Belle Mare is relatively stable. At Palmar and T. d'Eau Douce, large-scaled alongshore sediment transport has generated the remarkable eroded area (0.4m/year) and sedimentation area (1.1m/year).
Coastal utilization characteristics	Beach utilization	Utilized as PB (public beach). There are hotels and residents' houses behind. The frequency of beach utilization by local residents and tourists is high.
General assessment		Judging from the fact that some structures for controlling sediment transport such as groynes have been provided, wide-scaled alongshore sediment transport has generated the remarkable eroded area and sedimentation area. The hinterland has been considerably utilized such as hotels, and the existence of the scarp can be trouble. In light of these facts, it is required to study the current situation and devise a coastal protection program as well as countermeasures based on the study results.

5.3 Coastal Process

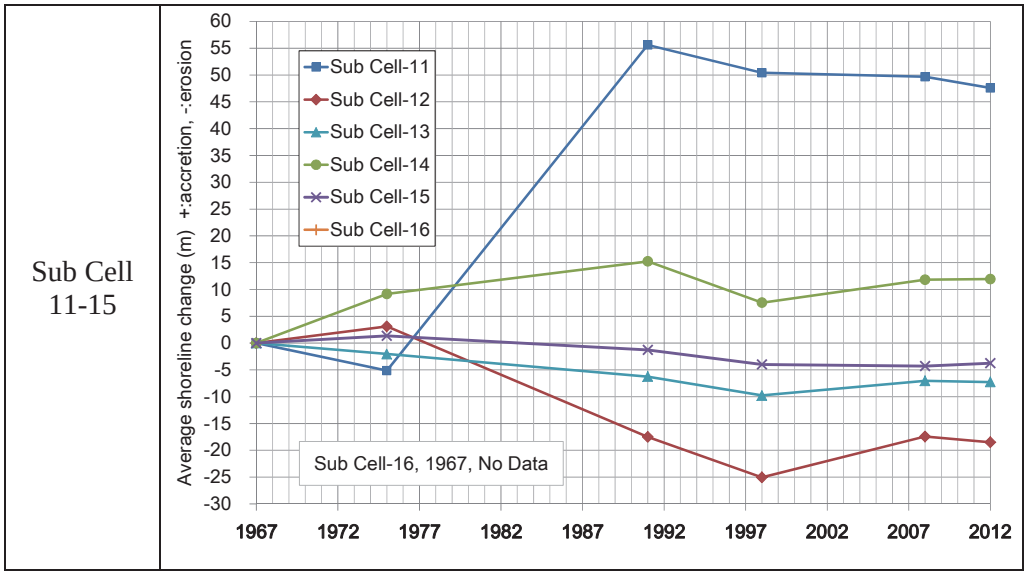
5.3.1 Coastal Change

a. Shoreline Change

The coast is divided into 6 sub cell from No.11 to No.15 as shown in Figure 5.3.1 and the shoreline change is shown in Figure 5.3.2. The sediment budget is shown in Figure 5.3.3 and Figure 5.3.4. The sub cell of No.11 at the entrance was accreted about 50m from 1975 to 1991 and became stable after. The accumulation reached about 40,000m^3. On the contrary the sub cell of No.12 at the east of No.11 was eroded about 20m from 1975 to 1997 and the volume became about 20,000 m^3. The sub cell No.13 shows erosion and No.14 shows accretion with some variation.

Source: JICA Expert Team modified based on the material from MHL

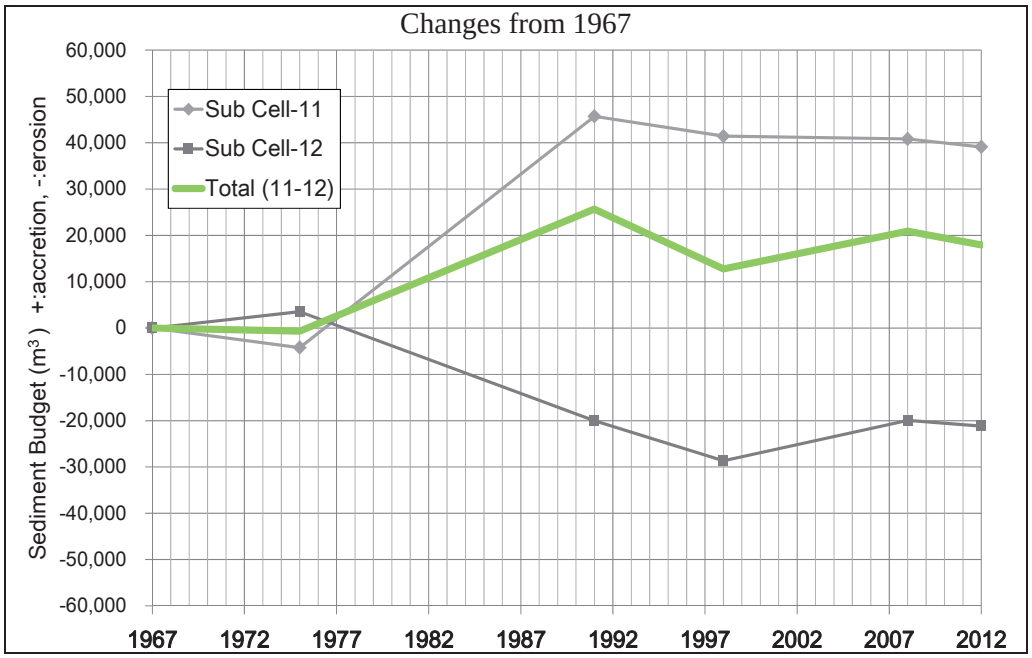
Figure 5.3.1 Coastal Condition of Bras d 'Eau and Photo Position



Source: JICA Expert Team

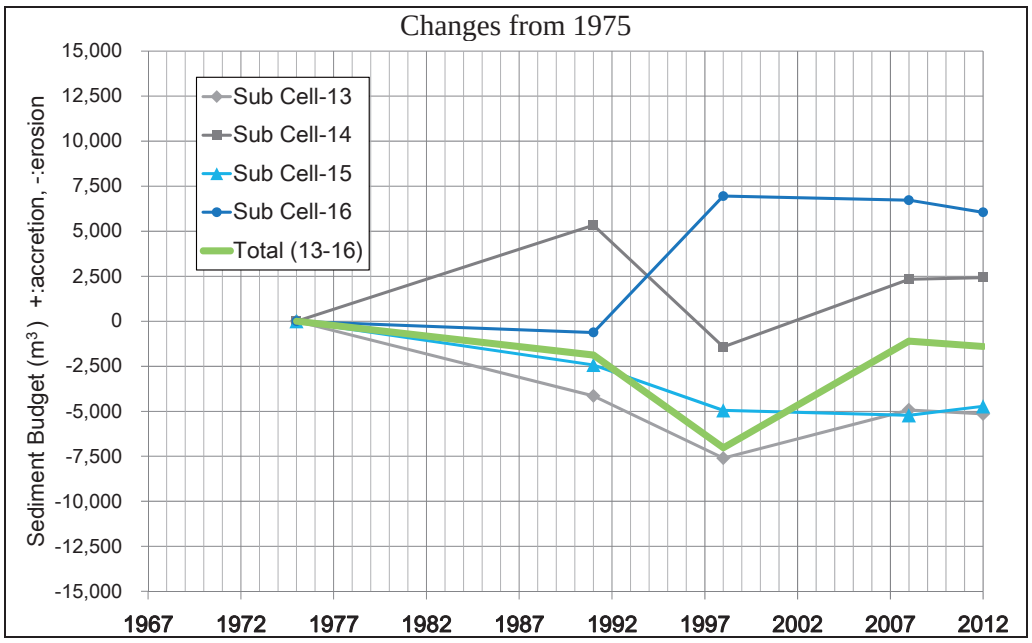
Figure 5.3.2 Shoreline Change at T. d'Eau Douce

The difference of accreted volume of sub cell No.11 and eroded volume of sub cell No.12 is shown in Figure 5.3.3 and becomes the accumulation of about 20,000m^3.



Source: JICA Expert Team

Figure 5.3.3 Sediment Budget (Sediment Cell No.5, Sub Cell-11-12)



Source: JICA Expert Team

Figure 5.3.4 Sediment Budget (Sediment Cell No.5, Sub Cell-13-16)

b. Beach Monitoring

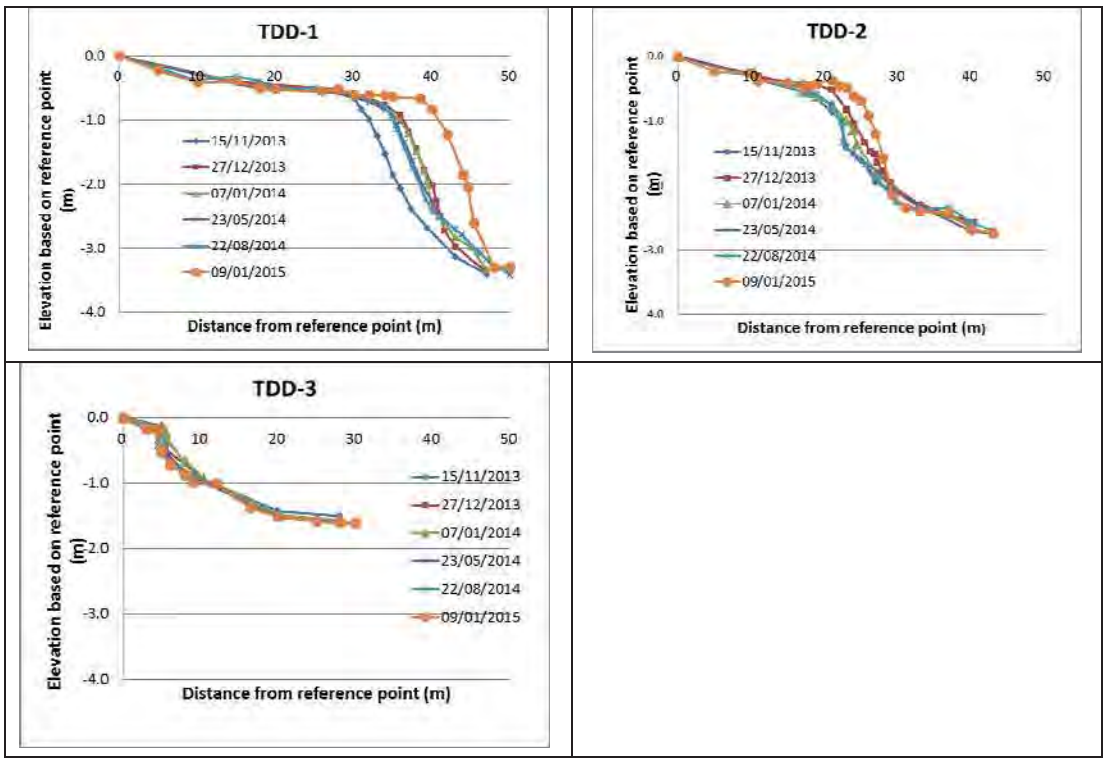
The beach has been monitored regularly to know the beach profile changes. Three transects were set at the west of a headland from northwest to southeast as TDD-1、TDD-2、TDD-3 as shown in Figure 5.3.5 The beach was measures at about 3months interval. At the beach gravels were nourished 2 times on November 2013 and 2014 for the measures of beach erosion by MOESDDBM.

Source: JICA Expert Team

Figure 5.3.5 Arrangement of Transect for Beach Monitoring

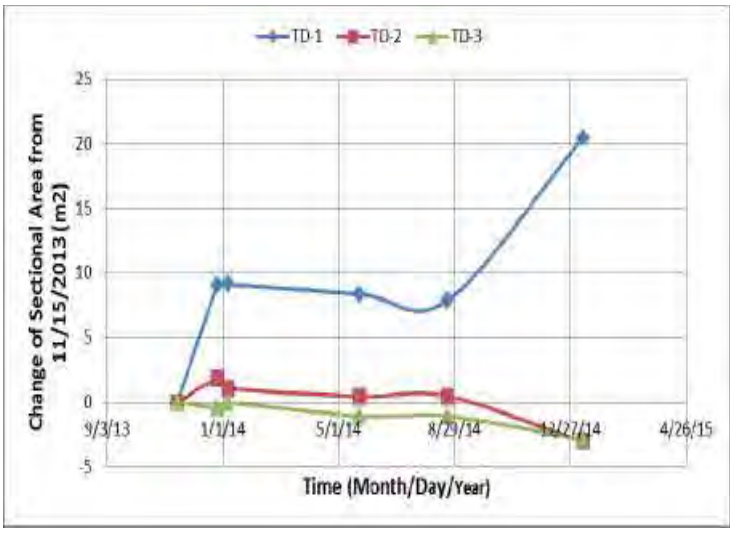
The monitoring results of 6 times from November 2013 to January 2015 are shown in Figure 5.3.6. At the site gravels were nourished at TDD-1 and TDD-2. The elevation is relative height and not the ground level above MSL.

The temporal changes of sectional area from November 2013 are shown in Figure 5.3.7 and shows the increase by the gravel nourishment. After the nourishment the gravel was moved but the volume was small. It is necessary to monitor several years for the estimation of the loss.



Source: JICA Expert Team

Figure 5.3.6 Beach Monitoring Results at T. d'Eau Douce



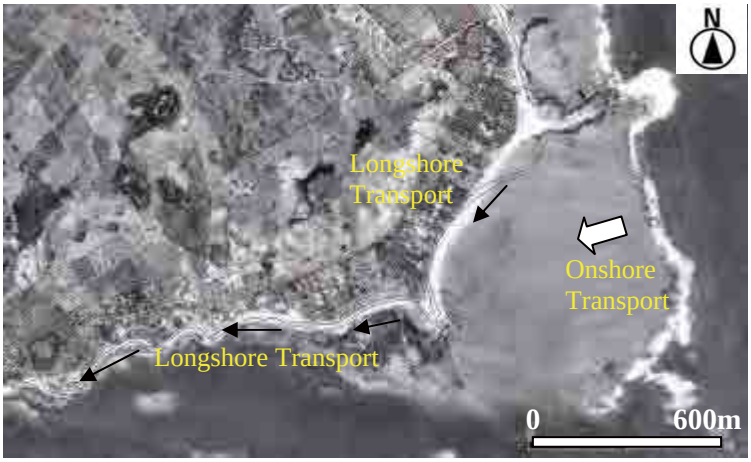
Source: JICA Expert Team

Figure 5.3.7 Temporal Changes of Sectional Area at T. d'Eau Douce

5.3.2 Sediment Transport

The coast receives waves from the bay entrance at east and exists longshore sediment transport to the west. Basalt head lands and groynes work as obstructions of longshore transport and sand accumulated between them. The total sediment budget shows accretion in a whole. However, the beach at the public beach is eroded around the head land. The beach at the west of the bay shows accretion because of the sediment supply.

Looking at the reef condition of sub cell No.11 where the beach was accreted, sea grass or coral was not exist in 1975 as shown in Figure 5.3.8. However sea grass or coral was grown up in the reef and sand was accreted from 1997 to 2008 as shown in Figure 5.3.9. This seems to cause the erosion at the down drift of sub cell No.12 and No.13. The impact affected further down to the sub cell No.14 and No.15. At the end of No.16 the beach was accreted with some time lag and the whole beach was accreted.



Source: JICA Expert Team modified based on the material from MHL

Figure 5.3.8 Aerial Photo (1975) at T. d'Eau Douce

Source: JICA Expert Team modified based on the material from MHL

Figure 5.3.9 Satellite Image (2008) of Beach and Reef at T. d'Eau Douce

5.4 Coastal Conservation Plan

5.4.1 Problems and Related Factors

Large coastal changes of accretion and erosion are problems caused by the change of coral condition in the reef together with the change of wave conditions.

At the eroded area hotel were constructed. Then it is necessary to reconsider the setback line of 30m. The structures at the eroded area such as vertical revetment, groynes and detached breakwaters have to review because they cause erosion at the down drift and modify sediment transport.

Hotels are located at the eroded area and houses are at the accreted one. There is a possibility that the hotel was constructed in fluctuated area. It is necessary to allow the changes and to avoid the construction in that kind of area. The groynes are not preferable without small scale or at the enough beach area because they cause erosion at the down drift.

5.4.2 Short Term Action

The maintenance of natural beach is taken as the course of action for the coast conservation plan because the coast is supplied sediment from coral reef with public beach and hotels and the natural beach is important resources of tourism. There are a few measures as shown in the Table 5.4.1. They are setback by accepting the erosion and dynamic beach changes, beach reprofiling to supply sand to the eroded area and the control of alongshore sediment transport by groynes. Reef exists offshore and is expected to supply sediment to the beach and the beach has tendency of accretion. The natural beach is important tourism resources to the hotels. From those conditions, the setback is suitable to maintain sandy beach and to allow the dynamic changes as shown in Figure 5.4.1.

The setback is 30m at present and the amount seems to be insufficient at the beach from the past erosion rate of 0.4m/y. The value is possibly temporally and in future will change to the accretion. It is better to revise the value if necessary after the monitoring.

Table 5.4.1 Alternative Measures at T. D'Eau Duce

Measures	Setback	Reprofiling (Nourishment by pebbles)	Groyne
Outline	Basically, sediment supply from the east is blocked by corals or sea grasses, which work as groynes. In total the sediment is accumulated. Erosion is limited around headlands caused by the change of wave conditions. The setback is the most effective measure.	The erosion seems to be temporal and one of the measures is reprofiling or nourishments if erosion happed. The sand can be obtained from the outside of the coast or accumulated areas at the entrance or bottom of the bay.	Constructing groynes is proposed to control longshore sediment transport, especially eroded beaches between headlands. However, there are impacts on the down drift side. It is acceptable if that is past accreted area.
Advantages	It will be possible to keep the natural scenery without the constructing facilities.	Accumulated sand in the eastern area will be moved to the western area. It is easy to take this measure.	Immediate responses will be expected by the constructing facilities at the eroded areas.
Disadvantages	There are residents and bungalow behind the beach and the distance from the beach to them is not enough. It may be difficult to obtain informed consent from them about the setback plan.	It will be necessary to carry out periodical sand nourishment. It may take time to obtain informed consent from those who are paying such maintenance costs. Also accessibility in transporting sand should be investigated in advance.	There is a possibility of erosion at down-drift of the groyne. It will be needed to obtain the agreement from concerned people about the locations of groynes and their impact, but it may take long time. In addition, more surveys are required before design can be submitted.

Source: JICA Expert Team

Source: JICA Expert Team processed based on the material from MH

Figure 5.4.1 Arrangement of Measures at T. d'Eau Douce

The basic policy is the conservation of coral and the setback with monitoring. The whole coast is accreting and the accretion was caused by the growth of coral patch with the erosion at the down drift side. The erosion has tendency to recover and the coral is deteriorating. It is necessary to keep natural condition with monitoring in a short term. Temporal erosion can be managed by beach reprofiling.

The existing vertical revetment should be improved as gentle ones to avoid the scouring in front and erosion of down drift side. The existing groynes and other structures have to be monitored the performance and to be improved if impacts of erosion become clear. The owner of the structure has to take actions.

The condition of coral is not good and the live coral coverage is 10%. The lagoon condition should be monitored. It includes the shoreline, coral and seagrass, the water quality and activities in the lagoon by aerial photos from helicopter and field survey.

5.4.3 Long Term Action

For the short term the setback is enough because the erosion has tendency to recover. However the condition of coral is not good condition. If the coral disappears the accreted beach will be eroded and returned to the original. The erosion will become 50m corresponding to the accretion. For the long term it is necessary to prepare those changes.

The first one will be to keep the reef condition for coral growth based on the monitoring and analyzed results. The regulation of human activities in the lagoon and the formation of protected area will be included. In order to avoid the risk the lease area can be keep before the accretion.

The coral farming is one of the measures for the degradation of coral caused by the change of sea surface temperature. The applicability will be decided by the information from

monitoring.

The establishment of sewage system and the improvement of existing one are also have to consider if the impact of eutrophication on the coral becomes clear.

5.5 Coast Maintenance Plan

5.5.1 Maintenance Problems

On a part of the beach sea algae and garbage are accumulated. Those seem to happen in front of the lease area in absence. (Figure 5.5.1)

Accumulated a lot of Sea Algae and Garbage, Possibly No Cleaning for a Long Term

No Cleaning in front of Lease Area and Accumulation of Garbage on the Beach

Source: JICA Expert Team

Figure 5.5.1 Accumulation of Sea Algae on the Beach

5.5.2 Maintenance Plan

In some hotels, seagrass and algae is buried in the sand by sweepers every morning. The beach is kept in a good condition. Buried seagrass and algae has a positive impact on conservation of ecosystems, especially on various organisms and marine life because it becomes feeds for them. It is recommended that the activity should be applied to the other beaches in front of the leased properties such as hotels, bungalows etc. in order to keep good landscape and clean condition continuously. This section shows improvement plan against present beach management issues of the beach as follows.

a. Existing coastal facility issues

- Modification of revetment from vertical type to sloping permeable type with plantation
- Demolition and modification of groynes depending on effective

b. Beach cleaning issues

- Enhancement of awareness of beach cleaning to lessees by using leaflet, etc.
- Periodic inspection by local authority
- To establish a new beach cleaning system and/or add responsibility of beach cleaning in lease agreement

c. Vehicle access issues into public beach

- Step-by-step upgrading of parking space in the whole Mauritius

- Installation of sign and information board, shrubs and flower trees as boundary

d. Removal of sand grass/creepers

- Enhancement of awareness of importance of sand grass to lessees by using leaflet, etc.
- To add protection and conservation of sand grass/creepers in lease agreement

5.5.3 Validity of 30m as a setback amount

The setback amount for eroded sand beach is configured as summation of the amount of erosion during a certain period, the amount of erosion which is caused by strong wave such as cyclones in that period, and the erosion due to the SLR (sea level rise) is anticipated in future which is described as following.

Amount of setback = Amount of erosion for a long period + Amount of erosion by temporally event (i.e. extreme weather conditions such as cyclones) + Erosion amount due to SLR

There are several proposed equations to estimate the amount of erosion due to the SLR. Among these, the equation proposed by Per Brune is applied generally. The equation is as follows.

E=C×S, where, E: erosion amount due to the SLR, C: coefficient of beach characteristic and S: amount of SLR.

The rate of the SLR from 1987 to 2011 is about 3.9mm/year in average, and the coefficient of C, which is related with the inverse of sea-bottom slope and transportation area of sediments, is set as 10 by the mean sea-bottom slope in Mauritius. The erosion amount due to the SLR, therefore, is calculated as 1.6 m by multiplying averaged erosion rate of 3.2mm/year, the coefficient of 10, and the period of 50years (E=10×3.9mm/year×50years=2m).

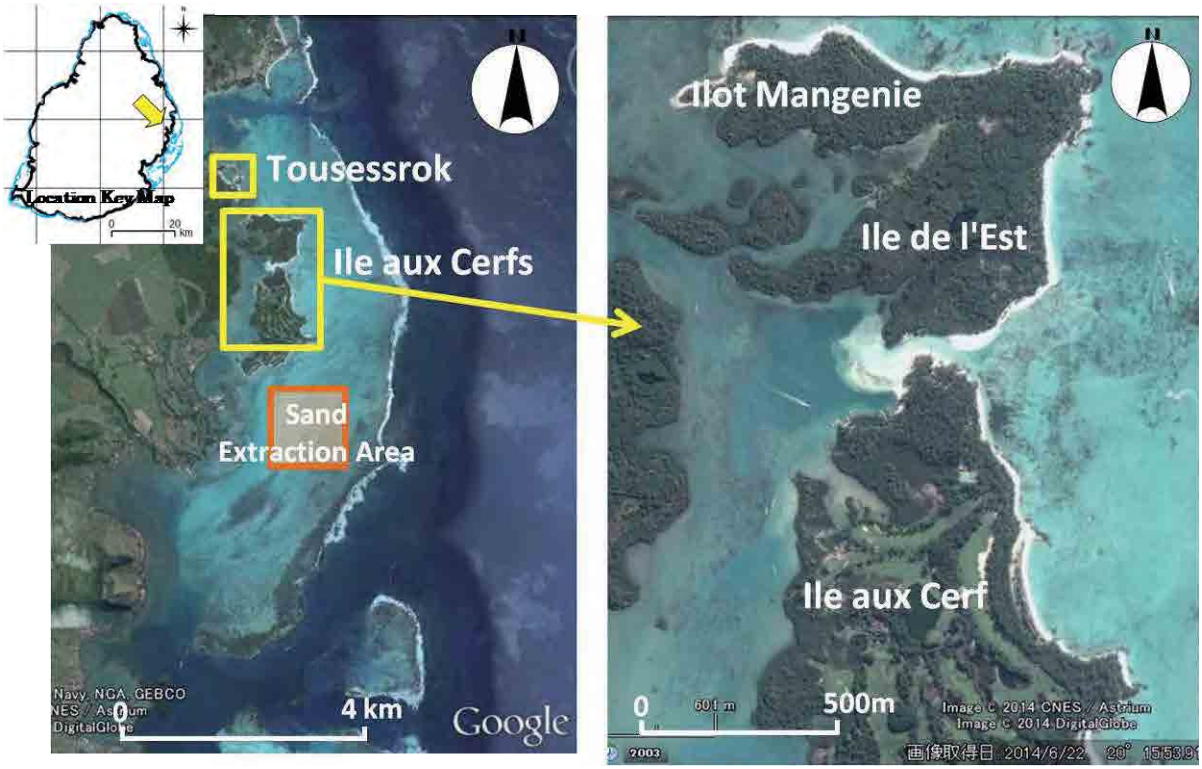
The amount of setback becomes 20m if the period is assumed 50 years, the erosion rate of 0.4m, and temporally erosion at the maximum caused by Cyclone Carol of 13m. (Refer Vol.1 Ch.2). The amount of 35m is over the present setback value of 30m. The erosion of 0.4m/year was caused by the growing of coral patch in a lagoon. In future the possibility of the same phenomenon is low. Then it is better to monitor the change of beach profile and the coral conditions and to revise the new amount of the setback based on the analysis if necessary.

Amount of setback= 0.4*50+13+2=35m

Chapter 6

Ile aux Cerfs

6 Ile aux Cerfs



Source: Edited by JICA Expert Team based on the data from Google Maps and MOI

Figure 6.1.1 Ile aux Cerfs Coast

6.1 Outline of Coast

Ile aux Cerfs coast is the coral coast where two islands, Ile aux Cerfs and Ilot Mangenie exist in the eastern coast of Mauritius, and it is also where the most famous and luxury resort hotel, Touessrok Hotel, is located. A natural (shallow, 50 meter-wide) channel separates the two islands, Ile aux Cerfs in the south and Ilot Mangenie in the north (refer to Figure 6.1.1).

There is tidal exchange of water thorough the channel. This current always flows from the off-shore side to the lagoon side and there is no reverse flow. Its surroundings have become the central area where many tourists enjoy sunbathing on the white sandy beaches and playing with the current through the channel. In recent years, this channel has become closed because of sand sedimentation, causing beach use problems as well as seawater exchange problems. Therefore, the suction dredging of approximately 20,000 m^3 was carried out in October 2012 by Touessrok hotel. Dredged sand was deposited on the east and north sides of Ile de l'Est Island. However, since the sedimentation occurred again, the hotel removed approximately 3,300 m^3 of sand in May 2014 and it was stocked in the land area.

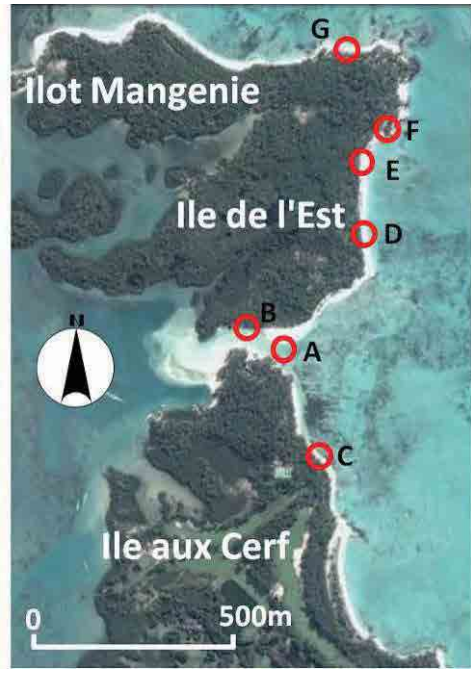
There is a continuous reef of approximately 9 km long in front of Ile de l'Est Island, starting from about 1.5 km to the north and continuing well past the southern tip of the island. The reef width is around 1.7 km in front of the Ile aux Cerfs Island and around 3.0 km in front of the hinterland area. The coast is comprised of numerous white sand beaches of coral origin, which are of concave shape between headlands. In the south side of Ile aux Cerfs Island (left figure of Figure 6.1.1), sand mining from the lagoon was carried out in the past. But since 2001 it has been prohibited by law and it is not performed now.

6.2 Present Condition

6.2.1 Site Reconnaissance

Photos of the coast taken from the positions shown in Figure 6.2.1 in April 2014 are presented in Figure 6.2.2 and Figure 6.2.3.

Point A shows the sea side and lagoon side from the channel. Since sand is deposited in the channel, most of the lagoon side in the channel becomes dry at low tide. In addition, the sedimentation area at the edge of channel is asymmetrical, and the coast shape in the north side edge looks like a tongue. On the other hand, the sedimentation area of the south side at the entrance to the channel is relatively small. A beach scarp is formed on the north side in the central part of the channel (Point B) while on the south side of the channel here there is significant sedimentation. Such asymmetric coastal formations (on either side of the channel) are a continuous tendency as confirmed from past aerial photos, which will be described later, as well as during the monitoring period in this study. It is thought that the prevailing direction of wave energy is from the south in this area judging from the fact that there has been a permanent beach scarp observed on the northern side of the channel. Sedimentation is occurring at a certain distance into the channel on the lagoon side after the wave energy has been dissipated in the channel.



Source: Edited by JICA Expert Team based on Google map

Figure 6.2.1 Photo Positions

In addition, since the tidal flow in the channel always goes to the land side from the sea side, it is considered that the sedimentation of the lagoon side does not return to the sea side.

Along the coast at south of the channel, there are concave shaped pocket beaches which were formed between natural rocky headlands. And no obvious erosion is observed at this area. However, local erosion occurs and beach scarp was formed near the channel at the north of Point C.

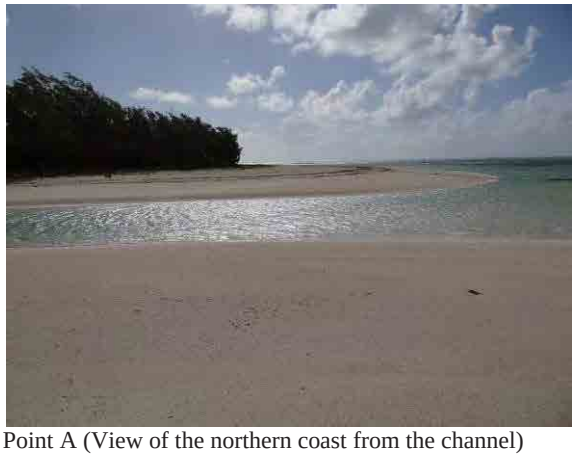
There is gently curving coast near the central part of the east side of Ile de l'Est Island and in the north side of the channel (point D, E and F). Most of the dredged sand in the channel carried out in 2012 was again deposited in this area. A beach scarp was seen in Point F on the north side, but this may occur as the process that the coastline is going to be restored from the advanced coastline because of the dredged sand nourishment.

Part of the dredged sand has been placed at Point G beyond the headland on the north side, however it seems that the beach has become stable.

6.2.2 Long-term Coastline Change and Sediment Budget

Figure 6.2.4 shows aerial photos of 1967 and 2008. Also, Figure 6.2.5 shows the sediment budget and the total amount of change in each sub-area in 6 terms from 1967 to 2012. Furthermore, Figure 6.2.6 and Figure 6.2.8 shows the condition change from 1967 of the channel and the north side sandbank (spit). As for the channel in Figure 6.2.4, it shows the state of before and after the dredging carried out in October 2012 and May 2014. The dredging was conducted because the channel was recently closed by sedimentation. In the estimate of sediment budget in Figure 6.2.5, calculation is made, like other coasts, by multiplying a movement height of 2.5 m by the coastline change obtained from past aerial photos of each sub-area located in the open seaside facing the reef.

On the other hand, the coastline in the channel is not the same, so that the calculation by a similar method is difficult. Therefore, sediment volume is estimated by multiplying a movement height of 2.5 m by the area of the sedimentation provided from the aerial photo analysis of the sub-area (Sub Cell-2 - 5) including the channel.



Point A (View of the northern coast from the channel)

Point A (View of the lagoon side from the channel)

Point B (Beach scarp at center part of the channel)

Point C (Approx.300 m south of the channel)

Point D (Approx. 500 m north of the channel)

Point E (200 m north of Point D)

Source : JICA Expert Team

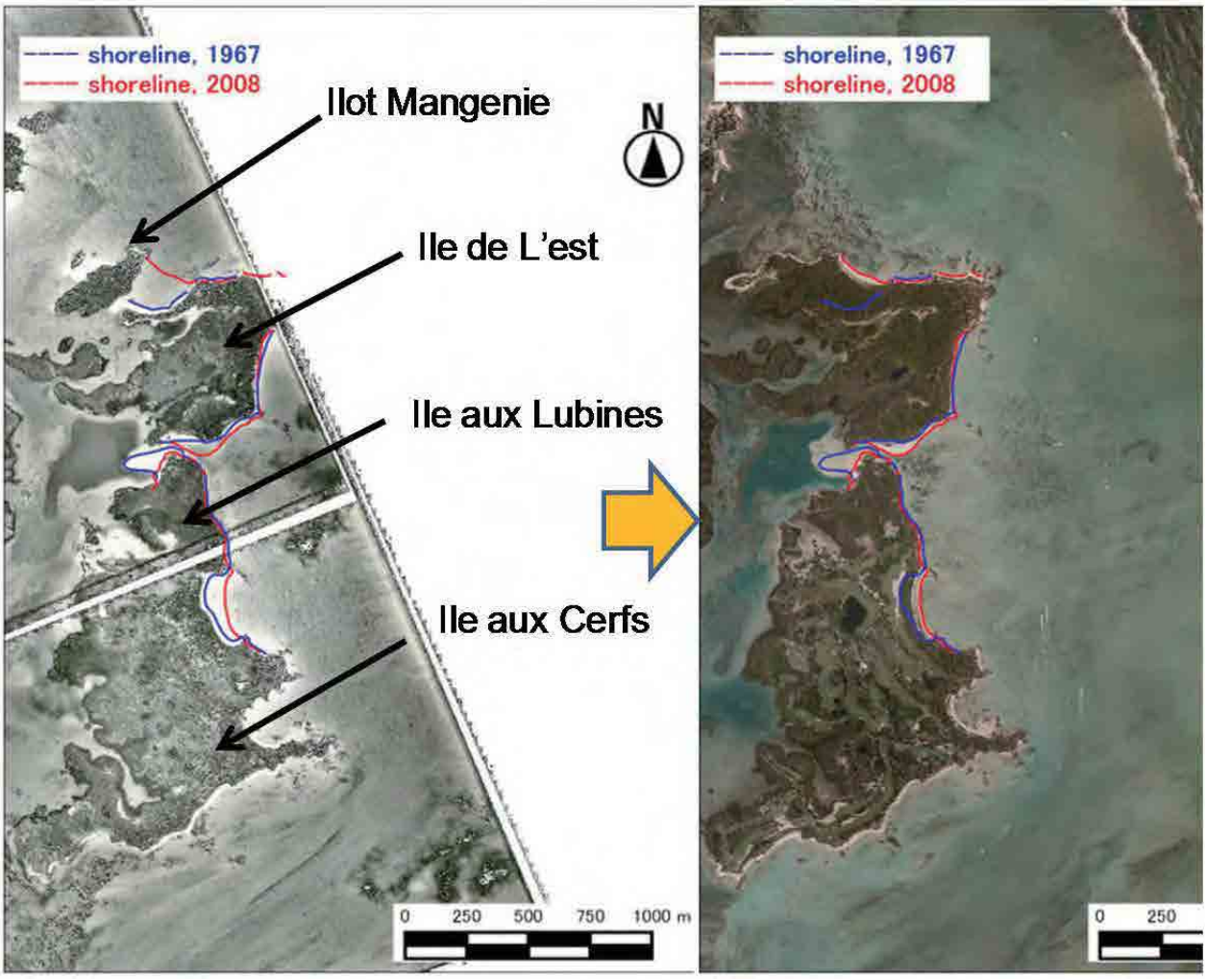
Figure 6.2.2 Present Condition of Ile aux Cerfs (April 2014)

Point F (View south of a cape that is 150 m north of Point E)

Point G (Northern coast beyond the cape of Point F)

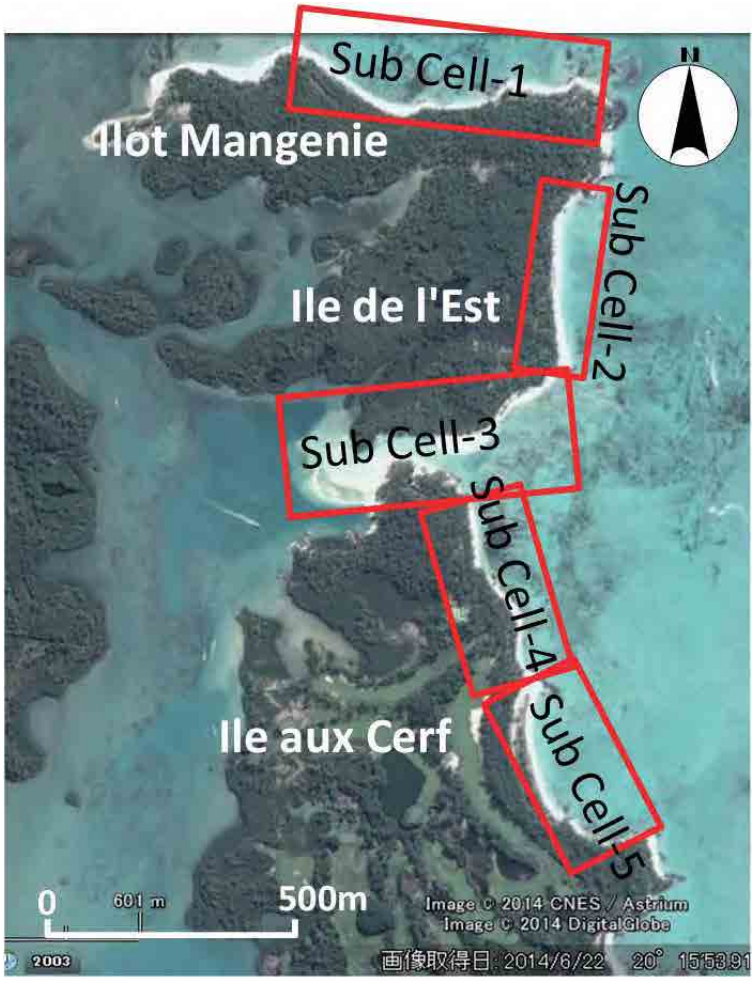
Source: JICA Expert Team

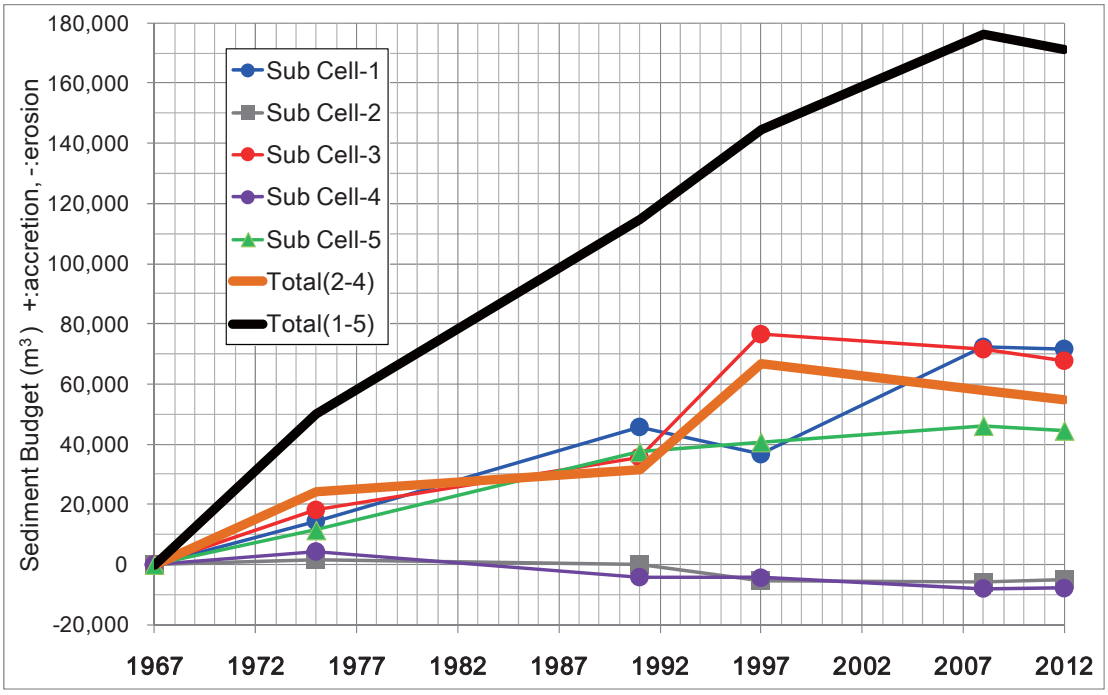
Figure 6.2.3 Present Condition of Ile aux Cerfs (April 2014)



Source: Edited by JICA Expert Team based on satellite image from MHL

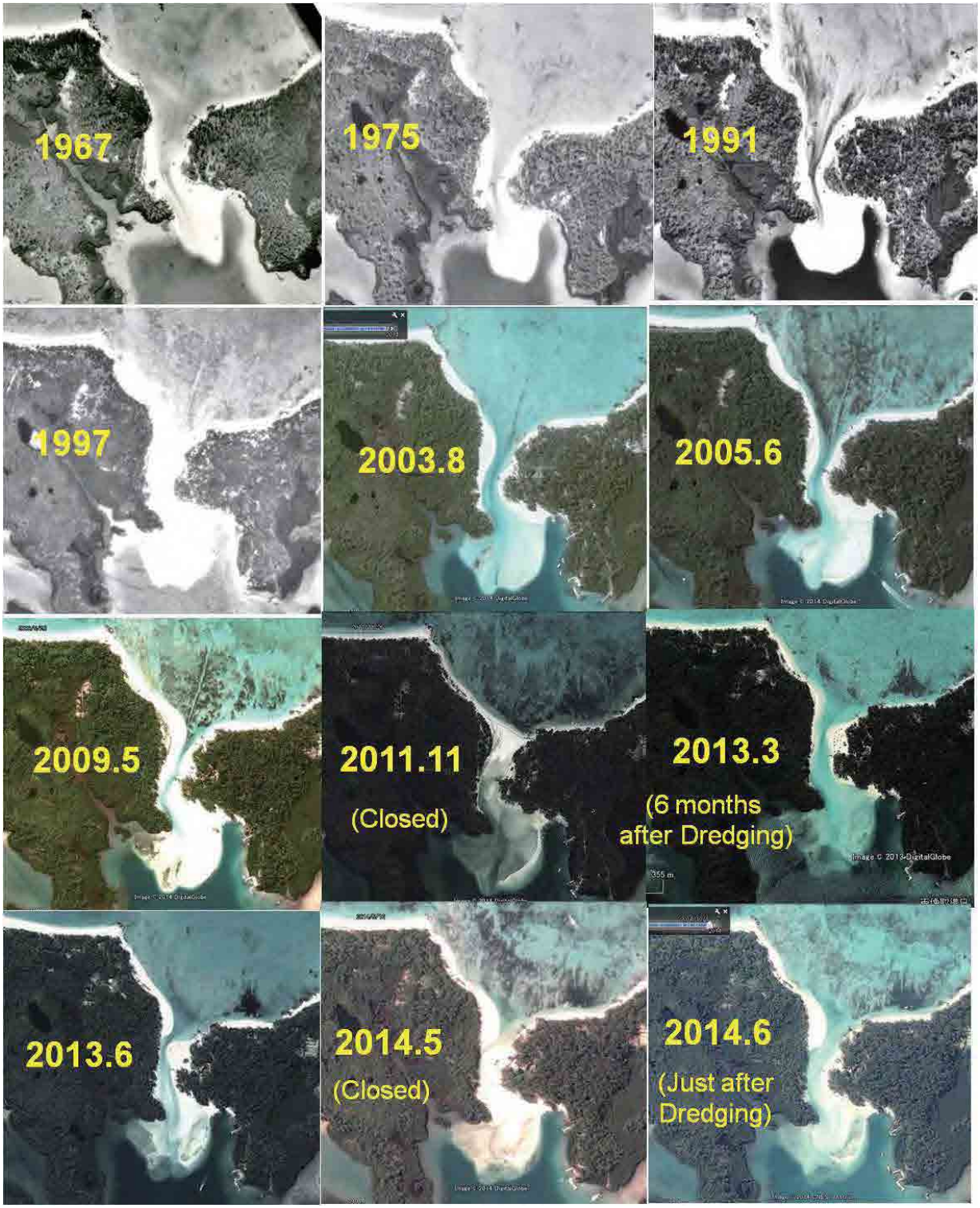
Figure 6.2.4 Comparison of Aerial Photos (Left:1967, Right: 2008)





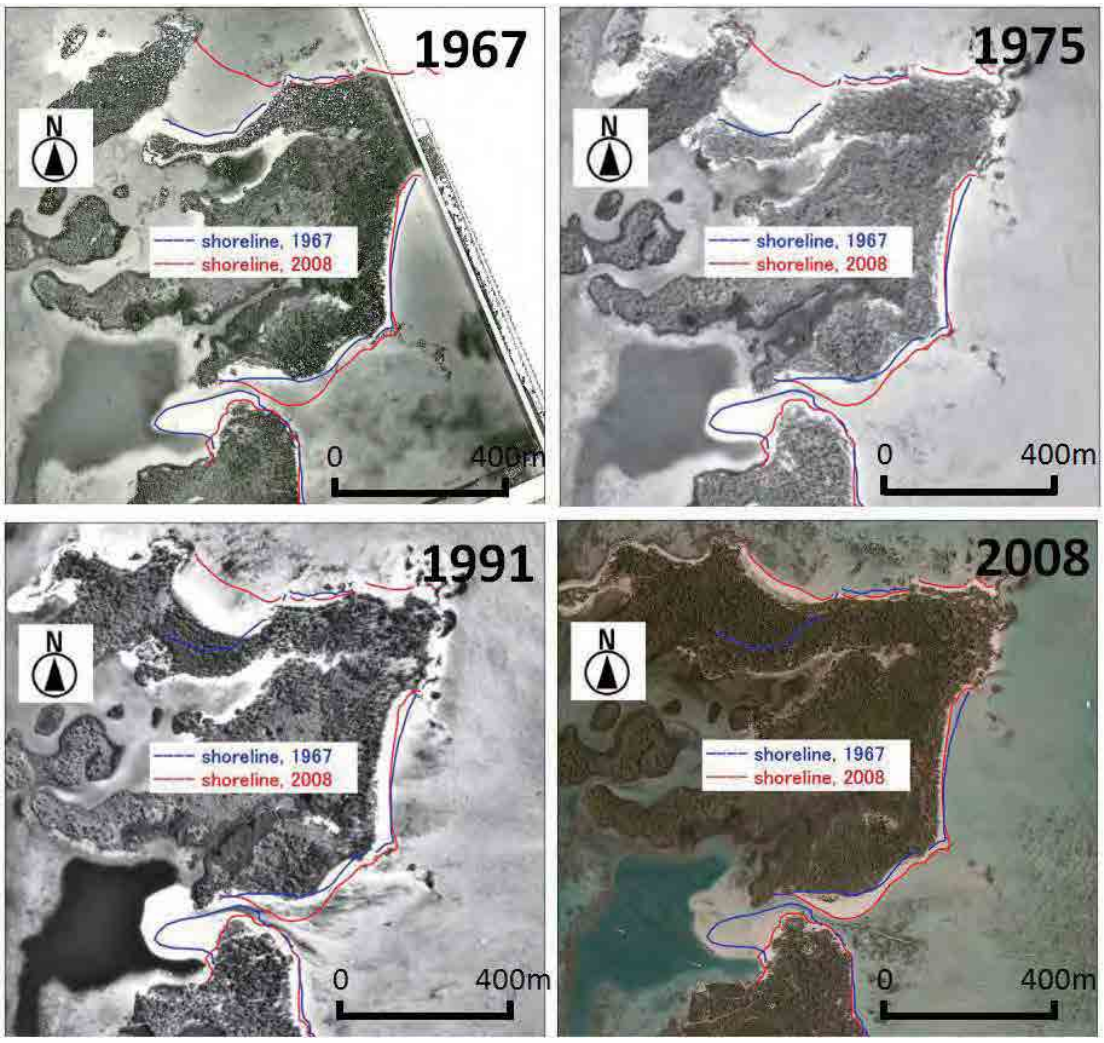
Source: Upper) Edited by JICA Expert Team based on Google Map, Lower) JICA Expert Team

Figure 6.2.5 Comparison of Sediment Budget in Each Sub-Cell



Source: Edited by JICA Expert Team based on satellite image from MHL and Google Map

Figure 6.2.6 Transition of Channel



Source: Edited by JICA Expert Team based on satellite image from MHL

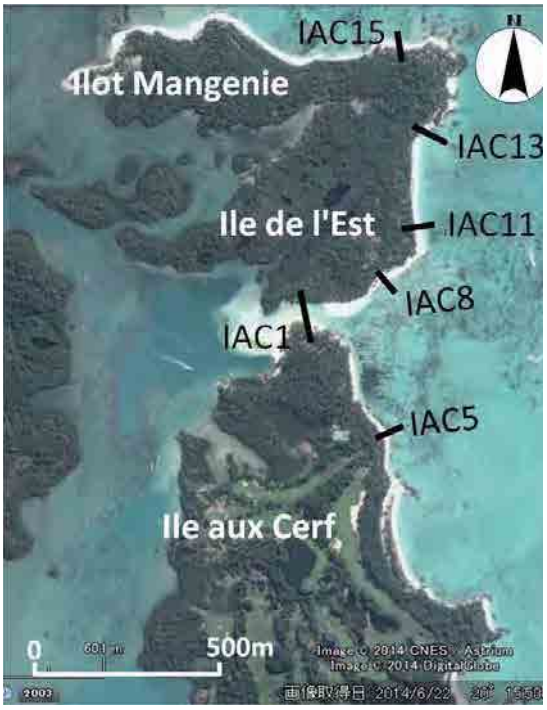
Figure 6.2.7 Transition of North Sandbar

- As shown in Figure 6.2.4, in the past Ilot Mangenie, Ile de l'Est, Ile aux Lubines and Ile aux Cerfs were four independent islands. At the time of 1967, the sandbar which extended to the west from Ile de l'Est Island developed and reached the Ilot Mangenie island. The sedimentation of this sandbar advanced more and completely became one island now (Figure 6.2.8). Coastline extended around 250 m in 40 years in this sandbar part. On the other hand, it is thought that Ile aux Cerfs Island of the south side was apart from Ile aux Lubines in the past. But now, both islands are connected into one. It may be said that this coast is in the tendency of remarkable sedimentation with sand supply from off-shore.
- Although the tendency of some erosion is seen at Sub Cell-2, 4 located in the north side and south side of the channel as shown in Figure 6.2.4, the coast shown in Figure 6.2.5 has the remarkable sedimentation as a whole. The sand acretion of the whole coast during 45 years from 1967 to 2012 amounts to 170,000 m^3 (about 3,800m^3/ year).
- In the consecutive sub-area (Sub Cell-3) including the channel, the increase of the sand volume is 68,000 m^3 (about 1,500m^3/ year), and it is 72,000 m^3 (about 1,600m^3/ year) in Sub Cell-1 including the sandbar part between Ilot Mangenie and Ile de l'Est of the north side, as well.

- With Sub Cell-2, 4 of the north and south side of the channel (Sub Cell-3), decrease of sand volume is 8,000 m^3 (about 180 m^3/ year) and 5,000 m^3(110 m^3/ year) in 45 years.
- If this decrease of sedimment is assumed that it is caused by the littoral drift movements to the channel, increase volume in Sub Cell-3 of the channel is estimated to be 55,000 m^3 (about 1,200 m^3/ year) as a net in 45 years. It is estimated that most of this acretion were supplied by the off-shore side of the lagoon.
- Sub Cell-5 of the south side of channel is the beach with concave shape between capes, and the advance of the coastline is estimated to be around 80 m on averge, 45,000 m^3 (about 1,000 m^3/ year) over 45 years.

6.2.3 Short Term Coastline Change (Continuous Monitoring Results)

This coast is one of the targets for continuous monitoring in this project. Fifteen survey lines have been established between Ile de l'Est and Ile aux Cerfs, and a monitoring survey has been carried out about every three months since June 2013. The monitoring results obtained since the beginning of Project for around 1.9 years until March 2015 of six representative points of Figure 6.2.8 are shown in Figure 6.2.9 (the result for all monitoring points are presented in the supporting report). During this period, cyclone passed the off-shore of Mauritius twice in January and February 2014.



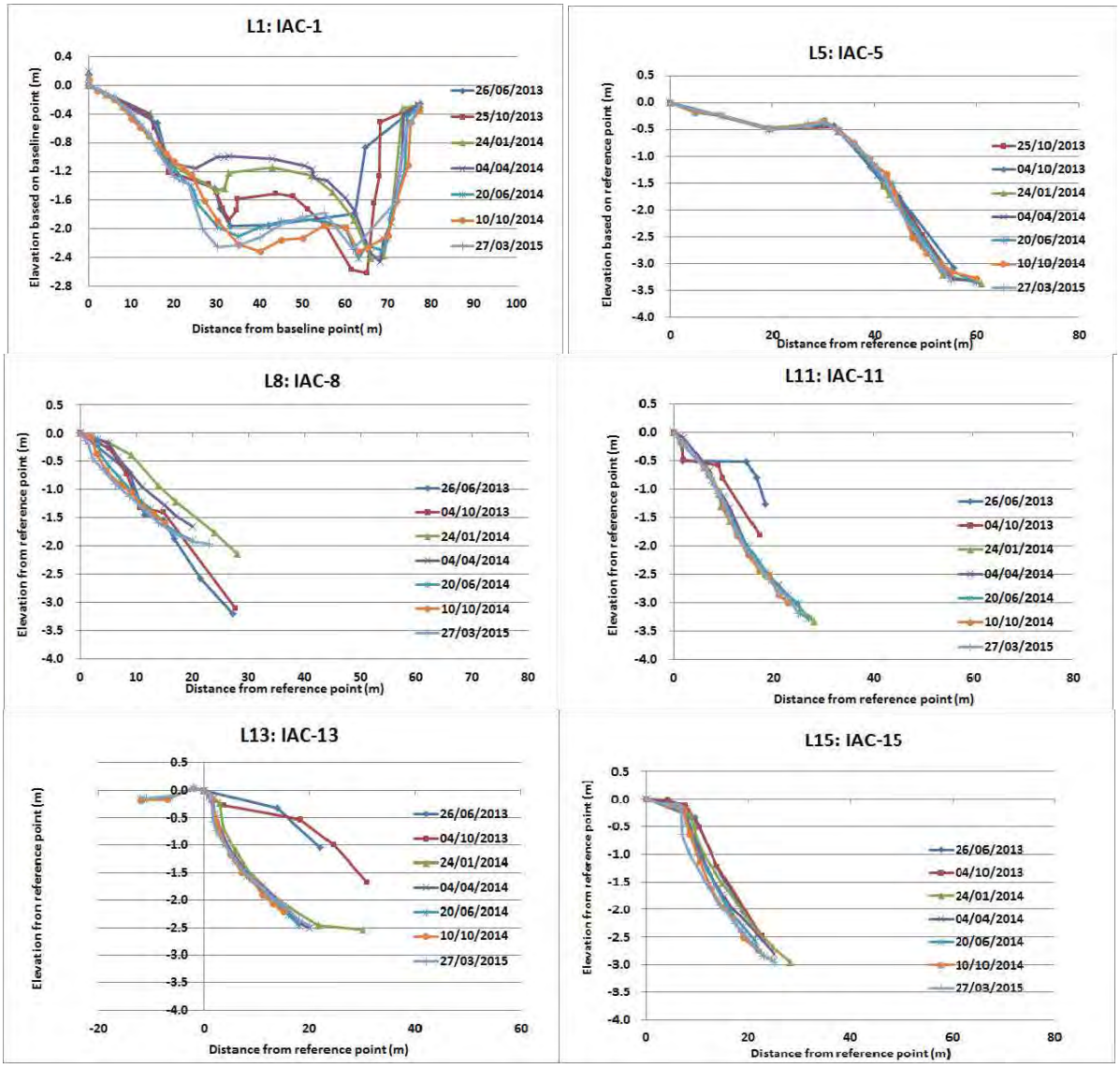
Source: Edited by JICA Expert Team based on Google map

Figure 6.2.8 Coastal Survey Location

- L1 cross section shows seabed elevation changes in a north-south direction across the channel.
- From June 2013 to April 2014, the accretion of sand in the channel was significant. The decrease in the sandbar in June 2014 is caused by the mechanical sand removal of around 3,000 m^3 which was carried out in the part of the channel.
- At L5 cross section to the south of the channel side, it was measured that the coastal incline was around 1:8 and the coastline erosion was around 1-2 m during the 1.4 year monitoring period.
- At L8 cross section near to the channel of Ile de l'Est, the coastline advenced around 5-7 m primarily from June 2013 to Janury 2014. But it has returned nearly to the original coastline position in October 2014.
- The dredged sand, which was carried out in October 2012, was placed at L11 and L13 cross sections located on the east side of Ilot Mangenie. The sand remained in this area until October 2013, but the coastline was eroded remarkably in January 2014. Then, big changes are not seen afterwards. It is thought that most of the deposited sand has already

been washed away from this area. It currently appears to be mostly stable and the coast is close to its original beach profile.

- The sand dredged to clear a navigation channel, which was carried out in October 2012, was also deposited at the L15 cross section located in the north side of Ile de l'Est. This coastline is gradually eroded since June 2013, and it reached around 3-4 m by March 2015 and the erosion still continues until now.



Source : MOESDDBM

Figure 6.2.9 Result of Continuous Coast Monitoring at 6 Representative Cross Sections

6.2.4 Characteristics of Wave, Water Level, Current, Topography, Bed Material and Reef Environment

a. Meteorological and Hydrological Conditions

Based on coastal condition changes in a long and short term, while there is a littoral drift

heading to the north in a long-term at this coast, it is found out that the changes associated with seasonal variation in a short-term is remarkable. Because the reef is wide in this coast, it is thought that the influence of the wind and waves that occurs in a reef is relatively big. There are mainly only significant waves from the southeast trade winds in winter. On the other hand, in the summer, the direction of the wind becomes northeast, and the wind velocity weakens in comparison with the southeastern wind of winter season. But there is cyclone in the summer season, and it is considered that the characteristics of the waves hitting the coast may be changed by the course of the cyclone.

b. Coastal Topography and Sediment Material

There are some rock reefs in coastal areas, and concave beaches are formed in between such rock reefs. The beaches are comprised of white colored coral sand. The foreshore inclines are mostly between 1:8 and 1:12. Because no particle size analysis is done, there are no quantity data about the particle size, but it is estimated to be around 0.2-0.3 mm by the observation. Near the channel, it is slightly smaller than that of the north side and the south side.

c. Reef Environment and Water Quality

Rock reefs of basalt are seen in the offshore of west beach. Coverage of living corals was 5 % in a basalt reef. Density of juvenile *Acropora* was 0.5 per square meter and higher than that in other lagoon. Recruitment of juvenile *Acropora* seemed to be stable at low density because several sizes of juvenile were seen on the basalt reef. Surrounding area of the rock reef was covered partly by the seagrass beds of *Halodule* and *Halophila*, and partly by sand. This area was covered by seagrass bed and sand bottom also in the aerial photos and analyzed chart, and there was no coral reef and no coral community.

The investigation results on water quality and impacts to water quality in the lagoon at Ile de l'Est and Ile aux Cerfs are shown in Table 6.2.1. Transparency is 3m and siltation is a moderate. In the offshore of lagoon, chlorophyll a, turbidity and nutrient salts are respectively 0.39ug/L, 1.18NTU, 0.03mg/L for NO_3 and 0.010mg/L for PO_4 on an average and generally good level as habitat of coral (the coverage of living coral is from 20 to 50%. This coast is an underdeveloped district of sewerage system. The most wastewaters are flowing into the coast through onsite STP (sewerage treatment plant) from the hotels, AP (absorption pit) and ST (septic tank) from the houses. However, this coast is not large population center but include vast sugarcane farms. Since the water quality of these coasts is relatively good, it is considered that the runoff of fertilizers and red soil from the sugarcane farms is unlikely to exert a direct influence on the corals of these coasts. And also, it is considered that the mangroves living near the coast is to protect the runoff of nutrient salts and red soils from the sugarcane farms by blocking and filtering.

Table 6.2.1 Investigation Results on Water Quality and Impacts to Water Quality in Lagoon

Check items		Conditions			
Water quality	Chlorophyll a (ug/L)	0.10-0.93(#) (Ave. 0.39)			
	Turbidity (NTU)	0.38-2.09(#) (Ave. 1.18)			
	NO_3-N (mg/L)	<0.01-0.04(#) (Ave. 0.03)			
	PO_4-P (mg/L)	0.006-0.02(#) (Ave. 0.010)			
Population density behind coast(per km^2)					
Sewerage disposal behind coast	Status of development of sewerage facilities behind coast	Absorption Pit, Septic Tank, Pit Latrine			
	Present condition of sewerage disposal from houses (Sewerage system, Septic tank, Pending arrangement, etc.)	T. d'Eau Douce VCA: SS: NIL, AP:1470, ST: 115, PL: 28			
	Present condition of sewerage disposal from hotels and restaurants (Sewerage system, Septic tank, Pending arrangement, etc.)	Hotels >75 rooms uses onsite treatment plants. Restaurant uses septic tanks.			
	Development plan of sewerage system for houses and hotels behind coast	NIL			
Impact of pollution from sugarcane	Incidence of red-soil runoff from land side	Yes. River Mouth, Lagoon Width: 1.9Km			
	Existence of sugarcane field behind coast. If there is it, area of the field behind coast.	Yes. Area: 10, 854 Ha			
Relation between living coral and water quality**	Coral coverage	Chlorophyll a (ug/L)	Turbidity (NTU)	NO_3-N (mg/L)	PO_4-P (mg/L)
	>50%	<0.2	<0.5	<0.012	<0.007
	20-50%	0.2-0.6	0.5-1.3	0.012-0.051	0.007-0.016
	10-20%	0.6-0.9	1.3-1.9	0.051-0.081	0.016-0.023
	<10%	>0.9	>1.9	>0.081	>0.023

#: Observation for water quality and coral reef was conducted from the shore to the reef edge.
**: This relation was obtained by the water quality survey in this study. Refer to Table 2.6.3 in Vol.1.
SS: Sewerage Systems, Ap: Absorption Pit, ST: Septic Tank, PL: Pit latrine
Source: JICA Expert Team

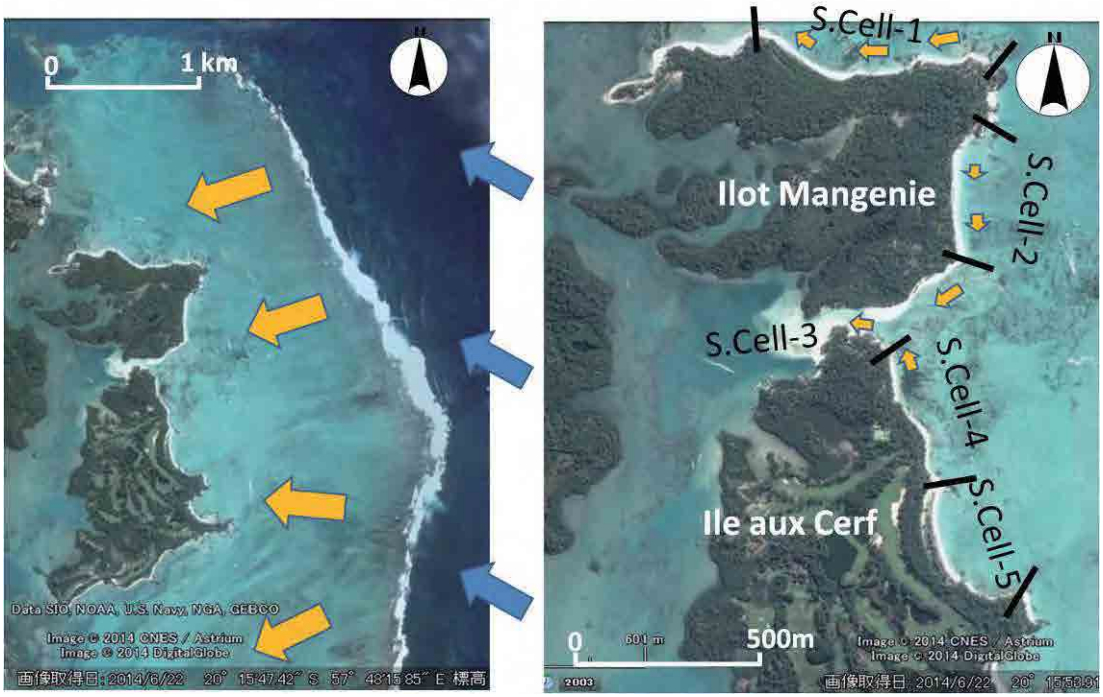
6.3 Littoral Drift and Cause of Problems

6.3.1 Littoral Drift

Figure 6.3.1(left figure) shows the movement direction of sand in the reef assumed from scour lines on the aerial photos and the reef topography, and Figure 6.3.1(right figure) shows the littoral drift direction in the shore assumed from the coast monitoring results.

- It is thought that the sand movement in the reef is influenced by the wave characteristics and reef shapes of this coast. The reef topography of off-shore side becomes convex near to Ile aux Cerfs. The sand from the off-shore may tend to gather in the front part of Ileaux Cerfs by the wave refraction changes due to this reef topography.
- In this coast, the sand supply from the reef is remarkable, and the sediment budget in each coastal area is prescribed by sand supplied from this reef and the littoral drift at the coast. Since the littoral drift changes according to the angles in each coast, it is thought that the uniform and unidirectional consecutive drift sand does not exist.

- In Ile de l'Est north side Coast (sub cell-1), the sand is always supplied by the lagoon side. Those sand are carried to the west side by the remarkable littoral drift leaving for the lagoon side. And a sandbar develops by the decrease of this littoral drift due to the decrease of energy of the waves hitting to the landside. As the result, it is thought that both islands are connected in one island now. The sand accretion is estimated to be 1800 m^3/ year as the result of sediment budget analysis shown in Figure 6.2.5.
- As the monitoring results in the costal area in front of the part of Ile aux Cerfs Island (Sub Cell-2 and 4), it is thought that littoral drift is headed weakly to the south direction in Sub Cell-2, and it headed weakly to the north direction in Sub Cell-4 as well. Annual sand loss is about 110m^3/ year in Sub Cell-2, and 180m^3/ year in Sub Cell-4.



Source: Edited by JICA Expert Team based on Google Maps

Figure 6.3.1 Pattern of Waves and Littoral Drift in Ile aux Cerfs

- The sedimentation (about 1,500m^3/ year) in Sub Cell-3 of the channel is the total quantity which is flowed directly from the lagoon side and from the north side of the channel by the littoral drift. It is estimated about 300 m^3/ year if it is assumed that the inflow from the surrounding coasts is the same as the sand loss of Sub Cell-2 and 4 obtained from sediment budget analysis in Figure 4.3.6. It is thought that most of the sedimentation sand (about 1,200 m^3/ year) is carried directly from the lagoon side.
- South side of the channel in Sub Cell-5 can be considered as the pocket beach with headlands on either side. Here is the advance of the coastline on an average of around 80 m, 45,000 m^3 (about 1,000m^3/ year) in 45 years. Assuming that there is no outflow by the littoral drift and this accretion is caused of the sand supply from the off-shore side of the reef, the sand supply volume is with 2.5 m^3/m/ year per coastline. Similarly, it becomes 2.0m^3/m/ year in Sub Cell-2 - 4 as well. As for this supply volume, it is bigger than 0.6 - 1.0m^3/m/ year of Palmar, and 1.2 - 1.75m^3/m/ year of Belle Mare which are shown in Baird (2003). Although it depends on the reef conditions and the estimated methods, the supply of the sand from the reef of Ile aux Cerfs is probably bigger than that of Belle Mare and Palmar.

6.3.2 Problems and Causes

The problems and causes of this coast are mentioned as below.

a. Remarkable sedimentation in the channel, less attractive for coastal usage

Sedimentation in the channel is caused by sand flowing from the reef directly and from the surrounding coasts by littoral drift. Of the two, littoral drift is dominant, as mentioned in the previous sections. Recently, this tendency is particularly remarkable, and approximately 20,000 m^3 of sand was removed in October 2012 and approximately 3,300 m^3 in May 2014. The reason for remarkable sedimentation is not clear, but the following two points are considered as the causes of it.

- The sand mining that was carried out in the past has been prohibited since 2000, and there is a possibility that this is increasing the sedimentation in the reef.

- In recent years, severe cyclones have not hit this area.

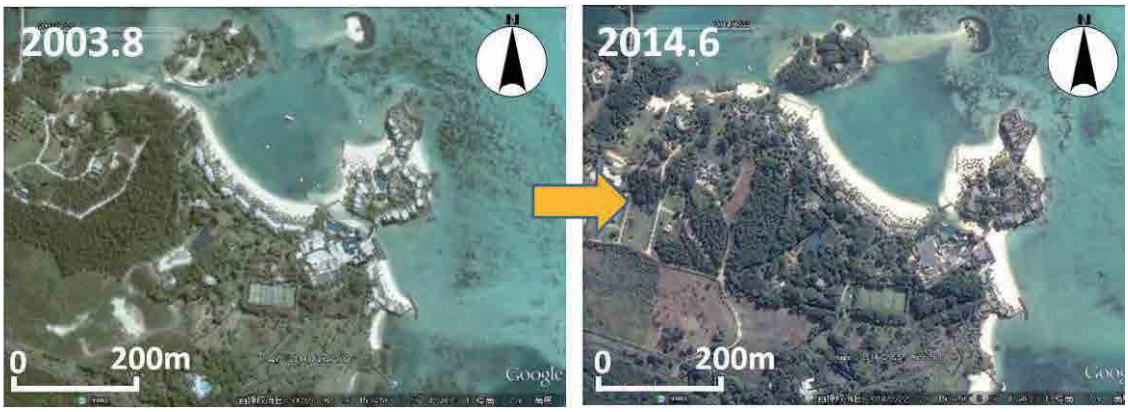
Tourists enjoy the wide white sandbar and the current of the channel in the natural coastal attraction area, and it is thought that it should be maintained as one of the attractive spots which is different from other coasts. Also, it is wished that the clogging of the channel does not occur to maintain the function of seawater exchange between the rear lagoon area and the open sea.

b. Coastline erosion at both sides of the channel

It is limited, but the coastline is in tendency to be eroded in the coastal area of both sides of the channel (Sub Cell-2 and 4). The tendency that coastline erosion becomes remarkable, it is seen from the monitoring results particularly in the winter season when a strong southeastern monsoon comes to this coast. In this coast, the reef width is wide, besides the special events such as hurricanes the waves of the coastline are strongly influenced by the wind and waves on the lagoon. It is thought that coastline may be eroded in the winter season when the frequency of strong winds increases. Some of sand is carried to the channel side by littoral drift, and as a result, it is thought that the coastline will be eroded on the whole.

c. Significant Sedimentation in Northern Hotel Area

The clogging by sedimentation is now significant in the channel which is behind the two existing islands and in front of the resort hotel located approximately 1 km north of Ilot Mangenie, as shown in Figure 6.3.2. JET has conducted the preliminary consultation to Touessrok Hotel and gave a suggestion to reduce the sedimentation at the channel.



Source: Edited by JICA Expert Team based on Google Map

Figure 6.3.2 Closing of Channel at Touessrok Resort Hotel

Currently, the countermeasures against it are being prepared by the Hotel. In addition, the south side of the island was expanded with hotel development artificially. As a whole, the surrounding of this beach is in tendency of sedimentation shown in Figure 6.3.2, and this becomes a problem with respect to sightseeing.

6.4 Coastal Conservation Measures

6.4.1 Outline

This coast is the only coast where sedimentation is a problem out of 14 other coasts. And, it is the one with the high quality beach resorts that represent Mauritius, and it is necessary to consider the sightseeing aspect as well as landscape aspect particularly on this coast. Furthermore, in the lagoon area behind Ile aux Cerfs Island is used for boats travelling from hotels in the hinterland to other islands. Since this area has the natural mangrove growth and rich picturesque scenery with full of environmental variations, due consideration must be given to environmental aspects.

The erosion of the coastline in both the south and the north coasts occurs, while the closing of the channel is also found. A short term measure against the above situation is necessary. On the other hand, this coast is the only coast which has remarkable sedimentation problem among the targeted coasts chosen in the coastal conservation plan. In the operation and maintenance carried out until now, the dredged sand has been basically placed on the surrounding coasts again. However re-placing of such dredged sand more than required may be accelerated the blocking of the channel. As most of the coasts in Mauritius have erosion problems, it is thought that the surplus dredged sand can be re-used in such eroded coasts. In addition, little coral distribution is basically found on the reef, and no influence on erosion problems caused by coral and water quality degradation is confirmed in this coast. As longer-term measures, the sediment control against the remarkable sedimentation as a whole of this coast is needed, also the monitoring and the water improvement measures are necessary for medium- and long-term maintenance plan on coral, water quality and water environment.

6.4.2 Principles of Measures

a. Short Term Measures

- It is necessary to prevent the closing of the channel and always secure channels, and prevent the coastline erosion of adjacent north and south areas.
- This coast does not have any man-made structures, and natural coastal scene is maintained well. This is the charm of this coast. Accordingly, no artificial structures will be constructed to conserve the beach resorts that represent Mauritius.

As short-term measures, it is suggested that periodical dredging of the channel + required sand filling in adjacent coast should be carried out.

b. Long Term Measures

- Surplus sand provided by periodical dredging as a short-term measure should be uses to maintain other coasts which are experiencing coastline erosion, with an appropriately integrated sand management plan.
- This coast is in the leasing area, and the hotels maintain the coast. However, public-private cooperation is necessary to use such surplus sand at ther coasts effectively. One practical method of public-private cooperation will be outlined below.
- It is necessary to undertake coral, water quality monitoring and water quality improvement measures.

6.4.3 Short Term Measures

a. Method of Sand Removal

About the periodical sand removal method in the channel, there are two ways, dredging in the water and open excavation on land, are considered. Table 6.4.1 shows the comparison of each method.

Table 6.4.1 Comparison of Sand Removal Method

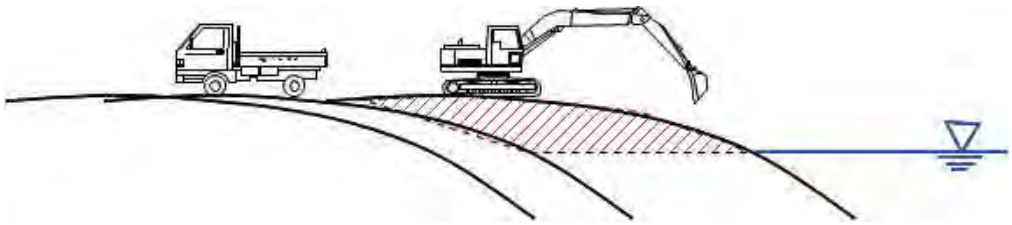
Method	Dredging (underwater)	Open excavation (on land)
Outline	Dreding and hauling by dredger (Backhoe dredger, or suction pump dredger) under water (this method was used in 2012)	Open excavtion from the land of both sides of channel (this method was used in 2014).
Workability	・ The removal of a large quantity of sand is possible in a short-term ・The arrangement of special workboats such as dredgers are necessary	・ Generally, removal of a large quantity takes time (but it can be solved if the number of equipment is added) ・ No special equipment is required
Cost	Cost is high, therefore periodical removal cost is also expensive (700 ～ 900 MUR/m^3)	Cost is low, therefore maintenance cost is not expensive (300～400 MUR/m^3)
Maintenance	Because specialized barges are necessary, cost of dredging will be kept down by dredging as much as possible at a time. By dredging about 10,000m^3 per time, the frequency of dredging may be practically every few years.	Frequency needs to be more than dredging. Periodical monitoring to judge the timing of removal is needed.

Method	Dredging (underwater)	Open excavation (on land)
Utilization aspect	Because there is several years between dredgings, the shape of the channel may change significantly (channel becomes wider and deeper just after dredging).	Due to short interval than dredging, shape of channel is not much changed.
Enviromental aspect	Remarkable contamination may possibly occur at the time of dredging beacuse the sand is mixed with seawater.	Because of dry excavation, contamination level can be kept lower than dredging.
Evaluation	Not recommended	Recommended

Source: JICA Expert Team

Based on the evaluation above, it is recommended to conduct periodical removal of the sand in the channel using open excavation method with appropriate monitoring.

The sand removal area is selected appropriately depending on the sediment condition as well as disturbance from the sedimentation area of the north side, the south side and the channel lagoon side. Excavation method should avoid any extreme changes in the beach cross section (changes in scenic value) because the beach is used by tourists (Figure 6.4.1).



Source: JICA Expert Team

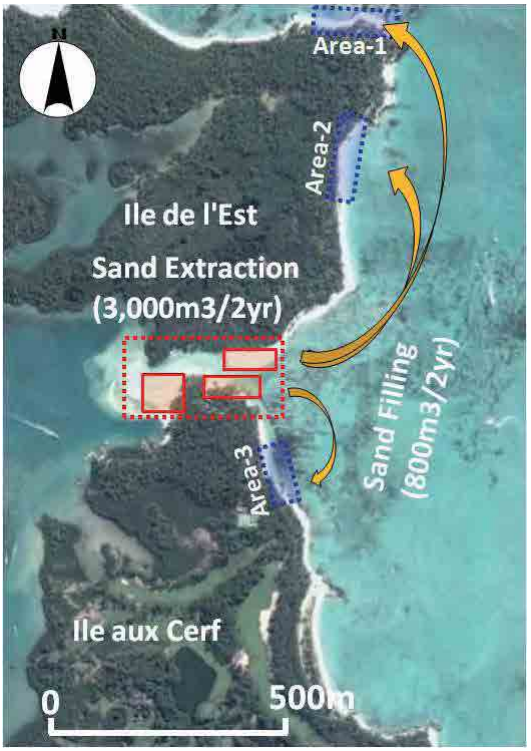
Figure 6.4.1 Image of Sand Removal at Channel

b. Sand Management (required removal volume, sand filling volume, frequency, etc.)

Necessary information for deciding on periodical sand removal is the frequency of the removal, quantity of removal and sand filling volume to the surrounding coasts. The sedimentation situation of the channel is greatly depending on the waves condition and the frequency of cyclones and its scales. Accordingly, it is decided based on the continuous coast monitoring results in an adaptive way. A reference is shown hereunder based on the tendency of the past sediment budget. The examination conditions are as follows:

- As a result of long-term sediment budget, an average of 1,500 m^3/year of sand is accreted in the channel every year.
- From the long-term sediment budget, it was judged that the outflow sand is 110 m^3/year on the north side of the channel, and 180 m^3/year on the south side. On the other hand, based on the coastal monitoring results, a remarkable difference of coastline erosion between the north side and the south side is not seen even during a limited period. Accordingly, in consideration of precision and seasonal variation of the long-term analysis, and addition of extra volume of sand, it is assumed that the additional sand shall be supplied into the north side and the south side at a rate of 200m^3/ year.

With the above-mentioned condition, Figure 6.4.2 shows the image of the sand management by the periodical sand removal as a short-term measure.



Source: Edited by JICA Expert Team based on Google Map

Figure 6.4.2 Recommended Sand Recycle

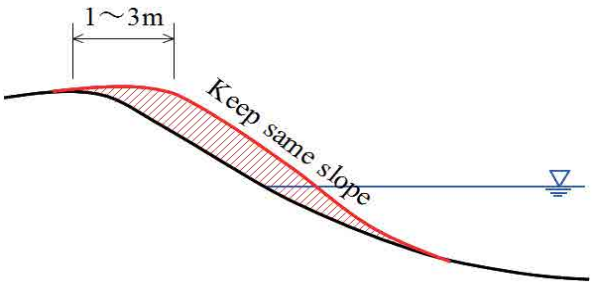
- Considering both the sedimentation speed in the channel and economics, the periodical sand removal is basicaly assumed to be undertaken around once every two years, and approximately 3,000 m^3 each time. It is thought that the clogging of the channel occurs because of increased littoral drift caused by prevailing waves scouring force. It is recommend to prioritize removal of sand of the backside of the channel (lagoon side) where it is hard to be affected by the littoral drift, but it is necessary to judge appropriately by observing the real sedimentation condition.
- It is planned that approximately 30% of the sand (around 800 m^3) from the sand removal work will be deposited into surrounding coastline erosion areas. But, by the annual change of waves and occurance of cyclones, the sedimentation process of the channel greatly fluctuates. Thus, through the periodical monitoring, it is necessary to judge the frequency, removal volume and filling volume in an adaptive way considering the annual change of the channel.
- About the other surplus sand (around 2,200 m^3 every two years is to be stock piled based on the above plan), it will be provisionaly put in an appropriate place to consider to use in the other coasts, but somewhere that will not affect tourist activities.

c. Filling method of the excavated sand

As shown in the monitoring result ofFigure 6.4.3, the remarkable movement and/or outflow occurs in order to come back to the original balanced condition even if the excessive sand is cast into a certain place at the time of sand filling. In addition, when littoral drift exists, the sand shall be deposited into the upper side of the drift sand, so that the sand will move to the down stream naturally and extend the time before coastal maintenance is again necessary. Based on these considerations, the filling method to the surrounding coasts is described hereunder. With the the above-mentioned condition, the methods of the filling and excavated

sand are as follows:

- The width of the nourished beach should not be excessively wide. It should be around 1-3 m wide as a reference. In addition, it is desirable that the nourished slope maintains a similar incline to the present condition (Figure 6.4.3).



Source: JICA Expert Team

Figure 6.4.3 Typical Image of Sand Filling

- In consideration of the littoral drift direction in each filling area, the sand should be deposited on the up-drift side (Figure 6.4.2).

d. Summary of Short Term Measures and Rough Estimate of Construction Cost

Table 6.4.2 shows the recommended short-term measures and the rough estimated construction cost.

Table 6.4.2 Recommended Measures & Cost for Ile aux Cerfs

Item	Description
Covered area	Sedimentation area at the channel, and coastline erosion area at the surrounding coasts
Method	Periodical sand removal (open excavation) + sand filling in adjacent coastline erosion area
Removal volume	3,000 m^3/2 years （adaptive treatment is necessary based on monitoring results）
Filling volume	800 m^3/2 years （ditto）
Estimated cost (as reference) (Note : Direct cost only、not incl. VAT）	Sand removal：1.2 million MUR（Assuming 400MUR/m^3） Sand filling：0.12 million MUR （Assuming 150MUR/m^3）

Source: JICA Expert Team

6.4.4 Long Term Measures

a. Effective Utilization of Excavated Sand (possibility of the application to other coasts)

Some of the excavated sand from the channel is to be used to nourish surrounding coasts. Since this coast produces a significant surplus sand as a whole, other uses of this surplus sand should be considered.

In the precondition which is shown in measures for a short term, the surplus sand of approximately around 2,200 m^3 will occur every two years. It is planned that this sand shall be used for the maintenance in other eroded coasts. The sand for maintenance is now purchased from the land quarry sites at Maconde. Excavation cost and unit price of the purchase sand are listed in Table 6.4.3.

Table 6.4.3 Unit Cost Comparison

Excavation cost（land）	Unit price of sand （Maconde）
400 MUR/m^3	2,000 MUR/$m^{3*)}$

Source: JICA Expert Team　　*) Information from suppliers

Excavated sand can be used at a much lower cost than purchasing sand from quarry sites. A hotel takes responsibility for the maintenance including sand excavation basically, but both the public and private sectors may find a merit by changing this system.

But this is just one suggestion, and further discussions between the government and hotels to manage this coast are necessary before any such plans are implemented. In addition, it is thought that the discussion in the similar viewpoint is necessary for divert sand from a certain coast to other coasts, because sand collection from the lagoon area has been prohibited by law since 2001.

b. Enforcement of coral, seaweed and water quality monitoring and water quality improvement measures

Regarding this coast including the reef, it is necessary to conduct the monitoring to sustain the reef environment and water quality from medium- and long-term standpoints because the regular monitoring for coral, seaweed and water quality have not been conducted. It is necessary to monitor the water quality deterioration due to stagnation of the lagoon water due to the blockage of the channel resulting from the sand accumulation. As for the long-term countermeasures, based on these monitoring results, it is considered necessary to promote the conversion to more efficient sewerage treatment facilities in the hotels in the hinterland and to septic tanks on islets.

6.5 Beach Operation and Maintenance Plan

6.5.1 Improvement Plan against Present Beach Management Issues

In regard to the Beach Maintenance and Land Utilization for Ile aux Cerfs, the present issues and the improvement plan are described in Chapter 5 in the Volume 1. The issues and the improvement plan for the system and implementation which common to the most of the target beaches are described in Chapter 5 as well. This section shows improvement plan against present beach management issues of the beach as follows.

a. Formation of scarp issues

- Enhancement of monitoring system under cooperation with institutions concerned
- Management of plantation on the beach

b. Dreading issues in coastal area

- Continuous periodic monitoring

- Evaluation of monitoring data which is submitted by lessees

6.5.2 Beach Management Plan for Coastal Conservation Plan

In this section, several concerns on management for beach conservation are specified. The Beach Conservation Plan of Ile aux Cerfs recommends Sand Recycle through which the dredging sand from the accumulated area can be reused for the erosion area.

This beach had been operated and maintained by a nearby high-class resort hotel. Based on the survey result by a local consultant, the channel dredging funded by the hotel had been conducted twice. For making effective use of the surplus sand dredging from the channel such as Sand Recycle, the following measures should be taken for beach maintenance.

- A regular monitoring of the beach and the sharing of the results with relevant organizations

While a regular monitoring of the beach has been implemented by MOESDDBM and JICA since 2013 under the project, it is expected that the hotel will take over the monitoring activity in the years following the project. For the adaptive management and the planning of effective measures based on the beach monitoring results, it is necessary to share the information and cooperate with the experts on beach mechanism in MOESDDBM.

6.5.3 Validity of Setback Amount

The setback amount for eroded sand beach is configured as summation of the amount of erosion during a certain period and the amount of erosion which is caused by strong wave such as cyclones in that period, which is described as following.

Amount of setback = Amount of erosion for a long period + Amount of erosion by temporally event (i.e. extreme weather conditions such as cyclones)

In addition, the erosion due to the SLR (sea level rise) is anticipated in future. There are several proposed equations to estimate the amount of erosion due to the SLR. Among these, the equation proposed by Per Bruun is applied generally. The equation is as follows.

$E=C\times S$

Where, E: Erosion amount due to the SLR, C: coefficient of beach characteristic and S: amount of SLR. Therefore, the amount of setback needed is described as follows.

Amount of setback = Erosion amount for a long period + Erosion amount by extreme weather conditions + Erosion amount due to SLR

The rate of the SLR from 1987 to 2011 is about 3.2mm/year in average, and the coefficient of C, which is related with the inverse of sea-bottom slope and transportation area of sediments, is set as 10 by the mean sea-bottom slope in Mauritius. The erosion amount due to the SLR, therefore, is calculated as 1.6 m by multiplying averaged erosion rate of 3.2mm/year, the coefficient of 10, and the period of 50years ($E=10\times3.2mm/year\times50years=1.6m$).

6.6 Issues on Implementation

6.6.1 Adaptive Management on the Basis of Continuous Coast Monitoring and its Result

As aforementioned, the sedimentation and clogging situation is quite different by each season, wave conditions and number of cyclones each year. The government of Mauritius shall carry out the coast monitoring planned by this project continuously in future, and it is necessary to make the maintenance plans such as time of removal, removal quantity, and sand filling plan to the surrounding coasts based on the results in an adaptive way.

6.6.2 Consistency with the Legal System and the Discussion between Public and Private Sectors about the Effective Utilization of the Sand

Planning of effective utilization of the obtained sand is more likely to be a merit for both the public and private sectors. On the other hand, recently, the public area is managed by the public, and the leased land area is managed by the private sector. The example of the shore management by the public-private cooperation is quite limited so far. About utilization of the sand, further discussion will be necessary about the management and administration methods in the future between the public and private sectors. In addition, it is also necessary to discuss the consistency in regard to the legal system regarding the application to other coasts.

Chapter 7

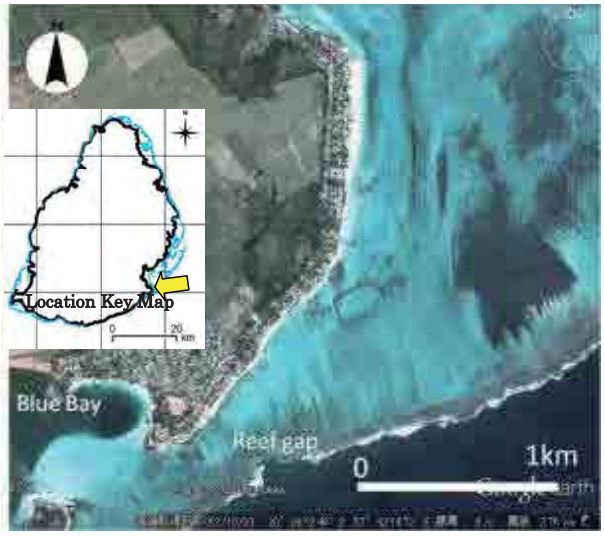
Pointe d'Esny

7 Pointe d'Esny

7.1 Outline of Coast

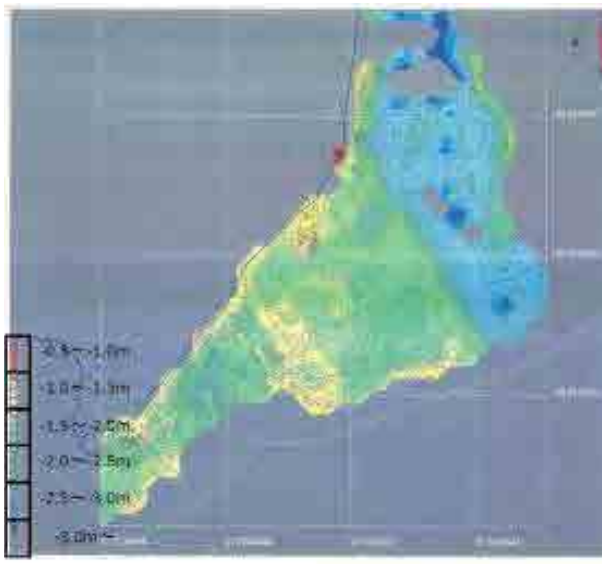
Pointe d'Esny is situated in a coastal resort area, having a 2.5 km coastline close to the east Blue Bay; the biggest coastal resort area in the south of Mauritius. There are 114 lease areas along the coast where residential areas, bungalows and small guest houses are located from old days. The lease area of this beach region is the most higher in the categorization of five different grades and it is positioned as a luxury land lease area. The beach is used for sunbathing and the lagoon for snorkeling, diving and sailing as marine sports by the residents and tourists. The north part of the lagoon was one of the typical sand mining areas before 2001. There are many groynes and revetments for the purpose of protection along the lease area since 1940 thereafter.

The coastal line consists of the southern part and northern part. The southern part extends from the northeast to the southwest, and the northern part forms a convex shape, changing its form from the south to the north (Figure 7.1.1). The shape of lagoon along this coast is significantly different from the south and north sides. The width of the lagoon in the southern part is about 500 m. The width of the lagoon around the groynes in the northern part is about 1.8 km, expanding from the south to the north. According to the results of the bathymetric survey by the Mauritius Oceanography Institute (MOI) as shown in Figure 7.1.2, water depths of the reef in the southern part are 1 or 2 m. On the other hand, water depths on the northern part are deeper than those of the southern part by 1 to 2 m. In the southern part, there is a small reef gap where the water depths are deeper than the surrounding area by 1 m.



Source: Processed by JICA Expert Team based on Google Earth

Figure 7.1.1 Topography of Pointe d'Esny



Source: Mauritius Oceanography Institute (MOI)

Figure 7.1.2 Bathymetry on the Coral Reef

7.2 Present Condition

7.2.1 Site Reconnaissance

Figure 7.2.2 and Figure 7.2.3 shows the photos of the coastal situation taken in January 2013 at the points shown in Figure 7.2.1. The present situations of this coast are described below.

- Point A: the point near the southern part of this coast. MOESDDBM took measures by placing sand to restore the beach profile in 2012 because of beach scrap at this point.
- Point B: the groyne near the coast on the side of southern reef gap. The shoreline along the southern part of this point has a tendency of accumulation, while the northern part has a tendency of erosion.
- Point C: the groyne located 300 m to the north from Point B. The tendency of this shoreline is the same as Point B.
- Point D: the point located 300 m to the north from Point C. The sandy beach drastically disappears from this point. The area behind the beach is protected by vertical revetments.
- Point E and F: The sandy beach is disappeared at the present and waves are hitting the revetment. The beach without sand extends about 150 m. The ground level in front of the revetment decreased by more than 2.5 m as shown in the photo of 1971 provided by the lessee who lives for a long time between point E and F.
- Point F: The waves hit the revetment directly during the high tide and the dry beach is appeared slightly at low tide. The sandy beach width gradually extends from this point and the beach can be found in places where there are no concrete revetments.
- Point G and H: The beach located at groyne G3 is accreted at the south and eroded at the north.
- Point I: In the vicinity of a small groyne 200 m north of groyne G3. The lessees are protecting their respective land by riprap and sand bags. The beach becomes wider for 1 km without groynes from this point.
- Point J: It is located 100 m south of groyne G4 in the northern end where the beach is wide and has the gentle slope of 1:12 to 1:15.
- Point I: The north coastline was eroded significantly from the groyne at the north end. Rock reef becomes exposed in the north coast.

Source: Processed by JICA Expert Team based on Satellite image obtained from MHL

Figure 7.2.1 Locations of Photos

Point A (south of jetty)

Point B (groyne G1)

Point B (from groyne G1 to the south)

Point B (from groyne G1 to the north)

Point C (groyne G2)

Point C (groyne G2 to the south)

Point C (groyne G2 to the north)

Point D

Source: JICA Expert Team

Figure 7.2.2 Coastal Condition at Pointe d'Esny (January 2013) 1/2

Point E

Between Point E and F

Point F

Point G (south of Groyne G3)

Point H (Groyne G3 to the north)

Point I (200 m north from Groyne G3)

Point J (Looking at Groyne G4)

Point I (Groyne G4)

Source: JICA Expert Team

Figure 7.2.3 Coastal Conditions at Pointe d'Esny (January 2013) 2/2

7.2.2 Long Term Coastline Change

Figure 7.2.4 shows the aerial photos of the whole coast including the reefs in 1967 and 2008. Figure 7.2.5 shows the coastal changes of each zone at two times on the satellite image of 2008. In addition to the aerial photo of the two periods, the sediment budget from 1967 at each sub cell is shown in Figure 7.2.6 at every five periods from the aerial photos of 1975 and 1991, and the Google Earth of 2012. The sediment budget was calculated by multiplying the shoreline movement obtained from the photos by 2.5 m, which is defined as mean movement in coral beaches in Mauritius. The results are as follows.

The change of coastline was small within about 40 years from 1967 to 2002 in Zone-1 between groyne G1 and G2. There is north ward longshore transport estimated from the change of coastline at both sides of the groyne.

In the south Zone-2 between groynes G2 and G3, the coastline eroded about 20m at its maximum from 1967, The sand has currently been eroded from a 150 m stretch of beach and waves hit the vertical revetment.

The groynes of G4 located at the north end of Zone-3 was constructed during 1940s. There is a significant accreted area at the south of the groyne and the coastline was about 50 m inland in 1940. The coast was rocky one the same as the north coast of the groyne before the construction of the groyne from the information of a resident who lives for a long time in the area.

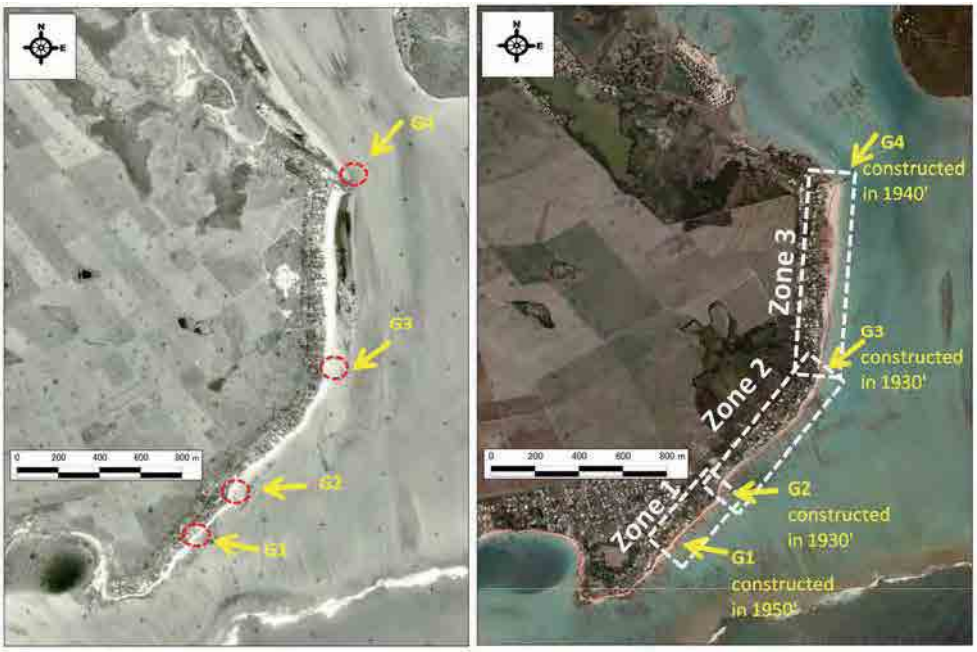
In the north area, sand spit that existed in front of the coast earlier disappeared.

The main 4 groynes existed from 1967 as shown in the Figure. The groyne G1 was constructed in 1950s, G2 and G3 in 1930s and G4 in 1940s from interviews with residents who live for a long time in the area. There are old revetments and groynes constructed after cyclone Carol in 1960 and those types of structures were increasing after damage from several cyclones.

The beach at the north area of sub cell No.3 is continuously accreted from 1967 as shown in the Figure 7.2.6 of sediment budget. There is no marked change from 2008 to 2012. The longshore sediment transport rate is estimated to be about 1,100m^3/yr from the change of sediment amount.

At the middle area of sub cell No.2 the beach was eroded from 1967 to 1997 and no changes after then. It is possible that the change of coastline cannot be read from the photo because there was no changes at the revetments which were constructed in many places. The ground level in front of the revetment at sub cell No.3 was lowering with the gradual loss of sand from the interviews with residents. At the sub cell No.4, the residents told that the erosion is continuous with the seasonal changes of sand.

The accumulation of sediment becomes 20,000m^3 within 40 years in a whole. The sand was mined at the north part of the reef from 1970s to1990s and also from the beach and the sand dune behind the beach. The sand mining was banned by law after 2001 from the reef and beach. This action is and will continue to increase the sediment budget of this coastline.

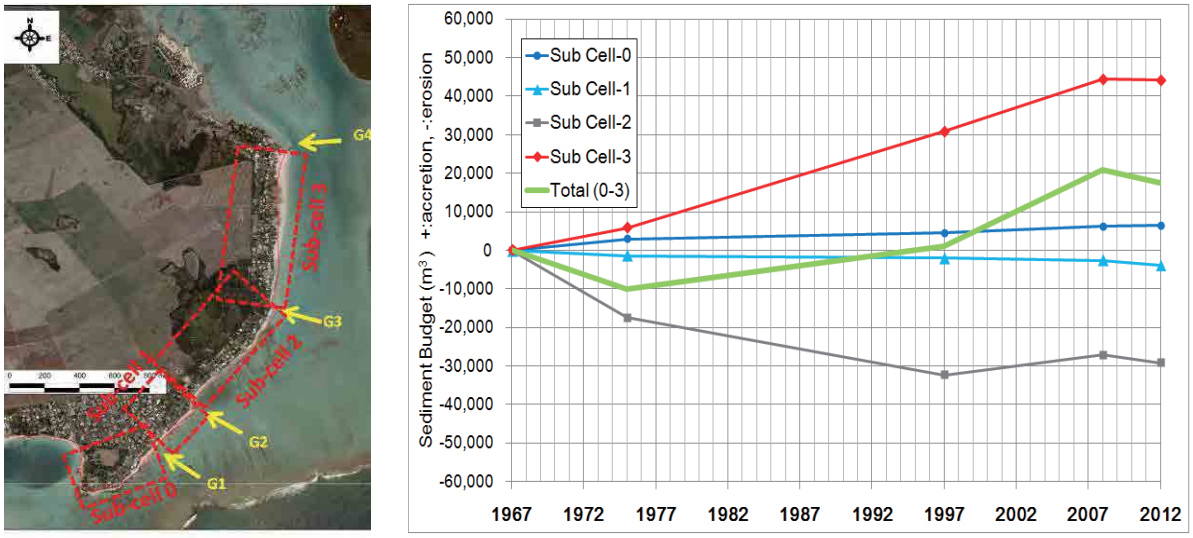


Source: Processed by JICA Expert Team based on materials obtained from MHL

Figure 7.2.4 Comparison of Aerial Photos (left 1967, right 2008)

Source: Processed by JICA Expert Team based on Satellite image obtained from MHL

Figure 7.2.5 Long Term Shoreline Change at Each Zone(Satellite Image:2008)



Source: left; Processed by JICA Expert Team based on satellite image obtained from MHL, right; JICA Expert Team

Figure 7.2.6 Sediment Budget at Each Sub Cell

7.2.3 Short Term Coastal Change (Results of continuous monitoring)

This coast is one of the object coasts selected for continuous monitoring in this project. Coastal monitoring survey has been conducted every about 3 months since November 2013 in this coast, setting 13 measuring lines along the about 2.5 km long coastline from the public coast in Blue Bay, the southwest area of this coast, to the G4 groyne at the north end. Figure 7.2.8 and Figure 7.2.9 present about one year monitoring results at (i) the 2 points in the public coast and (ii) the 7 representative points located separately to the north along the coast, respectively, of which the locations are as shown in Figure 7.2.7. The findings from the monitoring results are stated below:

- Points L-13 and L-11A on the north and south of the impermeable type groyne, which is used by leisure boats in the public coast located in the bay of Blue Bay, have little seasonal change and are stable. Near L-11A, slope protection works by rubble tipping were executed by MOESDDBM.
- The monitoring results at L10 and L9 are those on the both sides of the G2 groyne (Point C in Figure 7.2.2), respectively. There is a different tendency found clearly between both sides of this groyne. At L10 on the south of G2, a notable deposition tendency is found in particular during the winter season from March to July 2014. On the other hand, an erosion tendency and the emergence of scarp are found during the same season at L9 on the north. Their seasonal variations have attained a range of about 2 to 3m. These phenomena closely correspond to the seasonal variation of wind direction, and suggest sand movement to the north during the winter season when a south-southeast wind blows strong.
- The L8 survey line is set to the north of the vertical revetment where a dry beach has completely disappeared, and a groyne has been constructed to the north of this line (near Point C in Figure 7.2.2). As in the case of L10, an about 2 to 3 m advance of coastline is found and an existence of littoral drift to the north is confirmed. It is foreseen that this coast will have an erosion tendency again during the period up to the coming summer season. This tendency could be confirmed through further continuous monitoring.

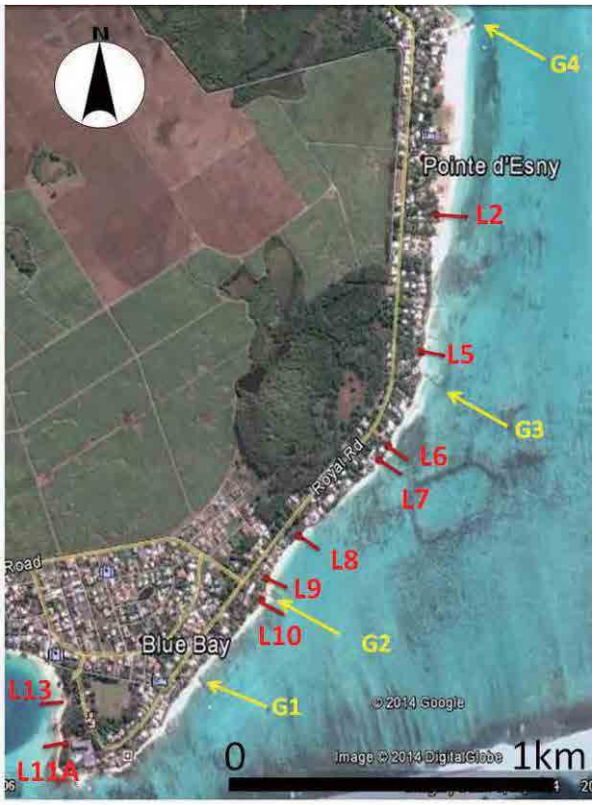
- The monitoring results at L7 and L6 are those on the south and north of the small groyne near Point F in Figure 7.2.2, respectively. Although their changes are smaller than those of the above-mentioned points, a similar tendency is found.
- The monitoring results at L5 are those to the north of the G3 groyne near Point H in Figure 7.2.2. Since L5 is located to the north of this groyne, it has an erosion tendency during the winter season.
- The monitoring results at L2 are those in the zone subjected to apparent sand deposition near Point J in Figure 7.2.2. No distinctive seasonal change is clear. Although this point is located in a deposition area, a scarp is found in the monitoring results during the winter season when the wave energy becomes comparatively high.

Based on the coastal monitoring results mentioned above, this coast has a remarkable sand movement following seasonal change: the sand moves to the north during the winter season when a frequency of strong south-southeast wind increases, and the sand returns to the south during the summer season when the wind weakens and an east- northeast wind prevails. It is considered that the sand in this coast has been moving to the north eventually, repeating such movements.

According to these findings, the approach from the following aspects is essential to understanding a littoral drift phenomenon:

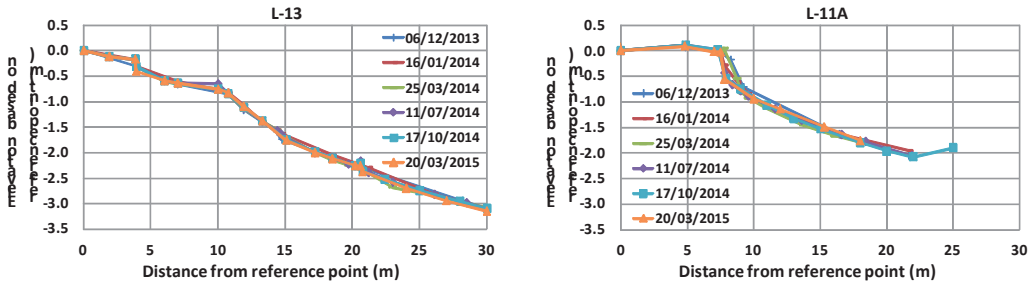
(i) Long term characteristics by using aerial photos and satellite images (the net direction of littoral drift), and

(ii) Short term viewpoint through periodical coastal monitoring (seasonal change and its direction).



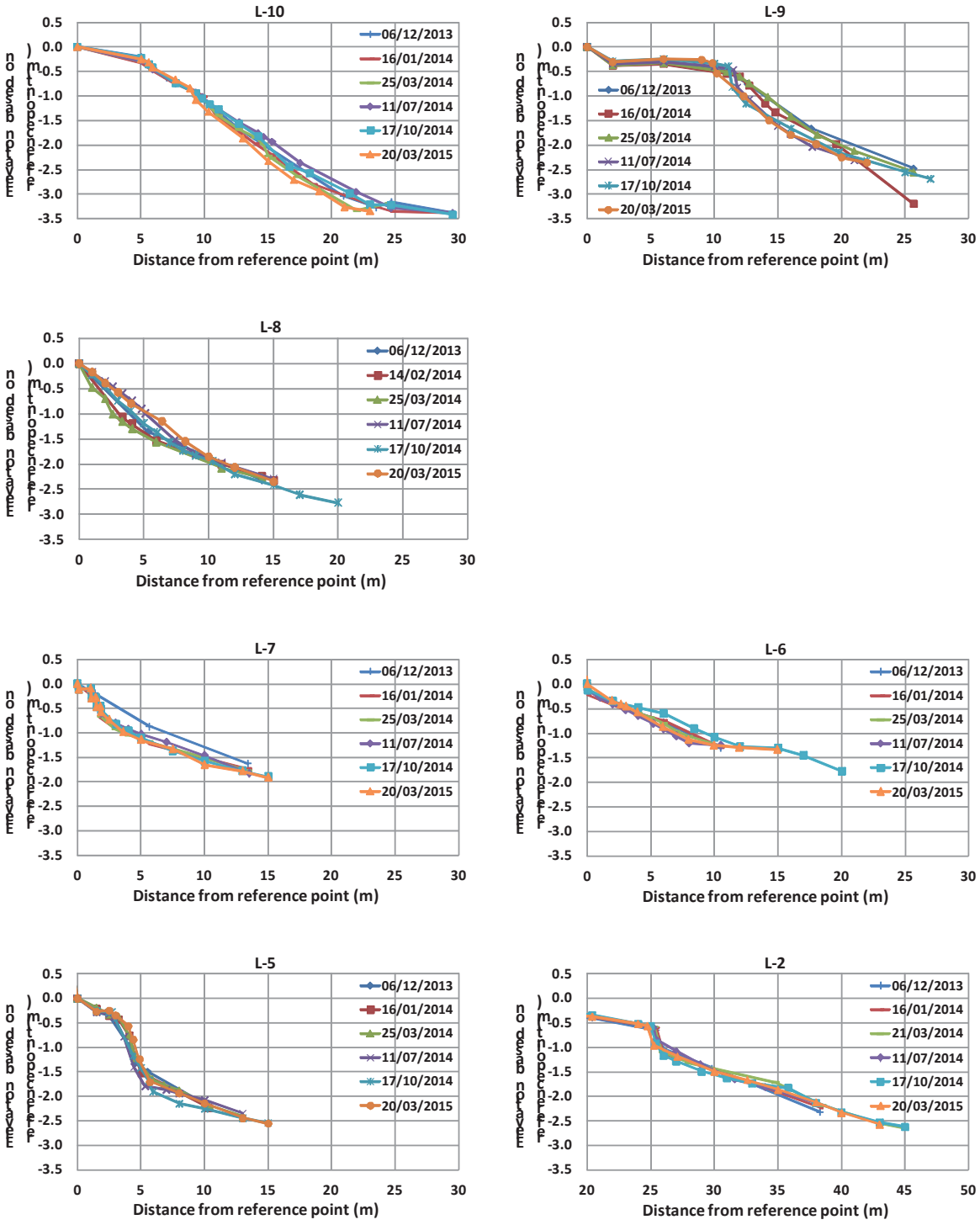
Source: Adapted from Google map by JICA Expert Team

Figure 7.2.7 Location Map of Coastal Survey



Source: MOESDDBM and JICA Expert Team

Figure 7.2.8 Results of Continuous Coastal Monitoring Survey along the Public Coast in the Bay of Blue Bay



Source: MOESDDBM and JICA Expert Team

Figure 7.2.9 Results of Continuous Coastal Monitoring Survey at 7 Representative Points in Pte. d' Esny

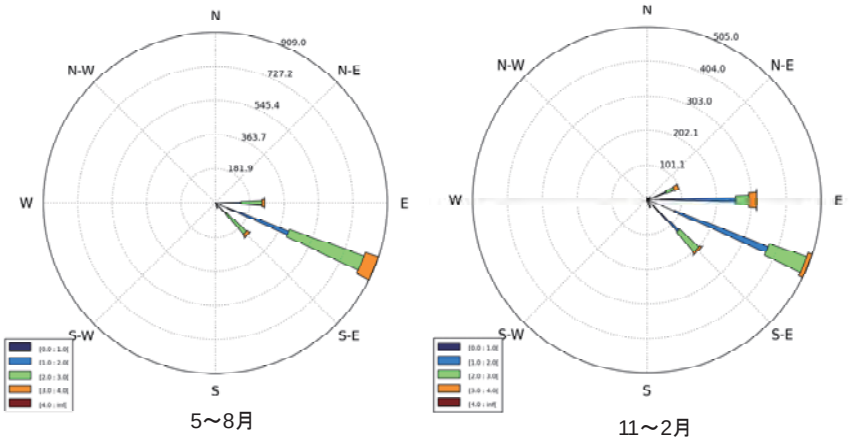
7.2.4 Characteristics of Wave, Water Level, Current, Topography, Bed Material and Reef Environment

a. Meteorological and Hydrological Conditions

Deep water wave (observation from MMS and MOI)

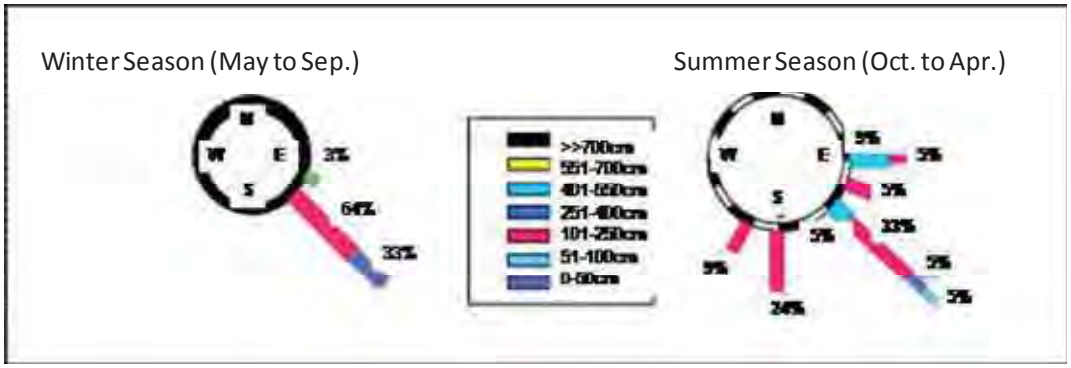
There are two types of waves which cause sediment transport and coastal changes on the coast. One is the waves generated by the southeast trade winds in winter from June to September and the other is the waves generated by cyclones in summer from December to March. The Mauritius Meteorological Service (MMS) observes waves from 2003 off Blue Bay and the Mauritius Oceanography Institute (MOI) off Roches Noires from February 2012. The seasonal changes of wave conditions of both points are shown in Figure 7.2.10.

- Off the coast of Blue Bay waves come from SE both in summer and winter. In winter the waves focus on mostly one direction of SSE. The trend off the coast of Roches Noires is the same.
- The seasonal changes of waves are corresponding to the change of winds. In summer the wind is weak with wide variation of directions and the frequency of calm waves is high except by the cyclones. In winter the waves become high compared with summer from the strong trade winds from southeast.



(1) Off Roches Noires

Source: Modified by JICA Expert Team based on the data from MOI



(2) Off Blue Bay

Source: MMS

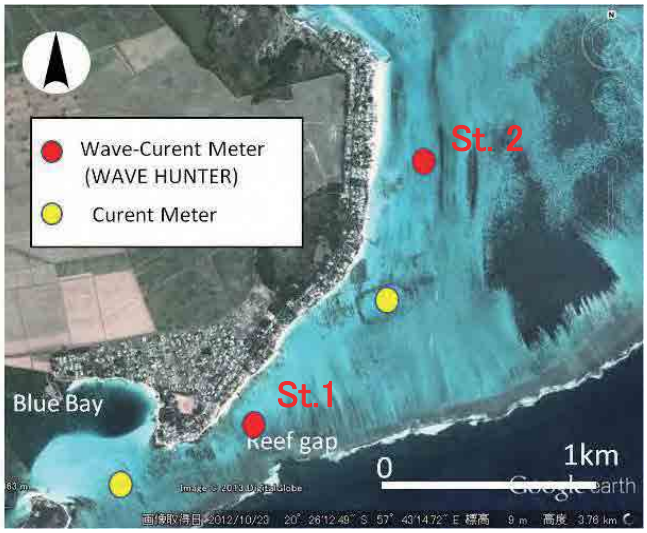
Figure 7.2.10 Seasonal Change of Offshore Waves

The cyclones come in summer frequently from December to April. It moves from north to the south sometimes through the east coast and in some cases through the west coast. It takes frequently its maximum at the north and if the cyclone is severe, it keeps the intensity after passing of Mauritius. The wave characteristics are influenced by the coast change according to the passage and intensity of cyclones.

Wave and water level observation

(1) Normal condition

The coast has reef of 0.5 to 1.8 km wide and the wave height decreases significantly according to its reef width. Also waves reached to the beach depends on the water level in a reef together with the wave height in deep water and becomes high if it is deep. The waves at the north is estimated to be smaller than those at the south because the reef is wider at the north. To confirm this waves and currents were observed at four points as shown in Figure 7.2.11. The red circles show the observation points of waves and currents.

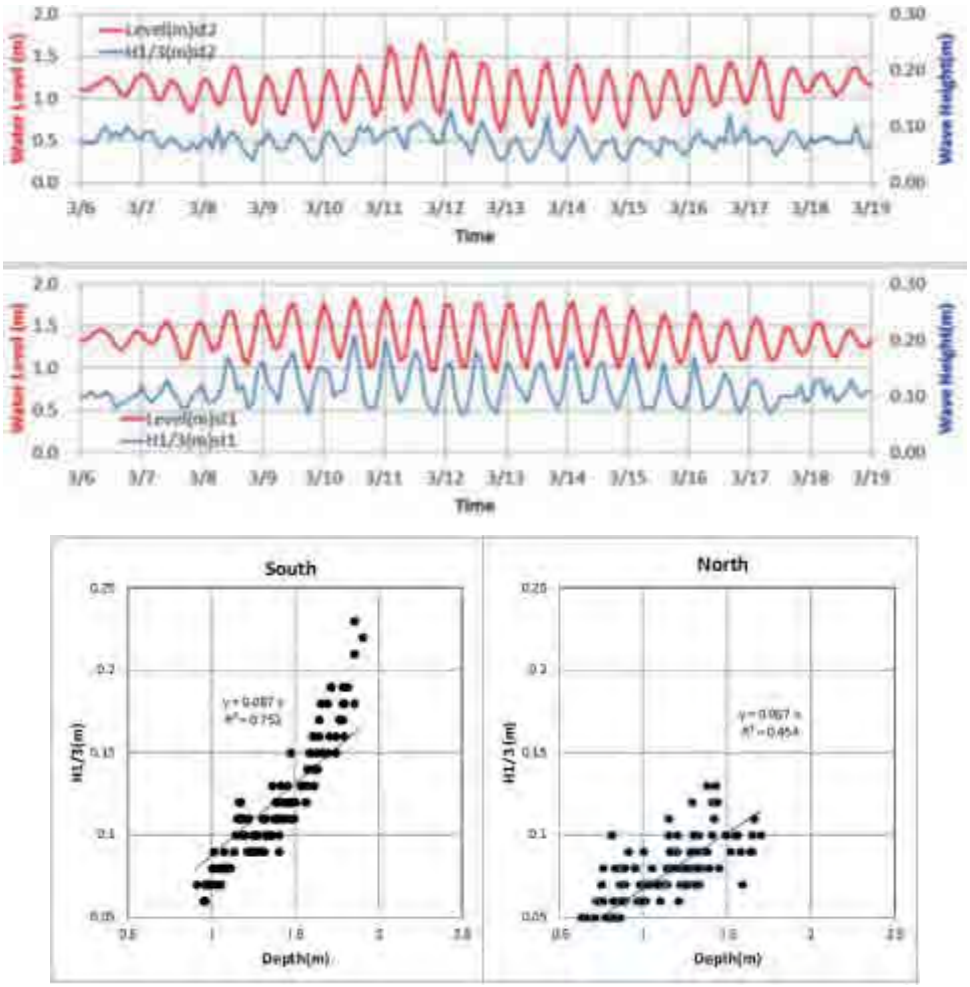


Source: JICA Expert Team based on the Google Earth

Figure 7.2.11 Location for Wave and Current Observation

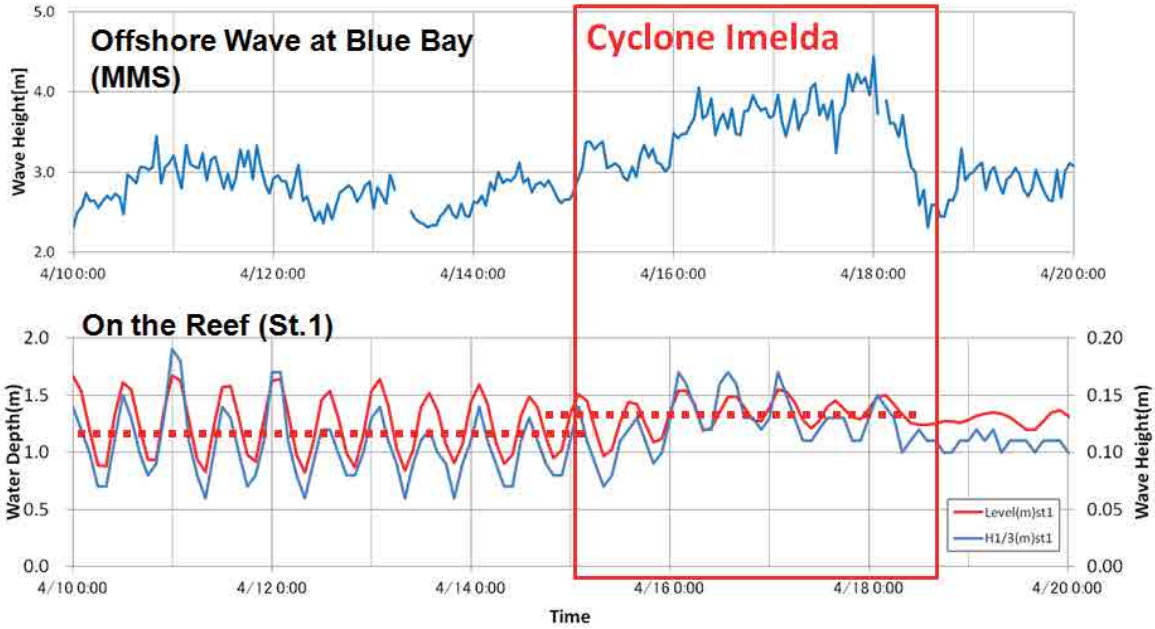
The observed results and the relation between waves (red line) and water level (blue line) are shown in Figure 7.2.12. The results are shown as follows.

- The wave height in a reef is controlled by the water level and waves become high if water level is also high. The wave in the reef comes after breaking at the reef edge and the breaking wave height is determined by the water depth.
- The wave height at St.1 located about 200m form the reef edge is different to the wave changes from the wave height at St.2 about 1.4km from the reef edge and smaller. At St.1 the wave height is 9 % of the water depth and 11% if the water depth becomes deep. On the other hand the wave height is about 7% of the water depth at St. 2 at any water level.



Source: JICA Expert Team

Figure 7.2.12 Relation between Water Level and Wave Height at St.1and St.2



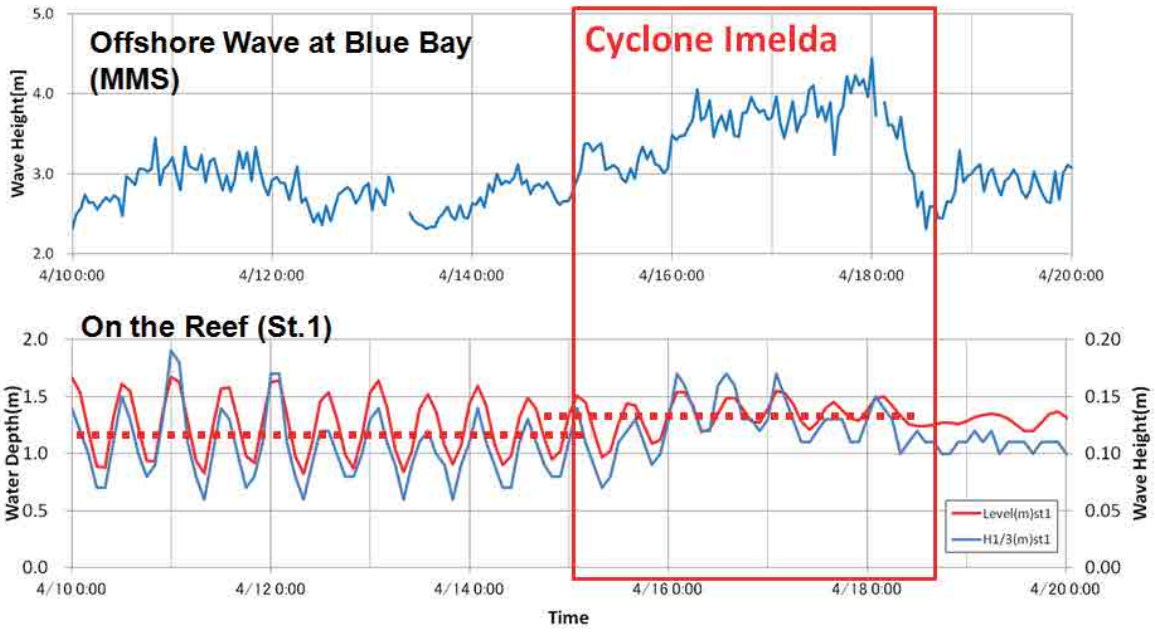
Source: JICA Expert Team

Figure 7.2.13 Relation between Water Level and Wave Height at St.1 in Cyclone Condition

(2) Cyclone condition

Cyclone Imelda passed along the east coast of Mauritius during the observation period from 16 to 18 of April 2013. The observed waves and water levels are shown in Figure 7.2.14 off Blue Bay by the wave buoy of MMS and in the reef of point St.1.

- The maximum significant wave of 4m was observed at its peak offshore. In the reef the waves were a little higher than usual.
- The water level in the reef is shown by dotted line of red before and during the cyclone. The water level is higher during the cyclone than before caused by the wave set-up. The set-up is about 3% of incident wave height and smaller than 10% of ordinary coasts uniform alongshore facing the open sea.



Source: JICA Expert Team

Figure 7.2.14 Wave Height and Water Level at Offshore and in the Reef (St.1) during Cyclone

- Cyclone Edilson came in February 2014 and the significant wave height of 4m was observed at the peak same as by the cyclone Imelda. The water level observed in the reef was also 3% of incident wave height.

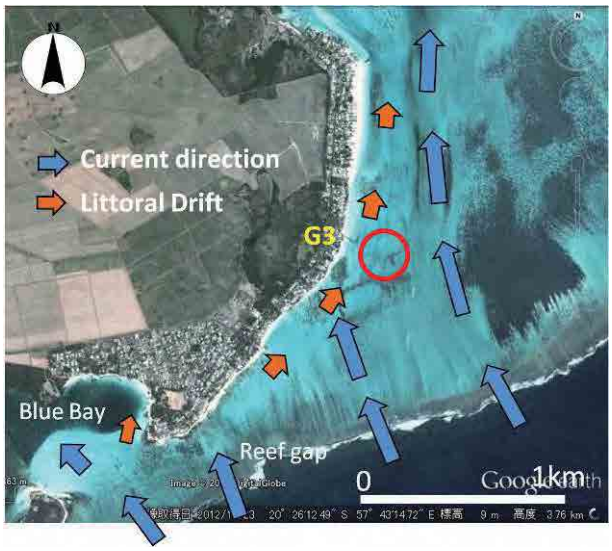
Current on the Reef

(1) Estimation from reef patterns

The waves and currents on the reef can be estimated from reef patterns of aerial photos and satellite images. The current pattern in the reef is shown in Figure 7.2.15 from the observation of surface patterns. At the south the trace of westward is shown to the bottom of Blue Bay. At the middle part the trace is the pattern from offshore to the beach and at the north it is to the north. The trace seems to show the wave direction in the reef at the narrow area of the south where the sediment moves mainly by wave action. On the other hand, it shows the current direction at the wide area of the north where the sediment moves mainly by current action.

b. Coastal Topography and Sediment Material

As mentioned before, the reef width on the southern area of this coast is about 500 m and that of the northern area is 1.8 km. It is assumed that the difference of the reef width greatly influences on the coastal topography or characteristics of littoral drift. On the southern side of Blue Bay, the reef does not exist and the water depth is deep. From the survey the steep slope of 1:3~1:5 was surveyed by diving. It seems that the bottom is formed by the sand transported from offshore to coast and deposited in the deep area by the decrease of transport capacity.

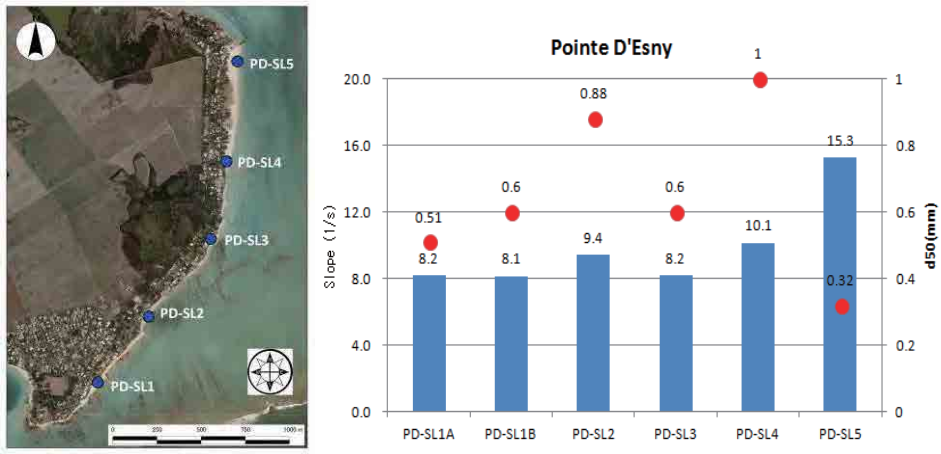


Source: Processed by JICA Expert Team based on the Google Earth

Figure 7.2.15 Direction of Current and Littoral Drift Estimated from the Reef Patterns

There is a small reef gap on the southern area in the coast. From the gap to the beach the reef is about 0.5~1.0m deeper than the surroundings of 2 m in water depth. The reef gap may affect the topography in the southern area.

Figure 7.2.16 shows the foreshore beach slopes alongshore obtained from the basic study. The slope is about 1:8 in general and becomes gentle of 1:10 to 1:12 at the north area. The sediment is fine at this accumulated area compared to other areas. The sand moves gradually to the north from those results.



Source: Left; Processed by JICA Expert Team based on satellite image obtained from MHL. Right; Processed by JICA Expert Team.

Figure 7.2.16 Foreshore Beach Slope

c. Reef Environment and Water Quality

Coral coverage was only 1 % dominated by branching *Acropora* at the central lagoon mostly covered by sand. While, coral coverage dominated by tabular- and branching- *Acropora* was 70 % in back reef. Density of juvenile *Acropora* was zero at the central lagoon, but it was 1.1

per square meter in the back reef and it was the highest density in the lagoons of Mauritius. There was no seagrass bed in the lagoon and a small amount of *Surgassum* and *Padina* was seen on the skeleton of corals. Area of coral community remarkably increases in these 18 years in comparison with the aerial photographs taken in 1996. By the survey of interview to residents, habitat of living coral remarkably became wide in this lagoon. Open water inflow directly to the lagoon and transparency was 15 m at the monitoring survey in 2013. This lagoon seems to be the best habitat for coral growth in Mauritius. Large net fishing is prohibited in this lagoon, but illegal fishing by diving were witnessed quite frequently according to the information from residents. Seagrass bed was arranged offshore in the chart made by AFRC around 1994 and also by the information from residents. However, the seagrass bed disappeared in the aerial photographs in 1996. Seagrass, *Halophila*, was observed in sand bottom of the central lagoon, but it did not form a seagrass bed. Shaded area in front of accumulation area is micro-algal mat and not seagrass bed.

Source: JICA Expert Team modified based on Google Earth

Figure 7.2.17 Coverage of living corals at Pointe d'Esny

The investigation results on water quality and impacts to water quality in the lagoon at Pte. aux Cannoniers are shown in Table 7.2.1. There is no Siltation. Chlorophyll a, turbidity and nutrient salts are respectively 0.08 ug/L, 0.30 NTU, < 0.03 mg/L for NO_3 and <0.005 mg/L for PO_4 on an average very and good level as habitat of coral (the coverage of living coral is more than 50%). This coast is an underdeveloped district of sewerage system. The most wastewaters are flowing into the coast through AP (absorption pit) and PL (pit latrine).

Table 7.2.1 Investigation Results on Water Quality and Impacts to Water Quality in Lagoon

Check items		Conditions
Water quality	Chlorophyll a (ug/L)	0.05-0.12(#) (Ave. 0.08)
	Turbidity (NTU)	0.16-0.43(#) (Ave. 0.30)
	NO_3-N (mg/L)	<0.02
	PO_4-P (mg/L)	<0.005

Population density behind coast(per km^2)					
Sewerage disposal behind coast	Status of development of sewerage facilities behind coast	Absorption Pit, Septic Tank, Pit Latrine			
	Present condition of sewerage disposal from houses (Sewerage system, Septic tank, Pending arrangement, etc.)	Beau Vallon VCA: SS: NIL, AP:1461, ST: 36, PL: 113			
	Present condition of sewerage disposal from hotels and restaurants (Sewerage system, Septic tank, Pending arrangement, etc.)	Hotels >75 rooms uses onsite treatment plants. Restaurant uses septic tanks.			
	Development plan of sewerage system for houses and hotels behind coast	NIL			
Impact of pollution from sugarcane	Incidence of red-soil runoff from land side	None			
	Existence of sugarcane field behind coast. If there is it, area of the field behind coast.	Yes. Area: 478 Ha			
Relation between living coral and water quality**	Coral coverage	Chlorophyll a (ug/L)	Turbidity (NTU)	NO_3-N (mg/L)	PO_4-P (mg/L)
	>50%	<0.2	<0.5	<0.012	<0.007
	20-50%	0.2-0.6	0.5-1.3	0.012-0.051	0.007-0.016
	10-20%	0.6-0.9	1.3-1.9	0.051-0.081	0.016-0.023
	<10%	>0.9	>1.9	>0.081	>0.023

#: Observation for water quality and coral reef was conducted from the shore to the reef edge.
**: This relation was obtained by the water quality survey in this study. Refer to Table 2.6.3 in Vol.1.
SS: Sewerage Systems, Ap: Absorption Pit, ST: Septic Tank, PL: Pit latrine
Source: JICA Expert Team

7.3 Littoral Drift and Cause of Erosion

7.3.1 Littoral Drift

The characteristics of the littoral are summarized as follows.

- It is clear that the littoral drift to the north is dominant from the reef gap at the south from the natural characteristics, field reconnaissance and long term coastline changes. The littoral drift is affected by the trade winds of seasonal changes of summer and winter because of the wide reef. In summer the sediment moves to the north by the strong trade wind from southeast. In summer the wind becomes weak and blows to southeast and northeast and the sediment is sometimes transported to the south. The sediment seems to drift toward north gradually by the repeat of seasonal variations.
- The significant beach changes were caused by the cyclone in summer. The cyclones impacted to the coast were cyclone Carol in 1960, cyclone Hollanda in 1994 and cyclone Dina from the interviews with residents. The groynes and revetments were constructed following cyclone events where erosion occurred on the beach.
- At the south of the reef gap to the south public beach, the sediment moves from the north to the south in the Blue Bay.

7.3.2 Cause of Erosion

At the coast there was the rapid erosion by severe cyclones in the past, the construction of revetments and groynes by individual lessees as preventive measures, seasonal beach changes, and the changes of erosion and accretion in some areas. The cyclone and seasonal changes were existed before the erosion problems. From those considerations the erosion factors are summarized as follows.

a. Decrease of sediment supply by the sand mining

The sand mining had been carried out from 1700s at the reef in Mauritius. The sand mining of this coast was carried out from 1970s to 1990s. (Mauritius Sand Dredging Study, 1993) At that time about 500,000 t (250,000m^3)/year of sand was mined at the 4 area in the east coasts of Mauritius namely Pointe d'Esny, Grand Rivière Sud Est, Grand Gaube and Poudre d'Or. The north area of this coast was one of the main mining areas. The sand was also mined at the beach and existed sand bar behind the beach at that time. The volume is not clear in total. The littoral drift of the coast is in the order of 1,000m^3. The sediment balance and the external forces would be affected if the sand was mined from several ten thousand m^3 to hundred thousand m^3 of sand. The sand mining in the reef was banned in 2001 and was not carried out thereafter. Possibly it is related to the recent deposition trend of sediment budget.

b. Rapid beach changes by cyclone and reduction of resilience

It is clear that the rapid beach erosion was caused by the large cyclones in the past from the interviews with residents. At the cyclone Carol in 1960 the beach was eroded in the order of 10m. The frequency of large cyclones was high in 1990s from the record. The high wave by the cyclone brings rapid erosion. The construction of groynes and revetments were effective as protection by each lessee. On the other hand, it may cause to break the balance of longshore sediment transport and to reduce the resilience of natural on-off shore sediment movement.

c. Change of coral environment in the reef

In the reef the sand was mined and dynamite fishing was carried out until 1980s. This had a negative impact on the coral environment, and decreased its wave dissipation and sand supply capacity. The coral environment is recovering at present since such activities were prohibited.

d. Presence of hard structures in dynamic beach zone

The presence of vertical retaining walls and groynes caused decrease of foreshore sandy slope due to scouring and interrupt of littoral drift to down-stream on sediment transport.

7.4 Direction of Coastal Conservation Measures

7.4.1 Outline

The coastal erosion is not severe on the whole because the sediment budget is positive and recovering. On the other hand, the coastline is recessing and the local people have a strong desire for emergency measures to be implemented at Zone-2 and the south of Zone-3. At the north of Zone-3 the sand was deposited significantly. The conservation plan will take three stages as follows.

- Emergency measures: The measures curried out by the lessees on the eroded beach of Zone-2 and the south of Zone-3 of leased area
- Coastal conservation measures (short term): The measures to improve the balance of the sediment and to maintain the stable beach
- Spatial and reef environment plan (long term): The measures to keep stable sediment supply and to correspond to future climate change

Even though the objective beach is evaluated as having an overall accretion trend based on the analysis of long term sediment budget, there are several coastal problems such as;

- Existence of partial erosion and accretion of the beach caused by unbalance of littoral drift due to construction of individual structures such as groynes, seawalls.
- Obstruction to public access (un-securing of the area between HWL and LWL)
- Deterioration of beach use and landscape due to existence of plenty of coastal structures

Based on such conditions, the objective of coastal conservation at Pte. d'Esny is to recover the natural sandy beach and to keep it in the same condition as much as possible for residents and tourists. However, the above issues cannot be solved if the current coastal management is continued, namely management that only takes into account the protection of individual private properties. The integrated coastal conservation taking into account the continuous sediment cell is surely required to solve the problems. To achieve this, what is necessary as the first approach is to obtain the public consensus for the principles of coastal conservation and recommended coastal conservation plan. Thus, this coast was selected as the site for a demonstration project of "non-physical measures" as referring to the Chapter8 on Demonstration Project in Vol.1.

7.4.2 Principles of Measures

a. Emergency Measures

The coastal erosion is in progress at Zone-2 and the south of Zone-3 and it requires emergency measures to protect houses and lands. The measures have been taken by the lessees individually. Measures are carried out by the lessees. The measures included revetment or gabions in front of the revetment, sand bag, riprap, improvement of groynes. In this study individual structures are not handled. The points to keep in mind are as follows.

- The measures taken by the lessee have to avoid further erosion at surrounding beaches. The long term sediment movement is northward. Seasonal variation of the beach can also be seen. These should be considered while developing measures for coastal protection. Construction of groynes individually should not be undertaken unless sediment balance of whole beach is taken into consideration. It is important to set the position and beach width for the improvement of revetments and the placement of riprap in front of the existing structures because of the possibility of impact to adjacent beach. Also considerations are necessary for the use of the beach and landscape and it does not worsen from the current situation.
- The coastal conservation measures of short term will be introduced to improve the coast. The individual measures have to be in line with recommendations being made in this CCP

for short and long term. Considerations should be given to the impacts of the constructions and also costs associated.

b. Short Term Measures

The purposes of short term measures are as follows.

- To protect the leased area where erosion is progressing at present
- To propose desirable beach use and convenient access to the lessee and tourist who use the beach together with the maintenance of public domain and natural landscape
- To maintain and improve the reef environment as one of the few good coral environment in Mauritius

The basic principles of measures is shown as follows based on the abovementioned purposes.

- To improve imbalances of coastal conditions of eroded and accreted areas and to rehabilitate the eroded beaches
- To plan and implement comprehensive coastal conservation measures taking into account the entire coast as opposed to individual measures carried out on leased area in the past. However, the present coastal situation will not be changed drastically as there are existing long-term countermeasures such as groynes and there have been associated changes in the coastal morphology and land use
- To minimize the artificial facilities for the maintenance of desirable coastal use and natural landscape with modification of existing structures and adding of facilities if necessary
- To reduce the effort and cost of maintenance to ensure the long-term stability of the rehabilitated beach

c. Long-Term Measures

- To monitor coral bleaching and conserve and preserve good conditions for corals and implement necessary measures to mitigate eutrophication to maintain current coral reef conditions
- To work towards achieving a setback at the time of the next lease contract renewal in 2068 to reduce the risk of flooding and overtopping to the private property due to future climate change

7.4.3 Short Term Measures

a. Option for Measures

The alternatives are (1) Sand nourishment (including sand recycle), (2) Rearrangement of coastal structures (including removal and improvement), (3) Setback, (4) Combination of the above.

(1) Sand nourishment (including sand recycling)

It is not realistic, judging from the past coastline changes, to expect increases in sediment supply from the reef to recover the present eroded beaches. Further, because of the existence of groynes the northward longshore sediment transport is not disrupted in places, therefore neither is this a reliable source of sediment supply. Then the nourishment is essential to recover the eroded beach. The issue is how to maintain the nourished sand with the presence of longshore sediment transport to the north.

The sand transported by the longshore sediment transport to the north, the majority of which is trapped by the north end by the groyne G4. The sediment balance of the whole coast tends to be of accretion. It can be considered to use the deposited sand for the nourishment of eroded areas effectively.

(2) Rearrangement of coastal structures (including removal and improvement)

It is not desirable to make significant beach changes with the removalof existing groynes because already the hinterland is used on receiving a history of topographic change due to existing groynes. It is not practical to return the natural state before the sediment balance was maintained without structures. On the other hand, there are groynes which are possibly required to remove or to improve for the increase of its functions to formulate conservation measures in light of sediment balance of whole coast. It is necessary to rearrange groynes, to decrease nourished sediment movement and to retain the nourished sand.

(3) Setback

The possibility of setback was discussed with MHL, the responsible organization for setback and lessor (owner of the leased areas). The details are explained in Chapter 8. The timing of a possible review for provision of setback for existing buildings and removal of existing building is limited to the end of the lease contract which is 2068.Implementation of setback would also be possible during new construction. As one of the realistic coastal protection measures, it is difficult to force the lessee implementset-back for the existing building.

It is possible to ask the lessee to move the revetment out of the setback line if it is necessary to improve the revetment and if there is a enough space between the revetment and building once the lessee understand the advantages of such measures.

(4) Combination

In each area of our coast, the purpose or function required for the measures and coastal situation is different. Thus, it is not necessary to be compared with individual measures as indicated above, a combination of measures is being proposed depending on the situation. The basic idea is shown in the following.

- The coast is divided into three zones according to the existing four key groynes (G1-G4) which is affecting sediment mechanisms and can stabilized in each zone. (refer to Figure 7.2.4 and Figure 7.2.5)
- Other existing groynes which do not significantly affect the sediment transport as a whole, shall be lowered or removed as much as possible.
- The beach is rehabilitated by nourishment if the foreshore was lost and the beach has problems of protection and access.

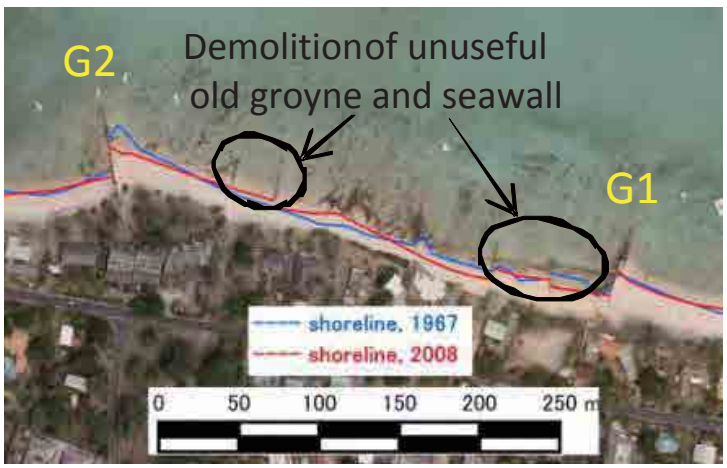
- The existing groynes to be rearranged and improved and new ones to be constructed to maintain and stabilize the sandy beach.
- The revetments which prevent natural recovery of sandy beach to be improved and realigned.
- Maintenance on a regular basis is essential because measures are based on nourishment. Thus, sand available in the coast will be used for the easy maintenance and cost reduction.

b. Short Term Measures (Draft Plan before Public Consultation)

The conservation measures proposed for the target coasts for non-physical measures will be finalized based on consultation with the related organizations and residents. The following description is the draft plan which is proposed by JET before conducting the public consultation.

b.1 Zone 1

Zone 1 is about 330m long and located between existing groyne G1 and G2 at the south area. The zone forms a partly closed sediment cell of limited northward littoral drift by the groyne G2 made in 1930s and G1 made in 1950s as shown in Figure 7.4.1. The coastline changes were small within 45 years (1967-2012) and the beach is stable. The beach will be maintained its stable conditions with the existing groynes G1 and G2. Several groynes and low revetments were constructed after between groynes G1 and G2. The necessity of those groynes to control littoral drift is not observed judging from coastlines changes on both sides of the groynes. There is a possibility that low revetments are disturbing the supply of sand from the reef to beach. Then those groynes and revetments should be removed as unnecessary from the viewpoint of maintaining the beach use and landscape. The coastline changes after removing of those structures are estimated from the numerical coastline change model as shown in Figure 7.4.2. From the results there are expected to be no adverse effects of removal. It is desirable to remove the groynes gradually from the north to the south with monitoring.



Source: Processed by JICA Expert Team based on satellite image obtained from MHL

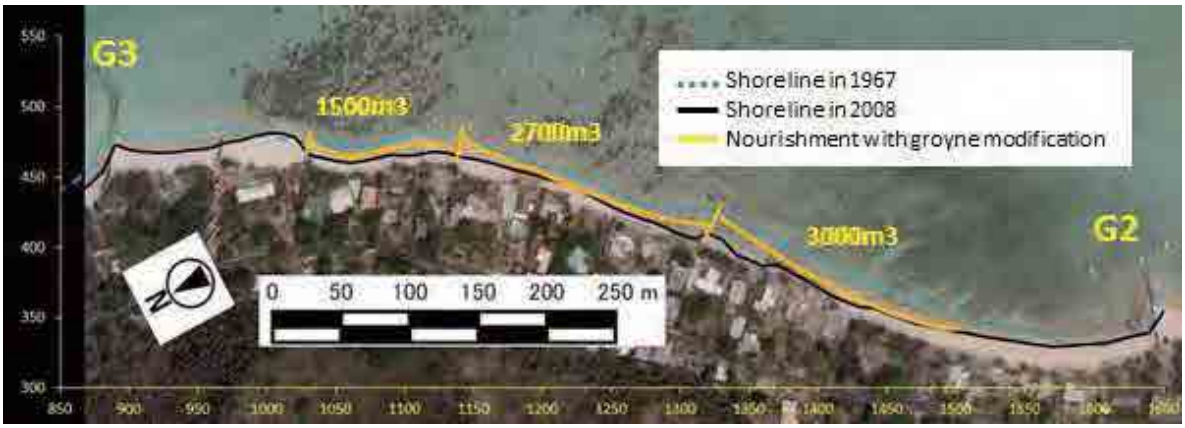
Figure 7.4.1 Plan of Coastal Conservation Measures in Zone 1

Source: Processed by JICA Expert Team based on satellite image obtained from MHL

Figure 7.4.2 Estimated Coastline Changes after Removal of Groynes

b.2 Zone 2

Zone 2 is about 760m and located between existing groyne G2 and G3 at the center area. The zone is the most problem area of the coast. The beach has eroded over a total length of 350m erosion is still in progress. Then the measures are to recover the beach by sand nourishment and to rearrange groynes by improvement, removing or construction for decreasing the loss of nourished sand to the north. The image of the measures is shown in Figure 7.4.3.

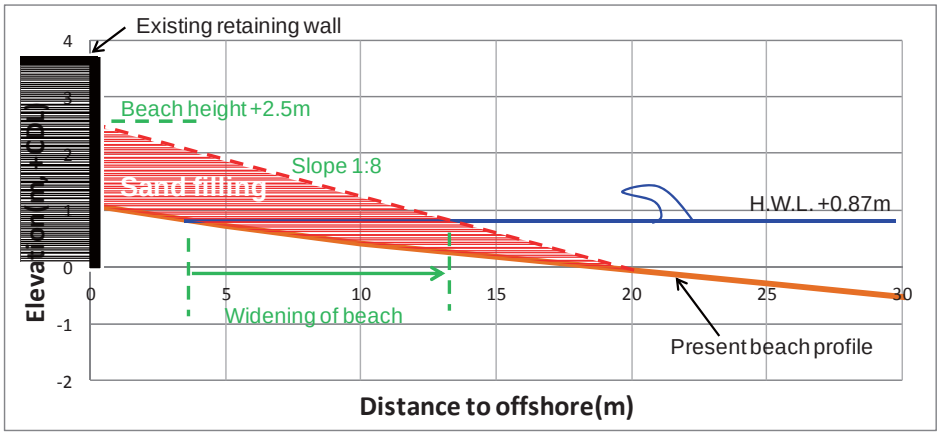


Source: Processed by JICA Expert Team based on satellite image obtained from MHL

Figure 7.4.3 Plan of Coastal Conservation Measure in Zone 2

Sand nourishment

The coastline after the nourishment is targeting the coastline at the time in 1967. In the plan the sand is nourished enough to secure a beach width of about 5m at the narrowest point. The initial estimated volume of nourishment is about 7,500m^3 in such assumption. The height of beach fill is basically the same as the existing one of 2.5m above MSL. The foreshore slope depends on the nourished sand and becomes steeper if the sand is coarser. Here the accumulated sand of 0.3mm in D50 will be used at the north and the slope is about 1:8. The sand source is explained after. The cross section image for proposed nourishment is shown in Figure 7.4.4.



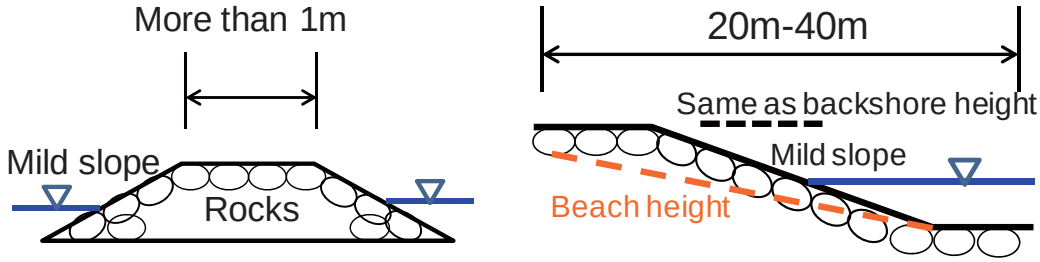
Source: Processed by JICA Expert Team

Figure 7.4.4 Cross Section Image for Nourishment at Zone 2

Groyne arrangement and dimension

The groyne should be arranged to trap the sediment and to improve beach use and landscape based on the estimated coastline formation after the nourishment by the suitable intervals, length, necessary height, section and structure type.

Three existing groynes are improved for the stability of nourished sand and the sand trapping function between groynes taking into consideration the coastal profile, the condition of present erosion, existing groyne arrangement and the boundary of leased areas. The length is set 20 to 40m though it is necessary to carry out a detailed design for the final position and the length. The height is determined by the balance between the sand trapping function with higher one and the damages to the beach use and landscape. At the shore section the height is set the height of natural berm and it is also possible to reduce the crest height toward the offshore. The cross section image for groyne is shown in Figure 7.4.5.



Source: Processed by JICA Expert Team

Figure 7.4.5 Cross Section Image for Groyne

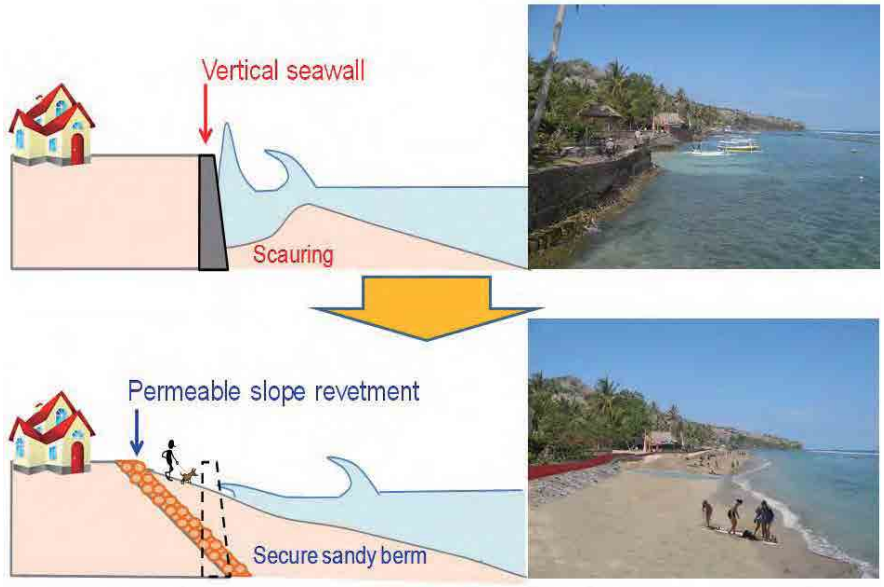
The present groynes are vertical type and cause scouring in their surrounds and trouble with beach access as shown in Figure 7.4.6. The groyne is rubble mound type and the weight of the rock is about 200 to 400kg/unit taking into consideration the stability by the wave action.

Existing revetment improvement

The existing revetments are almost impermeable vertical type as shown in Figure 7.4.7 and are accelerating beach loss in front. It is recommended to move their position as far landward as possible if there is a space between the revetment and the building and to improve it to gentle sloped one like the groyne. It is expected the reduction of scouring caused by the reflected waves and offshore sediment movement. By relocating the revetments further onshore and increasing the width of the beach through nourishment is expected to aid in maintaining the stability of the beach.

Source: JICA Expert Team

Figure 7.4.6 Vertical Groyne and Revetment at the Coast



Source: JICA Expert Team

Figure 7.4.7 Image of Improved Revetment

b.3 Zone 3

Zone 3 is about 1 km long and located between existing groyne G3 and G4 at the north end. In the zone there is a remarkable deposition area at the south of G4 by the blocking the littoral drift to the north. On the other hand at the north of G3 the coastline of about 340 m has been eroded and the lessees constructed revetments or put sand bags and ripraps as protection measures. The groyne G3 caused erosion by the blocking of littoral drift to the north. Groyne G3 will be maintained to stabilize the problem area of Zone 2. Based on the conditions, two measures are proposed as follows.

<Measure 1>: to make stable beach by dividing the 1 km coastline into several sediment cells with nourishment and groyne construction

<Measure 2>: to keep the natural beach and landscape by continuous nourishment because there are no existing groynes, and one end of the beach is eroded and a natural beach is maintained at the other

The rate of longshore sediment transport at Pointe d'Esny is estimated to be about 1,100m^3/y by the sediment budget analysis as shown in Figure 7.2.6. The beach will be maintained basically if the same amount of sand is put at the north of groyne G3. The <measure 2> is recommended because nature friendly ones are required as the basic policy of coastal conservation in Mauritius.

Step-1 Sand nourishment

The <measure 2> requires continuous sand nourishment of 1,100m^3/y on average. In practice the beach condition changes according to coming cyclones. The timing and frequency is decided after considering the efficiency and cost based on the monitoring. It will be about once every three years.

Four small groynes are located over 200m at the north area of G3 as shown in Figure 7.4.8. In case that such four groynes are left, the sand will be filled at the north side of the last northern groyne. On the other hand, there is an alternative that the sand will be periodically filled at the north side of G3 groyne to expect the transportation gradually to the north naturally. This should be determined by the further detail analysis taking into account the opinion of related residents at the hinter area.

The sand should be taken from an appropriate site(s) and transported in terms of maintenance and cost. At the coast about 45,000m^3 of sand was accumulated within 40 years by the blocking of littoral drift to the north caused by G4. We propose the use of the accumulated sand for the nourishment of zone 2 and zone 3. The necessary volume will be about 10,000 m^3 in total. The coastline after the nourishment and nourishment area is shown in Figure 7.4.9. The coastline after the nourishment is a little bit offshore of the coastline in 1967 and there is no impact on the present leased areas. This section of coast is expected to have a sand supply of about 1,000m^3 from the reef. The recovery the beach will continued to be monitored, but it is highly likely that sufficient sand for maintenance will be able to be secured from this site.

Source: JICA Expert Team

Figure 7.4.8 Small 4 groynes at the North of G3

Step-2 Improvement of G3 groyne, setback of existing revetments and vegetation (Figure 7.4.10)

The improvement of G3 groyne is recommended to enhance the effect for sand maintenance at down drift side of groyne. The image of the groyne is as shown in Figure 7.4.11. The shape of the groyne with a curved head is expected to mitigate erosion by dissipating wave energy on the up drift (north) side of the groyne.

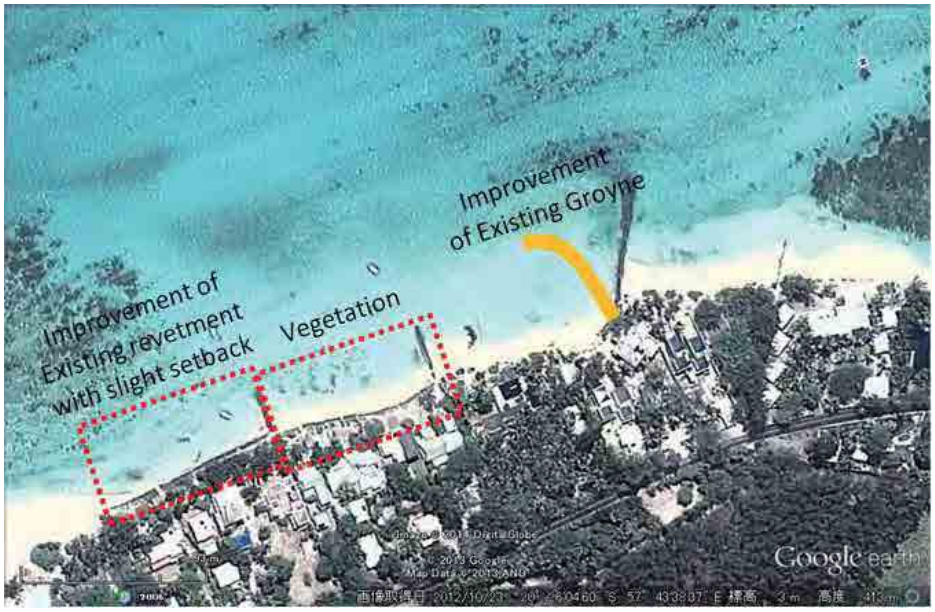
Furthermore, slight setback of the existing revetment and re-plantation of the vegetation (e.g. Veloutier Vert) is recommended to reduce wave reflection and scouring in front of the revetment (Figure 7.4.12). Even if the recommended setback line is not so significant, several

meters, it might be difficult to obtain the agreement of the lessees at present. Public consultation showing the quantitative evidence to explain the expected effectiveness of the proposed measures will be necessary to obtain the agreement for setback. Policies need to be developed for provision of setback at sand accumulated and eroded areas.

The placement of pebbles in front of the revetment is also possibility to improve for securing of public access.

Source: Processed by JICA Expert Team based on satellite image obtained from MHL

Figure 7.4.9 Plan of Coastal Conservation Measures in Zone 3



Source: Processed by JICA Expert Team based on Google map

Figure 7.4.10 Measures for Step-2 at Zone 3

Source: left: JICA Expert Team, right: Google map

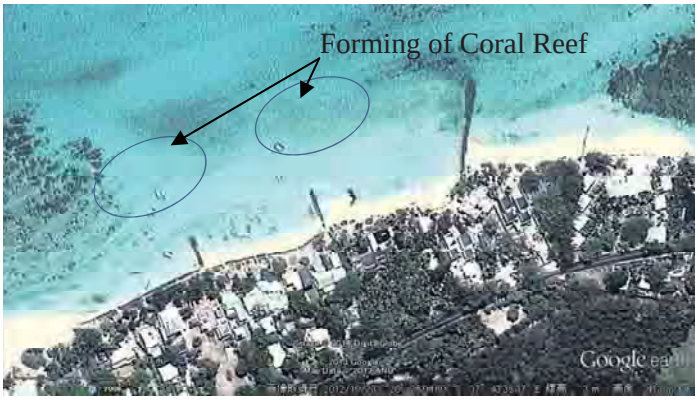
Figure 7.4.11 Image of Curvature Type of Groyne
(Case of Beach Conservation Project in Bali, Indonesia)

Source: JICA Expert Team

Figure 7.4.12 Existing revetment at Retreat Area in Zone 3

Step-3 Restoration of corals or seagrass in the lagoon (after confirmation of applicability)

Restoration of corals or/and seagrass is one of the possibility to reduce wave energy and strong northward current which is observed in accordance with tide change in the lagoon. However it shall be justified the applicability and effectiveness based on the result of experimental field test before planning of full-scale implementation.



Source: Processed by JICA Expert Team based on Google Maps

Figure 7.4.13 Idea for Forming of Coral Reef for Step-3 at Zone 3

c. Process of Public Consultation

The public consultations shall be taken into account when planning coastal conservation measures. Through the demonstration project as non-physical measures, this draft plan proposed by JET will be modified and finalized taking into account local knowledge from lessees.

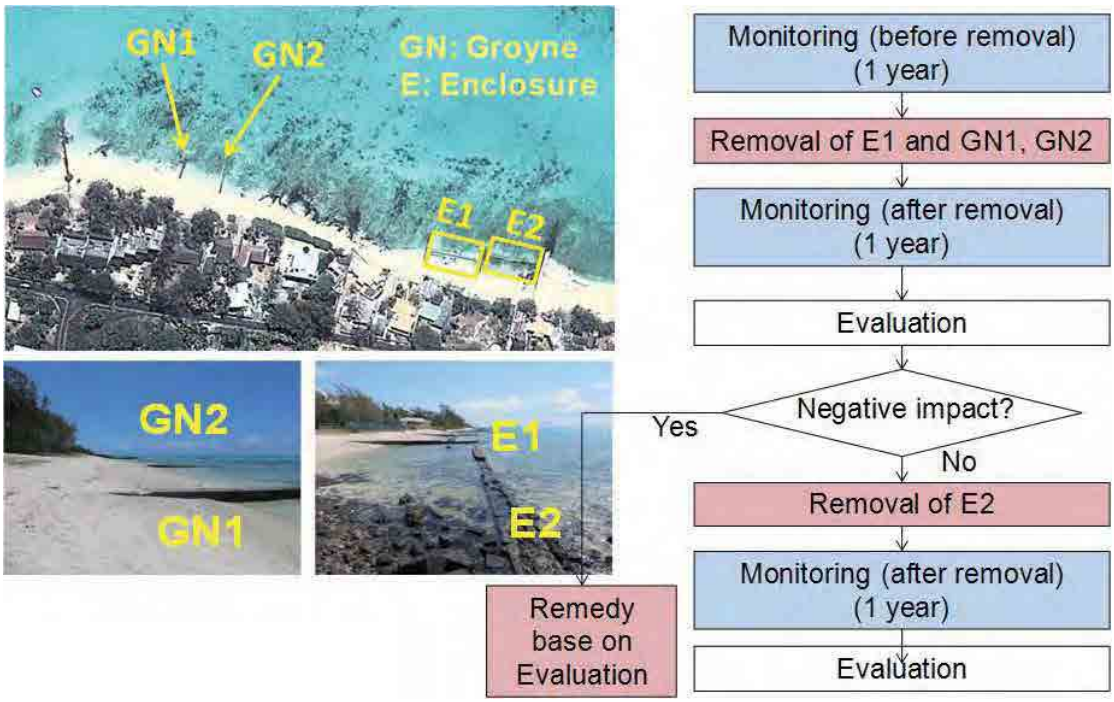
Public consultations were held 4 times as comprehensive meetings and 5 times for individual site meetings with each related lessee. Details of the public consultations are presented in Chapter 8.

d. Short Term Measures (Modified Plan after Public Consultation)

The final plan based on the results from the said several discussions with lessees and their opinions are as explained below by each zone.

d.1 Final plan in zone 1

As a result of the study on coastline change after removal of all structures in Zone 1 through mathematical modeling with a coastline simulation model, no notable changes are foreseen (refer to chapter8). However, in due consideration of uncertainty in change of natural conditions due to removal of structures, the plan will be modified as necessary. The modified plan is to remove structures in a step-by-step manner, not all at once, so that the impact of the removal can be confirmed through monitoring. The outline of the final plan is as presented below.



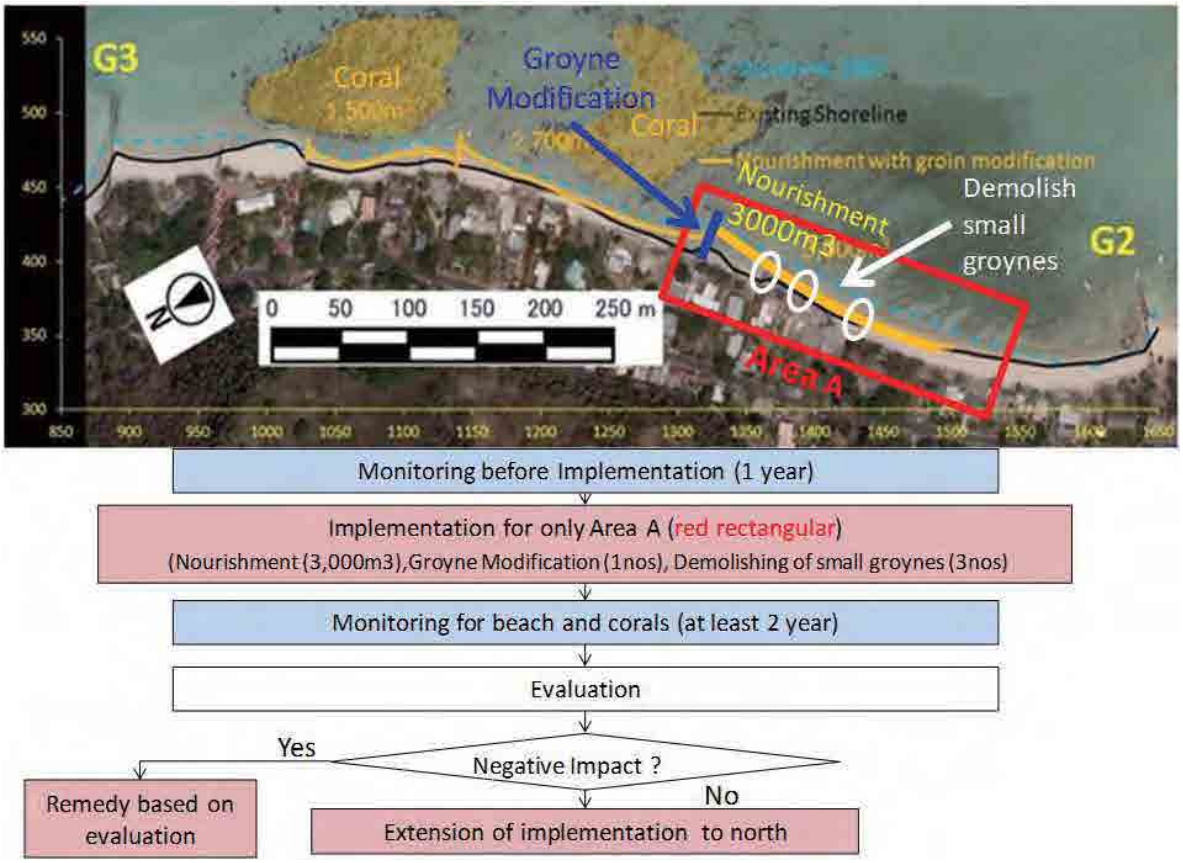
Source: Aerial Photos) Adapted from Google Maps by JICA Expert Team; Others) JICA Study Team

Figure 7.4.14 Final Plan in Zone 1

d.2 Final plan in Zone 2

The measures are to be conducted in a step-by-step manner starting in the area within the red box (in Figure 7.4.15 below), in careful consideration of coral conservation. Impacts on the surrounding environment are to be monitored after the implementation of measures in this area. When no impact is judged to occur due to the said measures, the measures area is to be expanded to the north and confirmation of impacts through monitoring is also to be conducted.

The setback of existing house walls shall be excluded from the plan, because according to the local people there is no available space behind the houses and hence the setback is considered impractical. Artificial beach nourishment shall secure widths of more than 2 to 3 m even at the narrowest area.



Source: JICA Expert Team

Figure 7.4.15 Final Plan in Zone 2

d.3 Final plan in Zone 3 (only Step-1 is modified from the original plan)

Based on public consultation result, recommended plan in Zone 3 is as follows.

Option 1: Sand bypassing using accumulated sand at south part of G4 groyne.

Option 2: taking into consideration the strong objection from lessees at accumulated area near G4 groyne, alternative sources of sand should be sought (Figure 7.4.16 as example)

The current cabinet decree (CAB(2001)12th Meeting-No.574) in Mauritius prohibits sand mining in a lagoon. Therefore, the remaining possible way is to procure the sand (coral sand) from land quarry sites. However, the coral sand is a precious resource and its price is high. In addition, artificial beach nourishment needs periodical maintenance. Therefore, sand procurement from a land quarry site is judged to be impractical in terms of sustainability in consideration of the periodical maintenance.

However, Mauritius is considered to have a high potential of excess sand, such as sand deposited in lagoons (in the north of Pte. d'Esny and off the coast of Grand Sable), sand dredged in channel (Ile aux Cerfs) and offshore sand at passes. It is desirable to examine the possibility of excess sand procurement in Mauritius from technical and institutional standpoints. The preliminary idea is presented in the technical guideline for coastal conservation project in volume 2.

Steps 2 and 3 are the same as those in the original plan (see the original plan).

Source: Adapted from Google Maps by JICA Expert Team

Figure 7.4.16 Example of Sand Potential Area

7.4.4 Long term measures

a. Implementation of monitoring on coral bleaching, and conservation and preservation of good conditions for coral growth

Area of coral community has been increasing since 1996 in this lagoon and has the highest rate of living coral in Mauritius. Coverage of corals is also the highest in this lagoon. Outer water flows into the lagoon by the ocean swells, and water quality is very good. Because the coral bleaching phenomena is caused by not only high seawater temperature but also ultra-violet rays, the coral bleaching phenomena occurs easily in areas of good transparency. So, we need to continue the monitoring survey on seawater temperature and the transparency. The coral coverage is very high in this lagoon, and it seems to be a mother population as a resource of juvenile corals, so we need to conserve and preserve all of the coral communities in this lagoon.

b. Measures for eutrophication improvement

No periodic and continuous water quality monitoring has been conducted so far in the project area and the current conditions of eutrophication which impose impacts on the coral environment are not understood yet. Recently, the aggravation of water quality, in particular near Blue Bay, has been pointed out and monitoring survey of water quality needs to be conducted with high accuracy. Furthermore, the following are also pointed out as the causes of water quality aggravation:

(i) Discharge of domestic waste water resulting from house land development in the rear areas, and

(ii) Discharge of nutritive salt due to usage of chemical fertilizer, etc. following agricultural land development.

In such a situation, it is required to promote behind the coastal areas (i) development of sewerage system and (ii) conversion to efficient purification system as long term measures.

c. Recommendation of setback and review of landuse plan on the occasion of next renewal of land lease contract

Most of the sites do not have a 30m wide buffer zone from HWM as they were developed before 2004 (the year in which setback was increased from 15m to 30m) and also because of (i) coastline retreat due to coastal erosion and (ii) construction of coastline revetment by lessees. Particularly in Zone 2, most of the revetment locations fail to meet this requirement. It has been confirmed through discussions with local people that it is difficult for them to agree on the setback idea, since currently most of them do not have enough land space for setback. In addition, their houses/bungalows are in good conditions, pulling them would not be cost effective. The only chance under the present legal system might be considered in 2068when the next renewal of lease is to be made. However planning for the upcoming 60yrs might not be practical. There is a necessity, as a possibility, to review the land use plan of the coastal areas, taking into account recommendation of the setback on this occasion and impacts on wave and water level rise due to climate change during the period up to this occasion. However, policy decision needs to be taken to review the setback issue and every 20yrs.

7.5 Beach Maintenance Plan

In regard to the beach maintenance and land utilization for Pointe d'Esny, the present issues and the improvement plan are described in Chapter 5 in Volume 1. The issues and the improvement plan for the system and implementation which is common to most of the target beaches are described in Chapter 5 as well.

In this Chapter, several concerns on management for beach conservation are specified. The Beach Conservation Plan of Pointe d'Esny recommends a stabilization of the beach through beach nourishment including sand recycling and re-construction of the coastal facilities such as groynes. Although a reuse of the accumulated sand in northern areas was proposed as sand recycling in the original plan, a part of the residents around the accumulated area have expanded their lease-lands to the newly formed area of sand accretion. There are some neighbors who are in the process of taking the same actions.

According to the Ministry of Housing and Lands that is responsible for the boundary of the lease-land, the expansion of the lease-land in the accumulated area has not been approved. But, in fact, it has already been approved as explained in Chapter 8.4. The complexity of the current inconsistent situation with the setting of the buffer zone between the lease-land and the coastline, namely a setback line setting should be discussed and clarified among relevant organizations as soon as possible. Then the land management should be kept properly based on the consensus and mutual understanding.

As a result of discussions among residents, the sand recycling from the accumulated area will not be planned for the time being because of the above issues on lease-land expansion and utilization of beach in an accumulated area. In such case, it is necessary to purchase sand from the two sand quarries on land because there is no utilizable sand at existing beach. Therefore, it

should be considered how to procure white sand with cheaper price for the beach maintenance. Possible ideas are as follows;

1) Utilization of sand dredging from accumulated areas, e.g. the channel at Ile Cerf

2) Utilization of seabed sand from offshore of reefs

3) Utilization of sand accumulated in the lagoons.

As for the case of 1), it is already planned to utilize the dredging sand from channels. A comprehensive sand management in close coordination and cooperation with relevant organizations are required to reuse the dredging sand.

As for 2), the seabed survey led by MOI in the offshore potential area was started. Further surveys are expected and its outcomes should be shared with the Project. In order to take seabed sand, dredging work on sea with a special ship is necessary, and the whole cost of the beach maintenance will be increased accordingly. Therefore, the implementation plan for the beach maintenance should be prepared taking into account such matters.

As for 3), there has been no sand extraction works in lagoons since sand extraction in lagoons for business purposes was banned in 2000. In the meantime, a large amount of sand has accumulated found in the lagoons. Through the study on possibility of sand extraction in lagoons and environmental impact assessment, further consideration and discussion including a review of the law will be required of the Mauritian government.

The details of such sand management are described in Chapter 5.3 or later in the Volume 1.

Basically, the tenants of the beach in the lease-land area are responsible for the beach maintenance. But the comprehensive measures based on a continuity of sediment transport are drastically different from the various countermeasures that have been taken by individuals. Therefore, the responsibility for the implementation and cost of beach maintenance should be discussed between public and private sector.

Improvement of revetments should be conducted by tenants as usual as long as they are protecting private lands. But their various improvement works may affect the whole system of sediment transport, despite the fact that MOESDDBM currently evaluates and approves each individual plan based on EIA prior to their implementation. In such case, they may have lack of sense on whole beach conservation. So each individual plan should be evaluated in accordance with the comprehensive beach conservation plan developed by the government. In addition, the government needs to explain about the impact, implementation and cost of the improvement works and maintenance for the tenants based on the comprehensive beach conservation plan.

For the groyne, the beach monitoring led by the Mauritian government will be required in order to measure remaining sand continuously. Based on the monitoring results, further countermeasures can be considered accordingly.

7.6 Issues on Implementation

7.6.1 Importance of Continuous Beach Monitoring and Sharing of Information with Lessees

The characteristics of natural conditions, littoral movement has been studied in the Project based on the field investigations, wave current measurement, beach profile survey, etc. The beach process in this coast is influenced by both factors, which are the seasonal change due to change of wind direction and strength, and the impact of cyclones, particularly severe cyclones of a scale which occur once every twenty to thirty years. Even though almost 1-year's beach profile monitoring data was obtained by the Project, it does not cover the impact of cyclones and is still insufficient to know the relation between the process of beach change and driving forces (waves and currents) for beach change. Thus, it is strongly recommended to continue the beach monitoring for long period. Also, it is very important to share the obtained information to the lessees. It is expected to enhance the understanding of beach conservation taking into account the integrated littoral movement and to be easy for consensus building for proposed measures.

7.6.2 Necessity to Perform Detailed Design

The recommended coastal conservation measures are still in the planning level and not the level of detailed design. The detailed prediction for the shape of shoreline and expected sand discharge after the nourishment, detailed arrangement and dimension for supplementary coastal structures, etc. shall be studied in the detailed design stage. After obtaining the consensus of residents for the proposed conservation plan, it is necessary to carry out such detailed design and to prepare the implementation plan.

7.6.3 Establishment of Executed Structure for Project

As mentioned before, the beach management including execution of protection measures and maintenance at lease area is owned by each lessee individually, according to the present beach management system in Mauritius. This management system without integrated point of view on beach conservation was one of the main reasons to accelerate the coastal problem at private lease area. It is necessary to reconsider the appropriate beach management system and budget allocation at private lease areas taking into account the possibility of adopting a policy of public-private partnerships (PPP).

7.6.4 Securing of Sand for Nourishment

The matter of most concern is how to secure sand for initial nourishment as well as for maintenance. At present, the procurement of sand for nourishment is basically limited to only two sand quarry sites, St. Felix and Maconde. However, to purchase and use this sand is not realistic considering the construction and maintenance cost. It is immediately required to start the discussion among the related organizations of how to sustainably secure the sand for nourishment. Necessary investigations and studies shall be started immediately and if necessary, revision of laws or acts related to sand extraction should also be considered.

Chapter 8

Bel Ombre

8 Bel Ombre

8.1 General

The coast is located at the south of Mauritius and receives waves from the south. There is wide reef in front of the coast. The current in the lagoon is fast and some part of sediment flows out through the channels. The coast is actively used by hotels. Coastal forest still exists behind the beach.

8.2 Coastal Conditions

8.2.1 Waves and Tides

The coast receives waves from the southeast trade wind and southwest long southerly swells. The tidal range at a spring tide is 0.86m estimated from the observation at Blue Bay and others. (ref. Vol.1 Ch.2) The water level in a lagoon has to be considered the storm surge and the wave setup together with the tide.

8.2.2 Beach Condition

The beach is formed in front of the lava plateau as shown in Figure 8.2.1 with 500m wide reef. There are several passes on the coral reef. At the west a river flows into the lagoon and is connected to a wide channel in front.

The coast is convex and the sandy beach is not smooth. The alignment of the beach is influenced by presence of rivers, passes, coral and seagrass in the lagoon.

Source: JICA Expert Team modified based on the material from MHL

Figure 8.2.1 Coastal Condition of Bel Ombre and the Position of the Photo

The beach is sandy as a whole and there are several structures on parts of the beach. At the east, a hotel is located and has a revetment as shown in the Photo A of Figure 8.2.2. In front of it three groynes made of rock are located as shown in the Photo B. They are intended to control the longshore current. The retaining wall of the restaurant of Heritage Awali Hotel is

located on the shoreline as shown in Photo C. At the west end, an old sugar storage and a jetty for shipment have been left as shown in Photo D.

Photo A: Revetment at the south

Photo B: Inclined rock groyne

Photo C: Retaining wall of restaurant near HWM

Photo D: Damaged retaining wall at the historic building

Source: JICA Expert Team

Figure 8.2.2 Coastal Condition of Bel Ombre

8.2.3 Reef Environment

By the monitoring survey carried out in 2012, shadow areas in the satellite photos were the seagrass beds of *Syringodium* partly covered with *Halodule* and coverage of living corals was zero inside the seagrass beds. Living coral community was also observed in a narrow area in a passage between seagrass beds and its coverage was 50 %. Density of juvenile coral was zero and natural regeneration by sexual reproduction seems to be low According to the satellite photos, shadow areas offshore of Tamassa Hotel seemed to be coral community and the areas are gradually increased. However, it need to be confirmed hereafter. Monitoring survey has not carried out in back reef, but most of corals seem to be alive because of the condition of corals in the passage mentioned above. Para-surfing is very popular in this lagoon and it seems to be no good for the habitat condition of corals and seagrass.

Source: JICA Expert Team modified based on Google Earth

Figure 8.2.3 Coral Condition at Bel Ombre Studied by Spot Check

The investigation results on water quality and impacts to coral in the lagoon at Bel Ombre are shown in Table 8.2.1. Transparency is 5m and siltation is low. Chlorophyll a, turbidity and nutrients are respectively 0.37 ug/L, 0.88 NTU, 0.04 mg/L for NO_3 and 0.008 mg/L for PO_4 on an average and generally good level as habitat of coral (the coverage of living coral is 20 to 50%). With respect to the water quality of river, compared with that of lagoon, the nitrogen concentration (NO_3in river: <0.13-0.20 mg/L) is several times higher, but the pollution loads from the river is less because the river flow is less. The coast is an underdeveloped district of sewerage system. The most wastewaters are flowing into the coast through onsite treatment plants from the hotels and absorption pit from the houses.

Table 8.2.1 Investigation Results on Water Quality and Impacts to Water Quality in Lagoon

Check items		Conditions
Water quality	Chlorophyll a (ug/L)	0.00-0.85(#) (Ave. 0.37)
	Turbidity (NTU)	0.00-1.24(#) (Ave. 0.88)
	NO_3-N (mg/L)	<0.01-0.05(#) (Ave. 0.04)
	PO_4-P (mg/L)	<0.005-0.02(#) (Ave. 0.008)
Population density behind coast(per km^2)		58
Sewerage disposal behind coast	Status of development of sewerage facilities behind coast	Absorption Pit, Septic Tank, Pit Latrine
	Present condition of sewerage disposal from houses (Sewerage system, Septic tank, Pending arrangement, etc.)	Bel Ombre VCA SS: NIL, AP: 676, ST: 36, PL: 25
	Present condition of sewerage disposal from hotels and restaurants (Sewerage system, Septic tank, Pending arrangement, etc.)	Hotels >75 rooms uses onsite treatment plants. Restaurant uses septic tanks.
	Development plan of sewerage system for houses and hotels behind coast	NIL

Impact of pollution from sugarcane	Incidence of red-soil runoff from land side	Yes. River Mouth Lagoon Width: 832 m			
	Existence of sugarcane field behind coast. If there is it, area of the field behind coast.	Yes. Area: 373 Ha			
Relation between living coral and water quality**	Coral coverage	Chlorophyll a (ug/L)	Turbidity (NTU)	NO_3-N (mg/L)	PO_4-P (mg/L)
	>50%	<0.2	<0.5	<0.012	<0.007
	20-50%	0.2-0.6	0.5-1.3	0.012-0.051	0.007-0.016
	10-20%	0.6-0.9	1.3-1.9	0.051-0.081	0.016-0.023
	<10%	>0.9	>1.9	>0.081	>0.023

#: Observation for water quality and coral reef was conducted from the shore to the reef edge.
**: This relation was obtained by the water quality survey in this study. Refer to Table 2.6.3 in Vol.1.
SS: Sewerage Systems, Ap: Absorption Pit, ST: Septic Tank, PL: Pit latrine
Source: JICA Expert Team

8.2.4 Coast Use

Hotels are located along the beach and a public beach at the west end. The parasailing is popular in the lagoon. At the west end, there are presence of a historic building. The coastal condition is summarized in Table 8.2.2.

Table 8.2.2 Condition of Bel Ombre

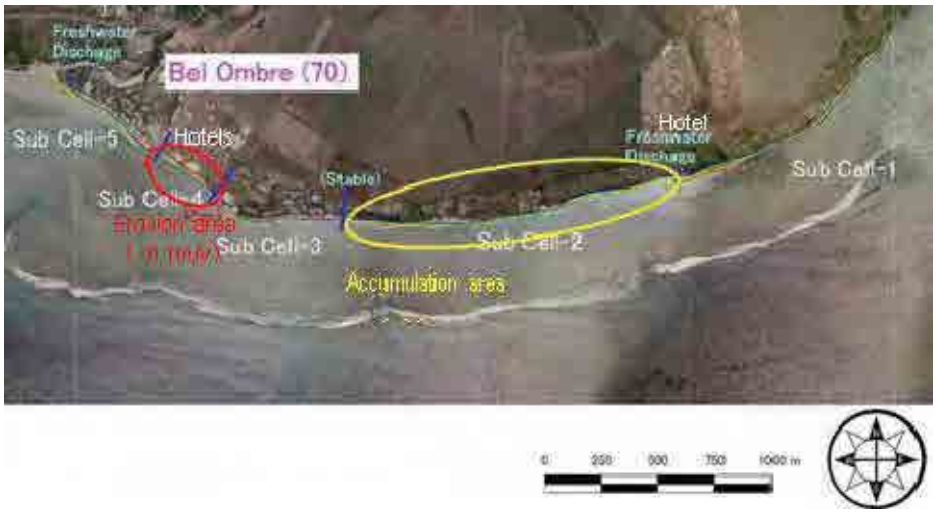
Basic investigation No.	No. 14 (Sediment Cell No.9)	PB No.	No.
Coast name	Bel Ombre		
Natural and topographic characteristics	Sea state	Located on the south side of the island, and affected by waves from the south and southwest.	
	Topography	Sand beach with around 500m-wide lagoon on the south side.	
Environmental characteristics	Coral reef	Near beach, seaweeds flourish and coral reef coverage is 0%. Coral reef coverage behind reef edge is 20%. According to the results of coral reef monitoring by AFRC, coral reef coverage varies widely depending on year and does not show the distinct decline trend from 2000 to 2010.	
	Water quality	Near beach, transparency is 5m and siltation is low. According to the results of water quality monitoring by this study, the parameters were within the environmental standards (standards for type A1 sea areas) in Mauritius and the water quality is relatively good.	
Coastal transformation characteristics	Disaster and structures	The seawalls groins, detached breakwaters (or similarly shaped structures) and one jetty on piles have been observed.	
	Coastal transformation	According to the results of topographic interpretation by aerial photos, coastal erosion with (0.2m/year) has been observed at west side.	
Coastal utilization characteristics	Beach utilization	Utilized for the hotel. The frequency of beach utilization is relatively high.	
General assessment		Coral reef is on the verge of a crisis conflicting with state of reef given above with cover of 50% to revise and still expanding erosion is observed. In front of hotel, the seawall and jetty have been constructed by the hotel. The broad-based protection program should be devised for this coast, because some structure has a potential to foster the coastal erosion and the projection of hotel facility might be implemented.	

Source: JICA Expert Team

8.3 Coastal Process

8.3.1 Shoreline Change

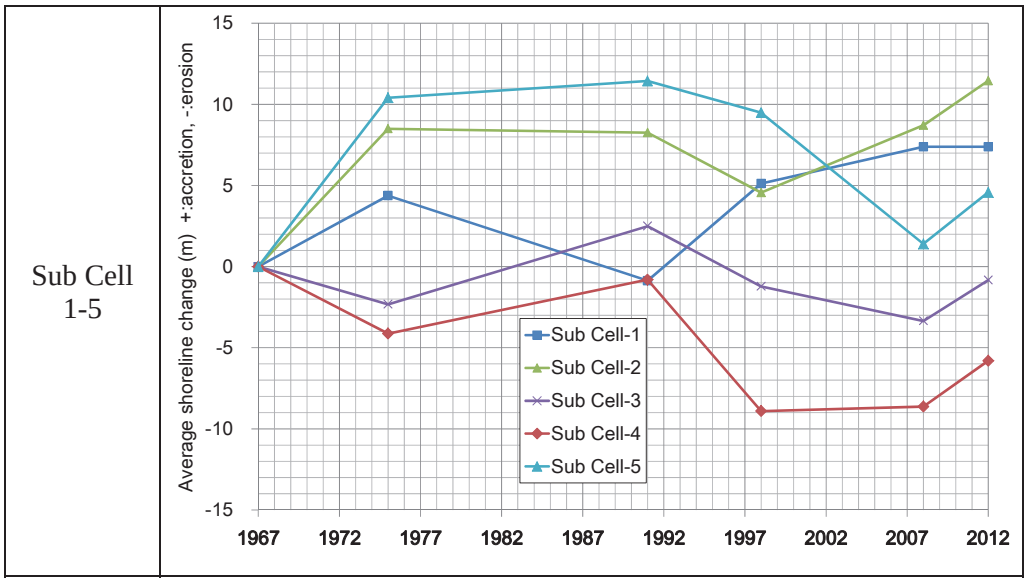
The shoreline change is studied by dividing the coast into 5 sub cells as shown in Figure 8.3.1. In the long term, the sub cell No.4 is eroded, No.2 is accreted and the others are stable.



Source: JICA Expert Team modified based on the material from MHL

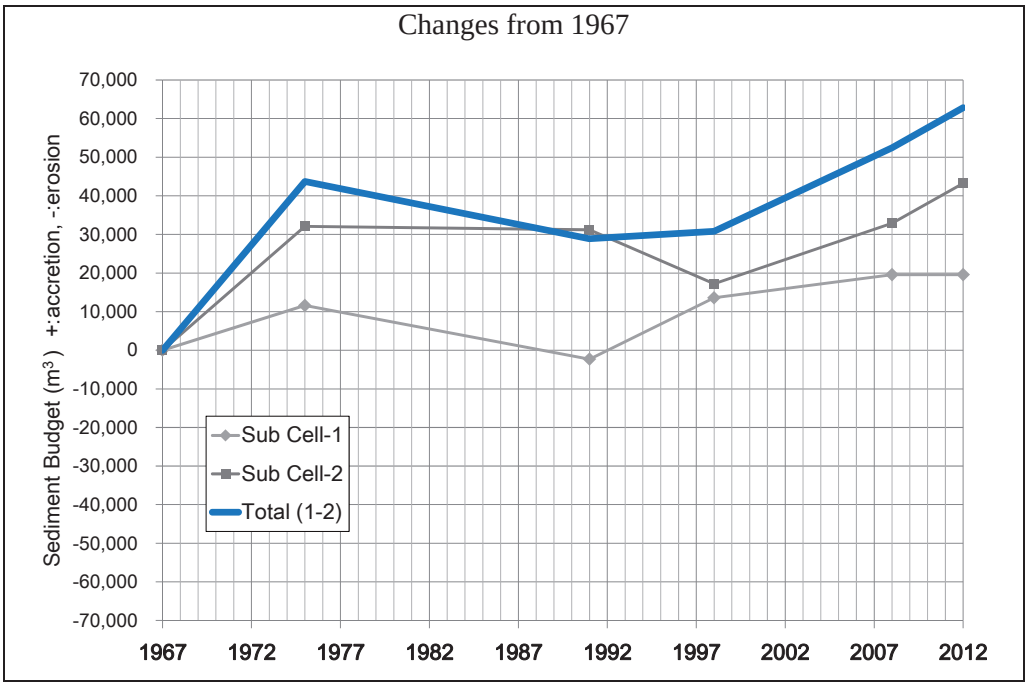
Figure 8.3.1 Location of Sub Cell and Shoreline Changes at Bel Ombre

The temporal shoreline changes are shown in Figure 8.3.2 and the sediment budget is shown in Figure 8.3.3 and Figure 8.3.4. The sub cell No.4 was eroded from 1991 however it is not serious. The erosion at No.4 seems to correspond to the accretion at No.1 and No.2 though the shoreline change is small. Most sub cells are accreted and the volume of accretion becomes about 60,000m^3 within 45 years from 1967 to 2012.



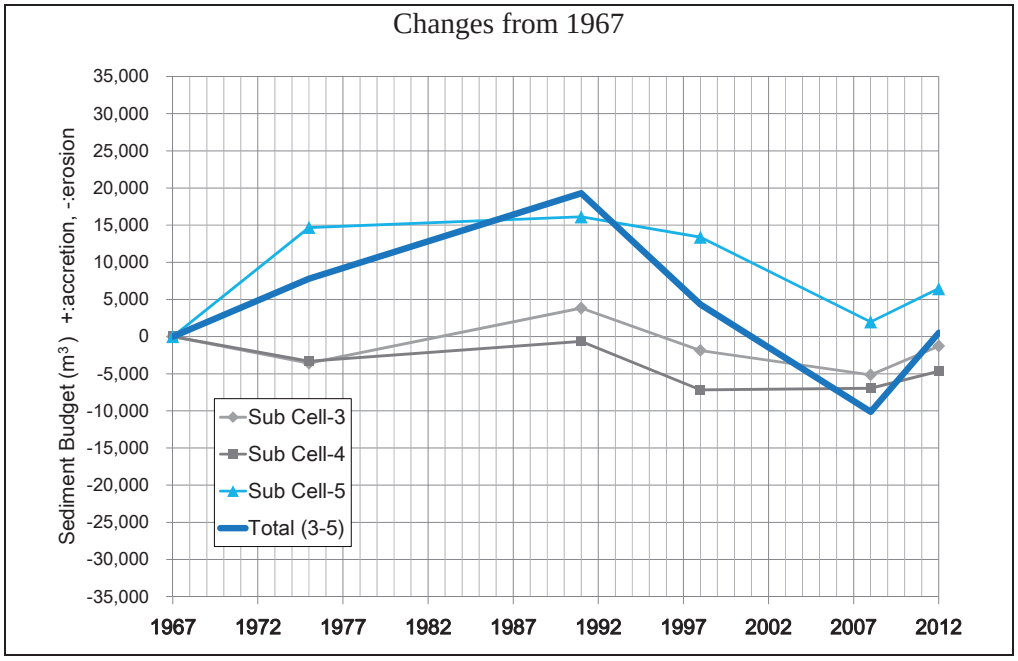
Source: JICA Expert Team

Figure 8.3.2 Shoreline Change at Bel Ombre



Source: JICA Expert Team

Figure 8.3.3 Sediment Budget (Sediment Cell No.9, Sub Cell-1-2)



Source: JICA Expert Team

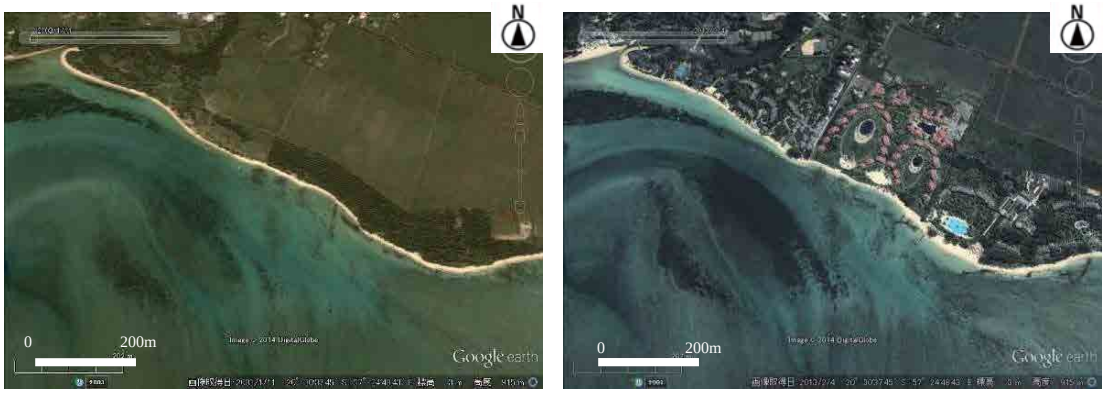
Figure 8.3.4 Sediment Budget (Sediment Cell No.9, Sub Cell-3-5)

8.3.2 Sediment Transport

The coral sand produced at the front edge of the reef is transported to the beach by wave generated current. A part of it is deposited on the beach and the others are transported alongshore. Some parts are lost offshore through the channel and passes. The generation and disappearance of coral and seagrass in the lagoon influence the sand transport.

The seagrass community was seen before 1991 in front of sub cell No.4 where the beach was eroded and decreased after 1991. The relation between the erosion at No.4 and the accretion at No.1 and No.2 suggests the possibility of longshore sediment transport to the east. In this beach, the accretion and erosion are affected by the change of coral and seagrass in the lagoon. The impact of hotels is not clear because it is short period after the construction of 2006. The fact that the erosion occurred before the construction of the hotel suggest other causes of erosion. Large net net fishing is being carried out in this lagoon. Previously, before 2000, the exiting sugar industry was discharging its effluent in the lagoon, high silt content in the wastewater was smothering the corals and the seagrasses. The exact causes of erosion before the year 2000 could not be determined due to lack of information.

The current pattern in the eroded sub cell No.4 shows in Figure 8.3.5 that the longshore current from the east separates into two paths, one is alongshore and the other is offshore to the channel from the trace pattern of sediment. The coastline changes from smooth pattern in 2003 without hotels to eroded in 2013 with hotels. At the hotel area inclined groynes are located and the beach is accreted in the east and eroded in the west. This shows the impact of structures though the erosion is not so large. A river mouth is located at the west side. Sediment is accumulated at the mouth and may cause clogging.



Source: JICA Expert Team modified based on the Google Earth

Figure 8.3.5 Beach Change at Bel Ombre by Sea Grass Change: Left Google Earth 2003, Right Google Earth 2013

8.4 Coastal Conservation Plan

8.4.1 Problems and Related Factors

Beach sand has been lost in a limited area and analysis and its countermeasures are necessary. Hotels are located and there are groynes and revetments on the beach. The impact of those structures is also necessary to evaluate.

The coast is accreting in a whole and the eroded beach is seems to be related the disappearance of seagrass. At present the erosion is not serious. However there are possibly several problems. They are disappearance of seagrass, the impact of revetment and groynes constructed by hotels on the beach erosion and river mouth clogging.

At the south part there is a historic building with vertical retaining wall which has some possibilities to impact sediment transport. Next to the building, people live on seaward side of the coastal road where the ground level is low and has flood risk.

For the long term, they are the decrease of sand supply from coral degradation, the beach changes caused by the change of coral and seagrass in the lagoon and the sea level rise by the climate change. The impacts of tourist activities like kite surfing are also have to considered.

8.4.2 Action Plan

The maintenance of natural condition of the beach is taken as the course of action for the coast conservation plan because public beach and hotels are located. There are a few measures as shown in the Table 8.4.1. They are setback by accepting the dynamic beach changes and beach nourishment to eroded part. The plan of setback is suitable because of the sediment supply from offshore and little sediment loss. A hotel is located at the eroded area and residents are located at accreted area. It is necessary to accept the natural beach changes without any structures. The proposed plan and arrangement is shown in Figure 8.4.1.

The setback distance has to evacuate based on the detail study of beach profile and the condition of buildings together with the agreement of local residents. Setback is proposed based on the available information and basic study results. From the result of past coastline changes the setback of 30m proposed at present is enough from available data.

Table 8.4.1 Alternative Measures at Bel Ombre

Measures	Setback	Beach Nourishment
Outline	In order to reduce the potential erosion with the sea level rise in the future, setback line will be established. Enforcement on land utilization will also be conducted.	Beach nourishment will be conducted to solve long term erosions. The issue is a source of sand to be used for nourishment. It will be necessary to examine if sediment moves offshore through the channel. The possible measures should be examined.
Advantages	There is coast forest behind the beach except the hotel area. Considering the erosion speed and sea level rise in the future, establishing a setback line is effective for the middle and long term measures.	After the beach nourishment, the foreshore width will become wider. The shoreline change is 20 cm/y and the beach nourishment will be effective for a long period.
Disadvantages	There are restaurants and marine facilities at the hotel area. There is a possibility that erosions will occur in the future and damage the existing facilities.	The recycling using sand from accumulated area at the river mouth to eroded areas will not be effective as the sand would continuously move away from the eroded areas towards the river mouth. This is due to the dynamics of the site. Proper investigations for taken sand will be necessary if it is suitable for beach nourishment in quality and quantity.

Source: JICA Expert Team

Source: JICA Expert Team modified based on the material from MHL

Figure 8.4.1 Arrangement of Measures at Bel Ombre

The beach sand is possibly transported offshore because the coastline is convex and there are a few channels on the reef. If accumulation of sediment is found, they can be used as the source of sand nourishment. Recently the beach shows recovering trend. In this case the setback will be suitable measures.

It is necessary to investigate the structural measures which were taken by hotels because the effect and impact is not clear. Monitoring is necessary to evaluate the impacts of groynes. The groynes have been constructed to create swimming zone or sandy beach. The design method is not effective for the control of strong longshore currents like at Bel Ombre. The monitoring gives new measures for this kind of structures.

One of the possibility is the erosion caused by the degradation of coral and seagrass. The regulation of the activity in the lagoon is also one of the measures.

For the river mouth improvement at Le Telfair Hotel, necessary information is not enough such as the river discharge, water level and the change of topographic changes at the mouth. Jetty construction is one of the measures. However it causes beach erosion at the down drift side. Then it is difficult to find suitable measures at present. As the first step, the monitoring has to be conducted by the responsible organizations which include MOESDDBM. The monitoring includes the topographical change at the mouth and the degree of the clogging.

The historic building at the west is better to keep present conditions because the wall is small and exiting for a long time. Large renovation will cause some impacts on adjacent beached. At the west of the building the ground is low and inundation will occur by flooding or high waves. Then the land use has to be regulated and the relocation of residents will be suitable.

As for the immediate efforts as the short-term countermeasures at the coast, it is necessary to conduct the water quality monitoring with high precision analysis to grasp the detail

conditions of eutrophication. As for the medium- and long-term countermeasures, it is necessary to promote the conversion of more efficient sewerage systems.

8.5 Coast Maintenance Plan

8.5.1 Maintenance Problems

Source: JICA Expert Team

Figure 8.5.1 Position of Setback Line and Hotel Facility at Bel Ombre

8.5.2 Maintenance Plan

Hotel Heritage Awali exists on this beach and the restaurant run by this hotel is located close by shoreline in front of the hotel. The foreshore hardly exists in front of the restaurant. The positional relation between the restaurant and setback line is verified based on previous aerial and satellite photographs. Although the restaurant is not in aerial and satellite photographs from 1997 to 2000, it can be seen in satellite photograph in 2008. A line of HWL is put on the satellite photograph in 2008 and then from a line of HWL as starting point, lines with 15 m and 30 m from HWL are added on the land side. As the result, it proves that the restaurant and a part of swimming pool are located between HWL and setback line with 15m. On the other hand, the guest room is located at land side of setback line with 15m. It seems that the restaurant and swimming pool was constructed without permit. If hotel facilities were constructed after 2004, the facilities not only the restaurant and swimming pool but also guest rooms do not follow setback rule because setback rule was renewed from 15 m to 30 m from HWL in 2004 and guest rooms are located in setback area with 30 m. It is necessary to carry out demolition or relocation of these facilities through discussion between hotel and related institutions after checking construction year and date of approval of EIA at every facility. In addition, this section shows improvement plan against present beach management issues of the beach as follows.

a. Existing coastal facility issues

- Modification of revetment from vertical type to sloping permeable type with

plantation

- Demolition and modification of groins depending on effective

b. Existing facilities/structures issues in dynamic beach zone

- Control and management of boundary at accumulated area. The boundary should not be shifted to offshore side
- Demolition and relocation by verifying location and construction data of existing facilities and structures by aerial and/or satellite photos.

c. Formation of scarp issues

- Enhancement of monitoring system under cooperation with institutions concerned
- Management of plantation on the beach

d. Removal of sand grass/creepers

- Enhancement of awareness of importance of sand grass to lessees by using leaflet, etc.
- To add protection and conservation of sand grass/creepers in lease agreement

e. Lack of drainage system

- Preparation of drainage to plan by confirming to the road rehabilitation and improvement plan behind coastal zone
- Installation of soak away type drains between parking areas/road side and public space

f. Other issues

- Include sensitization of hotel management on importance of seagrass and coral reef
- Regular maintenance of beach profile
- Relocation of the residential area located at the flood level.
- Control of nautical activities within the lagoon
- Zoning of the lagoon – implementation of VMCA -voluntary marine conservation area

8.5.3 Validity of Setback Amount

The setback amount for eroded sand beach is configured as summation of the amount of erosion during a certain period, the amount of erosion which is caused by strong wave such as cyclones in that period, and the erosion due to the SLR (sea level rise) is anticipated in future which is described as following.

Amount of setback = Amount of erosion for a long period + Amount of erosion by temporally event (i.e. extreme weather conditions such as cyclones) + Erosion amount due to SLR

There are several proposed equations to estimate the amount of erosion due to the SLR. Among these, the equation proposed by Per Bruun is applied generally. The equation is as follows.

E=C×S, where, E: erosion amount due to the SLR, C: coefficient of beach characteristic and S: amount of SLR.

The rate of the SLR from 1987 to 2011 is about 3.9mm/year in average, and the coefficient of C, which is related with the inverse of sea-bottom slope and transportation area of sediments, is set as 10 by the mean sea-bottom slope in Mauritius. The erosion amount due to the SLR, therefore, is calculated as 1.6 m by multiplying averaged erosion rate of 3.2mm/year, the coefficient of 10, and the period of 50years (E=10×3.9mm/year×50years=2m).

The amount of setback becomes 20m if the period is assumed 50 years, the erosion rate of 0.1m, and temporally erosion at the maximum caused by Cyclone Carol of 13m. (Refer Vol.1 Ch. 2). The amount of 20m is the below the present value of 30m.

Amount of setback= 0.1*50+13+2=20m

Chapter 9

Le Morne

9 Le Morne (Hotel sites)

9.1 General

The site is on the southwest coast of Mauritius and surrounded by reefs. In general, accumulation is expected along the coast. There is an artificial channel and a training wall, which hamper long-shore sediment transportation and as a result, erosion takes place on the beach down drift. Groynes were constructed to prevent erosion more than 40 years back. The beach is used for public purposes and tourists. The site also forms part of is a world heritage site. There are 4 public beaches in the area.

The coast is facing to the west and receives waves by cyclone from the north and southeast trade winds. On a yearly basis, long southerly swells travel from the South Pole and reach the coast. The tidal range at a spring tide is 0.5m estimated from the observation at Port Louis. The water level in a lagoon has to be considered the storm surge and the wave setup together with the tide.

9.2 Coastal Conditions

9.2.1 Beach Condition

The coast is formed at the foot of Mount Le Morne by the coral sand, as a peninsula. The lagoon is 500m wide at the west and wider at the north and south. Accumulated sand connected an island at the north to the mainland. There was a channel between the island and the main land. There is a channel on the reef offshore with a trace of the remains as a small channel.

The beach condition is shown in Figure 9.2.1 and the old channel was located at the boundary of sub cell No.1 and No.2 with a jetty at the entrance of the channel. The beach is eroded at north and accreted at the south of the jetty. On the north end sediment moves along the beach and deposits at the back. The public beach is located at the middle of the beach and sometimes beach scarp is generated during storm surges.

Source: JICA Expert Team modified based on the material from MHL

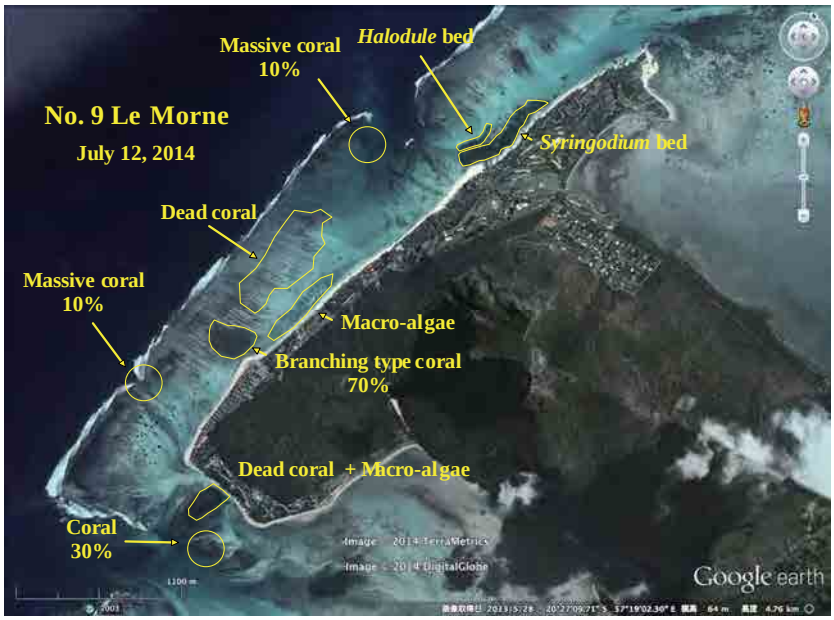
Figure 9.2.1 Coastal Condition at Le Morne

Source: JICA Expert Team

Figure 9.2.2 Coastal Condition at Le Morne: Left Erosion at the groyne (Photo A), Right Beach Scarp at the Public Beach (Photo B)

9.2.2 Reef Environment

Area of living coral decreases and area of seagrass increases at present in comparison with the aerial photographs and charts analyzed them in 1996. Coral community in back reef seemed to be alive in 1996 and there was a possibility of mass mortality during the coral bleaching event in 2003. Coverage of living coral was zero by the survey using Spot Check (SC) method carried out in October, 2012. Coral bleaching event in 2003 also seems to be mortality factor. Transparency was over 15 m and siltation was not observed at the time. Direct observation using glass bottom boat, coral community dominated by branching *Acropora* was observed with 70 % in coverage, and also seagrass beds of *Syringodium* and *Halodule* were also seen in this lagoon as shown in Figure 9.2.3. However, coral community in the shore reef at south tip was alive in 1996, but died and macro-algae grew thick on the skeleton of corals. Dense beds of macro-algae indicate eutrophication in the lagoon, but water condition seemed to be still good as habitat for corals. Coral community dominated by branching *Acropora* as donor was seen in the lagoon and it is also good condition for transplanting of corals in the same lagoon. Para-surfing is very popular in the beach of south tip and it is anxious about its effect on the coral community.



Source: JICA Expert Team

Figure 9.2.3 Coral and Seagrass Condition at Le Morne Studied by Glass Boat

The investigation results on water quality and impacts to coral in the lagoon at Albion are shown in Table 9.2.1. Transparency is 15m with no siltation. At nearby Ile aux Benitiers, transparency is 5m and siltation is a moderate. Chlorophyll a and turbidity are respectively 0.37 ug/L and 0.66 NTU on an average and generally good level as habitat of coral (the coverage of living coral is 20 to 50%). The coast is an underdeveloped district of sewerage system. The most wastewaters are flowing into the coast through onsite treatment plants from the hotels and absorption pit, septic tank and pit latrine from the houses.

Table 9.2.1 Investigation Results on Water Quality and Impacts to Water Quality in Lagoon

Check items		Conditions			
Water quality	Chlorophyll a (ug/L)	0.25-0.58(#) (Ave. 0.37)			
	Turbidity (NTU)	0.11-1.10(#) (Ave. 0.66)			
	NO_3-N (mg/L)				
	PO_4-P (mg/L)				
Population density behind coast(per km^2)		60			
Sewerage disposal behind coast	Status of development of sewerage facilities behind coast	Absorption Pit, Septic Tank, Pit Latrine			
	Present condition of sewerage disposal from houses (Sewerage system, Septic tank, Pending arrangement, etc.)	Le Morne VCA SS: NIL, AP: 148, ST: 156, PL:107			
	Present condition of sewerage disposal from hotels and restaurants (Sewerage system, Septic tank, Pending arrangement, etc.)	Hotels >75 rooms uses onsite treatment plants. Restaurant uses septic tanks.			
	Development plan of sewerage system for houses and hotels behind coast	NIL			
Impact of pollution from sugarcane	Incidence of red-soil runoff from land side	None			
	Existence of sugarcane field behind coast. If there is it, area of the field behind coast.	None			
Relation between living coral and water quality**	Coral coverage	Chlorophyll a (ug/L)	Turbidity (NTU)	NO_3-N (mg/L)	PO_4-P (mg/L)
	>50%	<0.2	<0.5	<0.012	<0.007
	20-50%	0.2-0.6	0.5-1.3	0.012-0.051	0.007-0.016
	10-20%	0.6-0.9	1.3-1.9	0.051-0.081	0.016-0.023
	<10%	>0.9	>1.9	>0.081	>0.023

#: Observation for water quality and coral reef was conducted from the shore to the reef edge.
**: This relation was obtained by the water quality survey in this study. Refer to Table 2.6.3 in Vol.1.
SS: Sewerage Systems, Ap: Absorption Pit, ST: Septic Tank, PL: Pit latrine
Source: JICA Expert Team

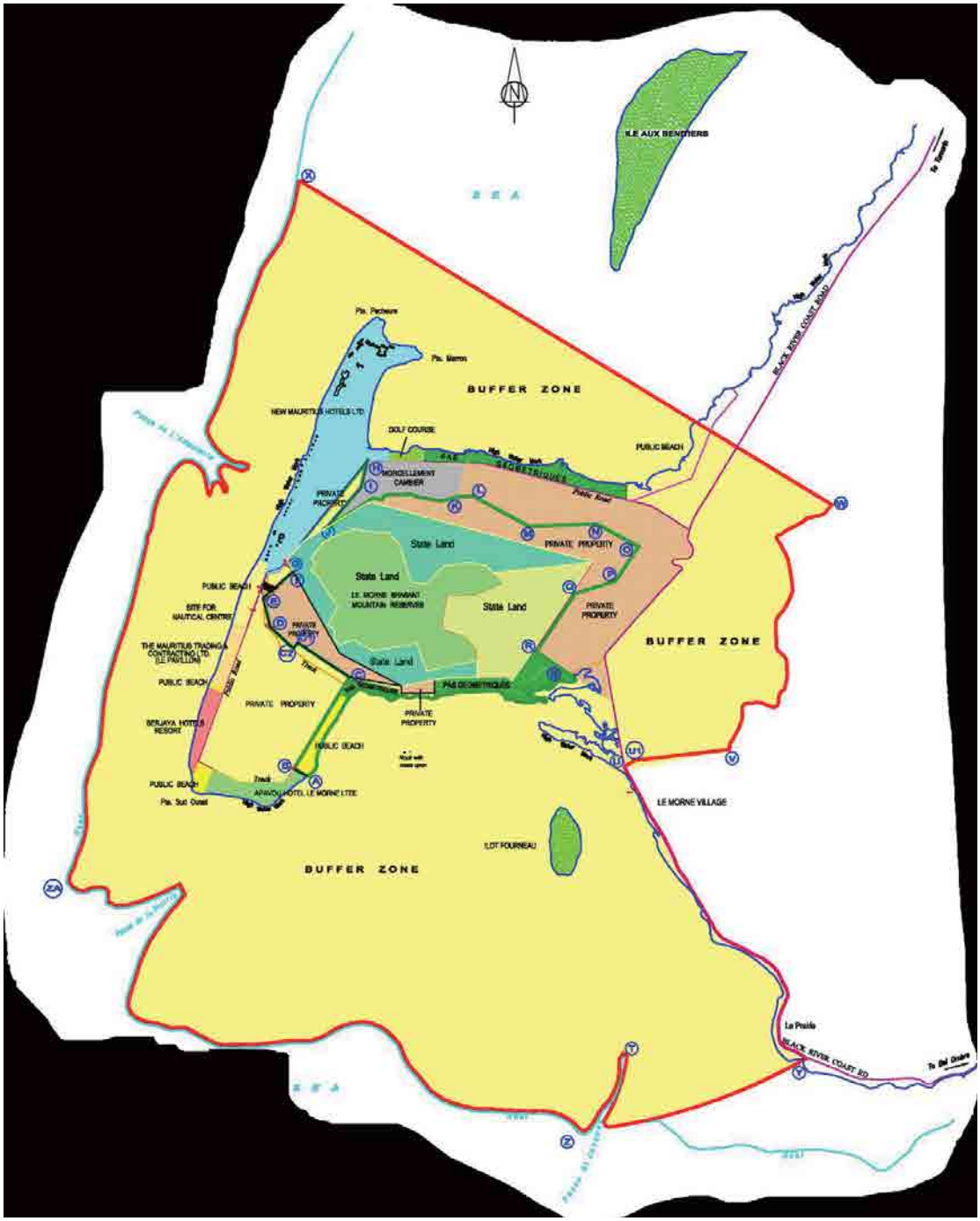
9.2.3 Coast Use

Hotels and a public beach is located along the coast. In the lagoon, kite and wind surfing is popular because of the good wind condition at the south part. The coast was inscribed as the Le Morne Cultural Landscape (LMCL) of World Heritage Sites in 2008 by UNESCO. The Lagoon Management plan was formulated in 2013 as a part of overall Le Morne Cultural Landscape Management Plan 2014-2019. In the plan the beach and lagoon were included in the buffer zone as shown in Figure 9.2.4.

In the plan ten management strategy and related action plan was formulated. The items related to the coastal conservation are as follows. (Source: Le Morne Cultural Landscape

Lagoon Management Plan Ver.1, 2013, Le Morne Heritage Trust Fund (LMHTF))

- Protect important sensitive ecosystems and biodiversity
- Ensure water quality suitable for public use and for the functioning of ecosystems and quality of the natural environment
- Identify and develop opportunities for local economic development through improved management of the Lagoon



Source: Le Morne Cultural Landscape Lagoon Management Plan Ver.1, 2013, Le Morne Heritage Trust Fund (LMHTF)

Figure 9.2.4 Core and Buffer Zone of Le Morne World Heritage Site

The coastal conditions are summarized in Table 9.2.2.

Table 9.2.2 Condition of Le Morne

Basic investigation No.	No. 16 (Sediment Cell No.10)	PB No.	No. 73.,74,75
Coast name	Le Morne		
Natural and topographic characteristics	Sea state	Located at the edge of the southwest and affected by waves from the southwest	
	Topography	Sand beach with around 650 to 900m-wide lagoon on the front Convex sand beach. The slope of beach berm is around 1/8. The medium diameter of sea bed material within coral reef is around 0.6 mm and that near the coral reef edge is coarse slightly.	
Environmental characteristics	Coral reef	Behind reef edge, coral reef coverage is 0% and algal coverage is 20%. According to the results of coral reef monitoring at Ile aux Benitiers by AFRC, it gathers that coral reef coverage near reef edge is on a declining trend from 2000 to 2010.	
	Water quality	Transparency is 15m and siltation is little. Lagoon water exchanges with open sea due to the strong wave and wind. Then water quality is relatively good.	
Coastal transformation characteristics	Disaster and structures	Damaged by Cyclone Carol (in 1960) Even now, scarps are observed following cyclone events.	
	Coastal transformation	According to the results of topographic interpretation by aerial photos, a lot of places are on a sedimentation trend and this beach is regarded as stable. At the north side of a groyne near Paradis Hotel, coastal erosion with erosion rate of 25 cm/year occurs. Further, the results of the field work show scarps are observed in PB.	
Coastal utilization characteristics	Beach utilization	Utilized as PB (public beach), where the hotel and guest house are available. Also this coast is famous for kite surfing and a good coast road is provided.	
General assessment		As a whole, though this beach is on a stable trend, erosion occurs in some place due to the construction of training wall. The protection program by the non-physical measures including maintenance management plan should be considered. Further special attention should be considered because of active utilization of the beach as well as the hinterland.	

Source: JICA Expert Team

9.3 Coastal Process

9.3.1 Shoreline Change

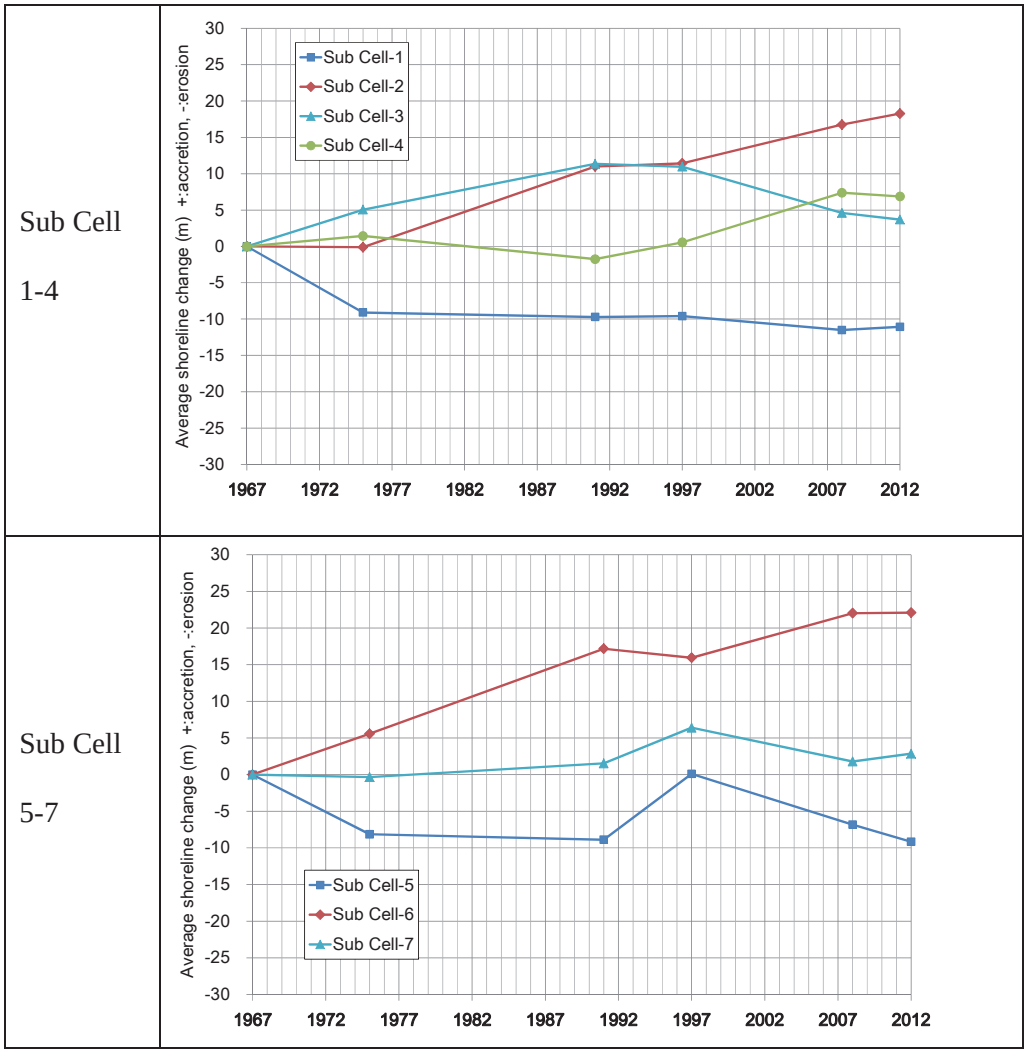
The coast is divided into 7 sub cells from sub cell No.1 at the north to No.7 at the south as shown in Figure 9.3.1 and the temporal changes of shoreline are shown in Figure 9.3.2. The total sediment budget becomes increase of about 50,000m^3 within 45 years from 1967 to 2012.

Source: JICA Expert Team modified based on the material from MHL

Figure 9.3.1 Study Area and Results of Shoreline Change at Le Morne

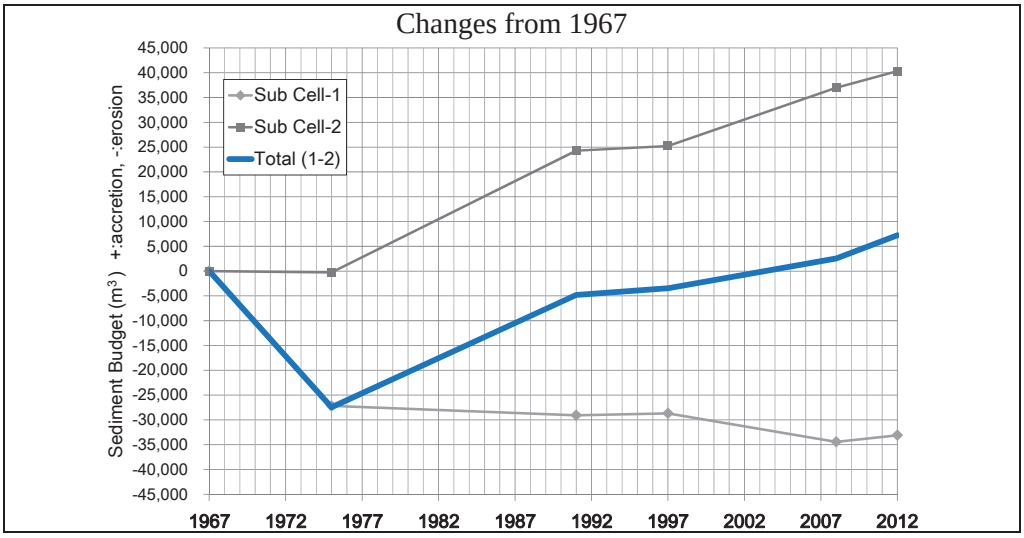
The erosion was caused at sub cells No. 1 at the north and No.5 at the south of the peninsula and others were accreted. The erosion at No.1 was about 10m from 1967 to 1975 and it becomes stable in the after. At No.2 the beach was accreted continuously 15m from 1967 to 2012. At the No.3 the beach shows the same tendency as at No.1 until 1997 and was eroded in the after. In total the beach is still accreted from 1967. At No.4 the beach was stable before 1997 and accreted in the after. The change seems corresponding to those of No.3.

At No.5 the beach was changed as eroded in 1975, accreted in 1997 and again eroded in the after. At No.6 the beach shows the same tendency as No.2 of accretion of 20m from 1967. At No.7 the beach shows stable and gradual accretion.



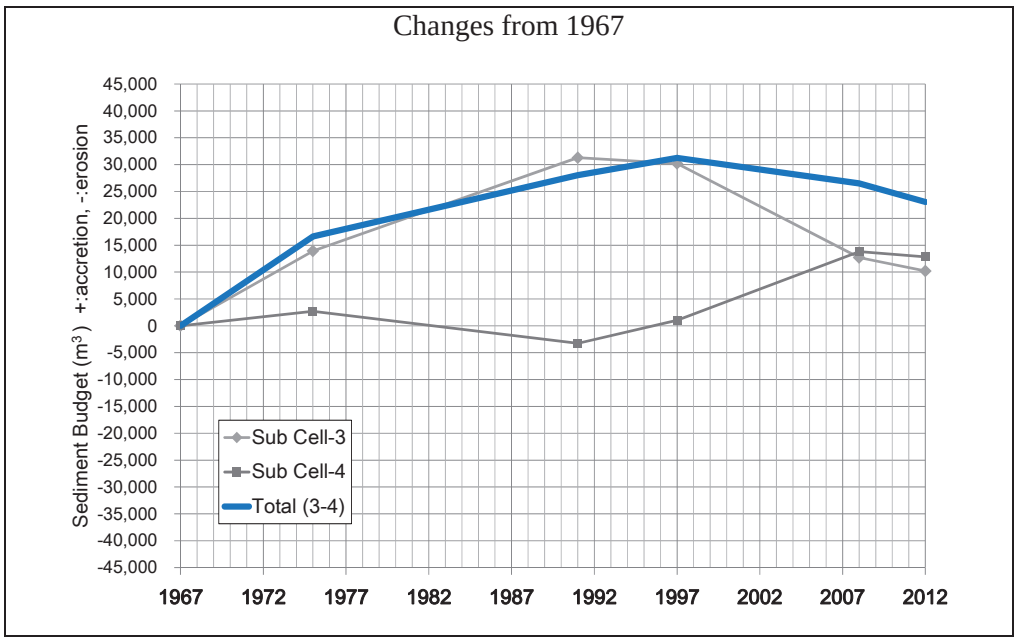
Source: JICA Expert Team

Figure 9.3.2 Shoreline Change at Le Morne



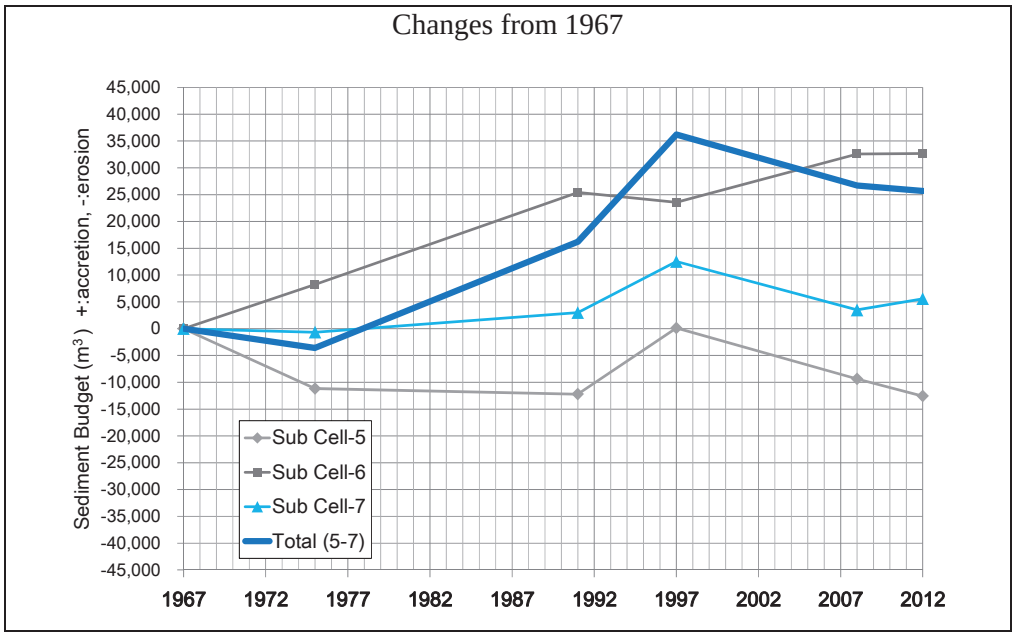
Source: JICA Expert Team

Figure 9.3.3 Sediment Budget (Sediment Cell No.10, Sub Cell-1-2)



Source: JICA Expert Team

Figure 9.3.4 Sediment Budget (Sediment Cell No.10, Sub Cell-3-4)



Source: JICA Expert Team

Figure 9.3.5 Sediment Budget (Sediment Cell No.10, Sub Cell-5-7)

9.3.2 Sediment Transport

The coral reef in front of the beach supplies coral sand to the beach. The sand is transported alongshore and deposited at the north and south of the peninsula. A part of the sand moves through the channel or passes offshore. The coral and seagrass caused beach changes according to its wave dissipation effects.

At the south the beach was accumulated as shown in Figure 9.3.6. The photo in 1967 shows no

changes along the coastline. Accumulation started around 1997 by the formation of shallow area of coral or sea grass and in 2008 sand bar was formed behind of the area along the coast of 200m. The movement of sediment is from the reef edge to onshore as shown by the trace of bottom sediment and separated to both sides to the north and south. There were no shallow areas in the photo of 1967. The shallows dissipate wave energy and brought accumulation by the sediment movement from offshore.

Source: JICA Expert Team modified based on the material from MHL

Figure 9.3.6 Accretion at Le Morne south: left 1967 and right 2008

The beach was eroded at the north of the jetty as shown in Figure 9.3.7. Groynes were constructed and accumulated sand was bypassed for erosion measures. Shallows of seagrass are located parallel to the beach just offshore. At the area the current directs to the south offshore of the shallow and to the north between the shallow and the beach estimated from the trace of bed material. It suggests that there are some interactions between the shallow and the beach changes. The seagrass of shallow contributes to dissipate wave energy and to stabilize the beach. However the shifting of the shallow to the beach brings beach erosion because the longshore current keeps a certain distance between the shallow and the beach.

Source: JICA Expert Team modified based on the material from MHL

Figure 9.3.7 Beach Change at Le Morne north: left 1967 and right 2008

The sediment movement is estimated from the response between coral and seagrass changes and the beach changes. The sand produced at the fore edge of the reef moves to the beach and to the north or south alongshore. The movement to the north was blocked once by the jetty. The beach at the south of sub cell No.2 was accreted and eroded at the north of No.1. Severe erosion was not happened by the passing of sand at the tip of the jetty, the sand bypassing and the construction of groynes. The seagrass on the front also contributes to stabilize the beach.

At the south side from No.2 to No.4 the beach was accreted continuously. After 1997 the growing of coral patch at No.4 caused accretion behind and temporary erosion at the down drift side of No.3. The sand moved to the south seems to be lost through the channel located at the end of the peninsula.

9.4 Coastal Conservation Plan

9.4.1 Problems and Related Factors

The beach erosion has been caused at the down drift side of the jetty and accretion at the up drift side by the control of alongshore sediment movement though the beach is accreting in a whole. Also the beach changes according to the appearance and disappearance of coral and seagrass. If structures are built in a dynamic zone, sometimes they cause beach erosion. Then regulation is necessary. In the lagoon the conservation of coral and seagrass is necessary because the nautical activities and large net fishing may cause the degradation of them.

The channel and jetty were constructed by the hotel owner and it blocks longshore sediment transport. The beach situated north of the channel has a phenomenon of erosion. The hotel is dredging the channel and dredged sand is used for beach nourishment for the northern beach. Demolishing the jetty may become a measure for erosions, but it causes erosion at the southern area.

The coast is accreting in a long term and the problems are limited. For the long term the degradation of coral which is the source of sand, the change of coral and seagrass in the lagoon and the impact of climate change have to consider.

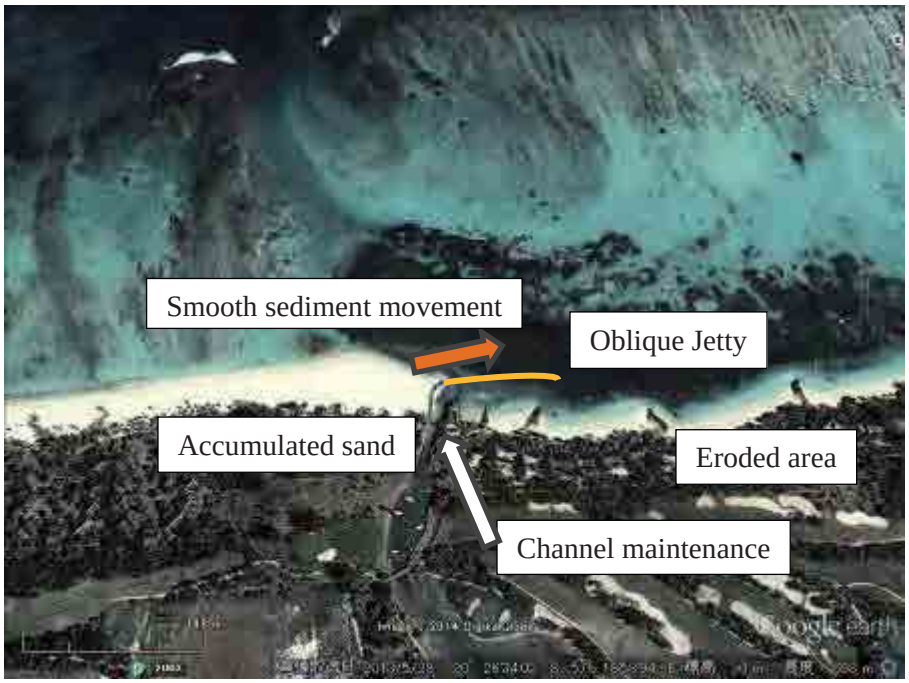
9.4.2 Action Plan

The maintenance of natural condition of the beach is taken as the course of action for the coast conservation plan because public beach and hotels are located. The coast has accreting trend with continuous reef and is expected sediment supply. In some part the beach is eroded. However the scale to the erosion is small. Then the measures proposed is to keep the present conditions.

For the long term the coral will be planted at the start of coral conservation in the future. The water quality is good and the coral coverage is high at present. The regulation of the lagoon started for the lagoon management as Le Morne Landscape Management. Then the coral plantation is suitable and will be done by MoF.

The erosion has been caused by the jetty which maintains the opening of an anchorage. Already sand has been bypassed from accreted area to the eroded beach by one of hotels. Then it will be continued as short term measures. There are shallow area by the coral or sea grass and sediment moves between the shallow and the beach. The shallow area decrease waves. The erosion is possibly corresponding to the formation of the shallows.

As one of the measures the improvement of the jetty to smooth one for long term measures as shown in Figure 9.4.1. The alignment of the jetty has to be investigated after the monitoring of the beach changes and the longshore current. If the sediment moves between the shallow and the beach, the beach can be maintained at the down drift side. Also the groynes can be removed in some cases. At the channel, sediment deposits in the calm area in some degree and it is necessary to dredge for maintenance. The deposition will be smaller than at present. Several studies are necessary to apply the plan and will be done by the hotel.



Source: JICA Expert Team modified based on the material from MHL

Figure 9.4.1 Channel Maintenance Plan at Le Morne

If we consider the sea surface temperature rise by the climate change, coral plantation will become necessary in Mauritius. The coast is suitable for this purpose such as Pte. d'Esny because the transparency is high and the exchange of water is good with the outside of the reef. Also the lagoon is located in the buffer zone of Le Morne Landscape site. The ocean current flows from the south to the north at the reproduction period of coral. Then the area is important for the supply of coral larva.

At present except a part of coral community the coverage of live coral is low in the reef. It is necessary to plant for the expansion of coral together with the conservation of existing coral. It is necessary to monitor after the coral planting.

For the seagrass there is no big problems because the area is increasing and the monitoring is necessary.

At the south of reef, wind surfing is popular. It is necessary the coexistence of other tourist activities and the conservation of natural environment such as the zoning with information exchange of related people.

In connection with the transplantation of coral and seagrass, it is necessary to conduct the water quality monitoring with high precision analysis to grasp the detail conditions of eutrophication in the lagoon as the short-term countermeasures. Based on the monitoring results, if necessary, the conversion of more efficient sewerage systems will be promoted such as the improvement of wastewater treatment facilities for the medium and long term countermeasures.

9.5 Coast Maintenance Plan

9.5.1 Maintenance Problems

There are several problems for the coast maintenance as shown in Figure 9.5.1. The dredging work is carried out for pleasure boats in the channel between hotels at least once a year. The dredged material is stocked on the beach. The erosion occurs in the north side of the channel.

Hotels already constructed. Many cars and motorcycles were parked on the backshore of the public beach because they could come and go freely at the coastal forest. But car parking issue was improved because car barriers were installed behind the beach during this study. On the other hand, cars are still parked on the backshore in the south side of the public beach. This activity has an influence on environment and utilization such as impacts on trees and marine organisms, car exhaust, reduction of utilization space and accidents to the beach users.

Rainwater drainage from landside washes away sandy beach locally.

Jetty along the Channel of the Hotel

Hotel Construction at the Eroded Site

Parked Cars at the Back Shore

Drainage and Erosion at the Public Beach

Source: JICA Expert Team

Figure 9.5.1 Problems of Beach Maintenance at Le Morne

9.5.2 Maintenance Plan

It is necessary to manage and control the wide-area longshore sediment transport because movement of supplied sand to the down-drift is blocked due to construction of training wall and periodic dredging works in the channel.

Although car parking issue is gradually changing for the better after installation of car barriers in some beaches, but car and motorcycle parking issue are still seen at many public beach in Mauritius. It is recommended that parking space should be prepared in the whole Mauritius in a step-by-step manner considering various impacts.

It is necessary to prepare a drainage plan behind the coastal zone, especially at the area where local scouring of sandy beach occurs due to rain drainage. This section shows improvement plan against present beach management issues of the beach as follows.

a. Existing facilities/structures issues in dynamic beach zone

- Control and management of boundary at accumulated area. The boundary should not be shifted to offshore side
- Demolition and relocation by verifying location and construction data of existing facilities and structures by aerial and/or satellite photos.

b. Construction of new facilities/structures issues in dynamic beach zone

- Enforcement unit be set up at level of MHL and DC to monitor construction within the dynamic beach zone

c. Plantation issues on the beach

- To set up suitable arrangement and composition of beach vegetation
- Selection of suitable species of plantation (native species as much as possible)

d. Dreading issues in coastal area

- Continuous periodic monitoring
- Evaluation of monitoring data which is submitted by lessees

e. Lack of drainage system

- Preparation of drainage to plan by confirming to the road rehabilitation and improvement plan behind coastal zone
- Installation of soak away type drains between parking areas/road side and public space

f. Vehicle access issues into public beach

- Step-by-step upgrading of parking space in the whole Mauritius
- Installation of sign and information board, shrubs and flower trees as boundary

Source: JICA Expert Team

Figure 9.5.2 Setback Line and Hotel at Le Morne

9.5.3 Validity of Setback Amount

The setback amount for eroded sand beach is configured as summation of the amount of erosion during a certain period, the amount of erosion which is caused by strong wave such as cyclones in that period, and the erosion due to the SLR (sea level rise) is anticipated in future which is described as following.

Amount of setback = Amount of erosion for a long period + Amount of erosion by temporally event (i.e. extreme weather conditions such as cyclones) + Erosion amount due to SLR

There are several proposed equations to estimate the amount of erosion due to the SLR. Among these, the equation proposed by Per Bruun is applied generally. The equation is as follows.

E=C×S, where, E: erosion amount due to the SLR, C: coefficient of beach characteristic and S: amount of SLR.

The rate of the SLR from 1987 to 2011 is about 3.9mm/year in average, and the coefficient of C, which is related with the inverse of sea-bottom slope and transportation area of sediments, is set as 10 by the mean sea-bottom slope in Mauritius. The erosion amount due to the SLR, therefore, is calculated as 1.6 m by multiplying averaged erosion rate of 3.2mm/year, the coefficient of 10, and the period of 50years (E=10×3.9mm/year×50years=2m).

The amount of setback becomes 25m if the period is assumed 50 years, the erosion rate of 0.2m, and temporally erosion at the maximum caused by Cyclone Carol of 13m. (Refer Vol.1 Ch. 2). The amount of 25m is the below the present value of 30m.

Amount of setback= 0.2*50+13+2=25m

Chapter 10

Flic en Flac

10 Flic en Flac

10.1 General

The beach faces the west, forming a dune and is surrounded by a narrow lagoon of 500m wide. The sandy beach is extended and the public beach and hotels exist behind the beach, characterized by one of the main tourist spots in Mauritius. Residential development occur on the landward side of the public beach in an ex sand land quarry.

10.2 Coastal Conditions

10.2.1 Waves and Tides

The coast is located at the west of Mauritius and receives waves mainly from the south west and during cyclonic months from the north side. The tidal range at a spring tide is 0.5m estimated from the observation at Port Louis. The water level in a lagoon has to be considered the storm surge and the wave setup together with the tide.

10.2.2 Beach Condition

The beach is convex and formed in front of the lava plateau as shown in Figure 10.2.1 with 500m wide lagoon. There are channels at the both end for the flow out of the longshore current and small passes on the coral reef. At the west two small water courses flows into the lagoon. They are Hilton River Marousem and Maradiva tributary of River Marousem.

Source: JICA Expert Team modified based on the material from MHL

Figure 10.2.1 Coastal Condition and Change at Flic en Flac (Cell No.11)

Mainly at the south hotels are located. A vertical revetment was constructed at the Gold Beach Hotel where the beach is narrow as shown in the Photo A of Figure 10.2.2. At the north wide beach is extended as shown in the Photo B. At the north a public beach, restaurants, shops and houses are located and hotels at the south.

Source: JICA Expert Team

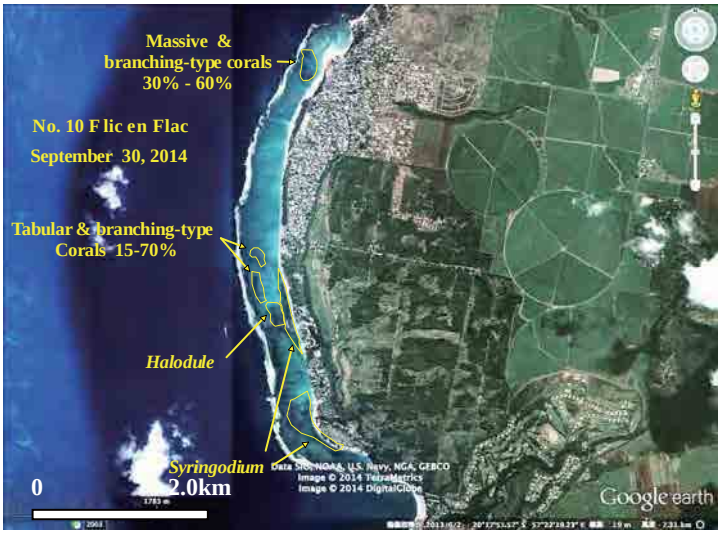
Figure 10.2.2 Coastal Condition at Flic en Flac： Left Revetment in front of Lease Area (Photo A), Right Beach Use (Photo B)

10.2.3 Reef Environment

In the north lagoon of Flic en Flac, there was the widest patch reef dominated by massive *Porites* and branching *Acropora*. Coverage of corals was estimated from 30 to 60 % by the monitoring surveys. Massive *Porites* and branching *Acropora* were observed on the small patch reefs surrounding sand bottom. Transparency was 5 m and siltation was low. By the evaluation criteria, the coral reef in the north lagoon was evaluated as “slightly poor” or “good”. Seagrass bed and macro-algal bed were rare in the north lagoon.

In the central lagoon, just offshore at the south tip of the public beach, living corals were rare with many skeletons and transplantation experiments were carried out by MOI and MOESDDBM

While, patch reefs dominated by tabular- and branching-*Acropora* were seen in the south lagoon. Living corals at the back reef of the south lagoon were alive in 1996, but the areas of living corals decreased over time. Coverage of coral communities at the central lagoon and slightly south lagoon kept high value from 60 % to 75 %, but their areas are decreasing gradually. Seagrass beds of *Syringodium* and *Halodule* were scattered in the south lagoon. The area of seagrass bed at the south tip did not changed in these 18 years, but the area of seagrass bed in front of Sugar Beach Hotel increased.



Source: JICA Expert Team modified based on Google Earth

Figure 10.2.3 Coral and Seagrass at Flic en Flac Studied by Glass Boat

The investigation results on water quality and impacts to coral in the lagoon at Flic en Flac are shown in Table 10.2.1. Transparency is 8m at Flic en Flac and 5m at Wolmar near Tamarin River and siltation is relatively low. Chlorophyll a in the vicinity of the coast is 0.5 ug/L and is generally good level as habitat of coral (the coverage of living coral is 20 to 50%). According to the results of water quality monitoring by AFRC, coliform is relatively low state (less than 100 MPN/100 ml). There is no sewerage system and most wastewaters are flowing into the coast through onsite treatment plants from the hotels and AP (absorption pit), ST (septic tank) and PL (pit latrine) from the houses.

Table 10.2.1 Investigation Results on Water Quality and Impact to Water Quality in Lagoon

Check items		Conditions				
Water quality	Chlorophyll a (ug/L)	0.50(*)				
	Turbidity (NTU)	-				
	NO_3-N (mg/L)	-				
	PO_4-P (mg/L)	-				
Population density behind coast(per km^2)		104				
Sewerage disposal behind coast	Status of development of sewerage facilities behind coast	Absorption Pit, Septic Tank, Pit Latrine				
	Present condition of sewerage disposal from houses (Sewerage system, Septic tank, Pending arrangement, etc.)	Flic en Flac VCA: SS: NIL, AP: 1294, ST: 1975, PL: 6				
	Present condition of sewerage disposal from hotels and restaurants (Sewerage system, Septic tank, Pending arrangement, etc.)	Hotels >75 rooms uses onsite treatment plants. Restaurant uses septic tanks.				
	Development plan of sewerage system for houses and hotels behind coast	In pipeline for development, Study stage				
Impact of pollution from sugarcane	Incidence of red-soil runoff from land side	Yes. River Mouth Lagoon Width: 446m				
	Existence of sugarcane field behind coast. If there is it, area of the field behind coast.	Yes. Area: 1,635 Ha				
Relation between living coral and water quality**	Coral coverage	Chlorophyll a (ug/L)	Turbidity (NTU)	NO_3-N (mg/L)	PO_4-P (mg/L)	
	>50%	<0.2	<0.5	<0.012	<0.007	
	20-50%	0.2-0.6	0.5-1.3	0.012-0.051	0.007-0.016	
	10-20%	0.6-0.9	1.3-1.9	0.051-0.081	0.016-0.023	
	<10%	>0.9	>1.9	>0.081	>0.023	

*: Observation for water quality was conducted close to shore.
**: This relation was obtained by the water quality survey in this study. Refer to Table 2.6.3 in Vol.1.
SS: Sewerage Systems, Ap: Absorption Pit, ST: Septic Tank, PL: Pit latrine
Source: JICA Expert Team

10.2.4 Coast Use

The public beach on the coast is used widely by tourists and local residents. Along the coastal road, hotels and restaurants are located. Housing has been developed at the low land and connected hill at the north. In some area the ground is below the level of the coastal road. In the lagoon tourist activities are popular such as jet skiing and large nets fishing is also being

carried out.

The coastal conditions are summarized in Table 10.2.2

Table 10.2.2 Condition of Flic en Flac

Basic investigation No.		No. 17 (Sediment Cell No.11)	PB No.	No. 79,80,81,82,83
Coast name		Flic en Flac		
Natural and topographic characteristics	Sea state	Located at the west side of the island and affected by waves from the south-west during most of the year and north during cyclonic season		
	Topography	Convex sand beach with around 500m-wide reef on the front. The slope of beach berm is within a range of 1/8 to 1/10 and the grain size of sea bed material with 0.3 mm of medium diameter is fine relative to the other beaches.		
Environmental characteristics	Coral reef	Coral reef coverage ranges from 1 to 30%. The coverage tends to become lower near the river-mouth (Black River, Grand River Noire).		
	Water quality	Transparency is 2.5 to 8m. Siltation is high at Preneuse and low at Tamarin and Flic en Flac. According to the results of water quality monitoring by AFRC, water quality at Tamarin and Flic en Flac is relatively good. Meanwhile, water quality at Preneuse is affected by Black River and is polluted.		
Coastal transformation characteristics	Disaster and structures	Gabions (in 1995, a total length of 700m), groynes (in 1995, 10 units), removal of the seawall (in 2007), implementation of sand bypass (in 2008), and removal of the gabions (in 2008)		
	Coastal transformation	According to the results of topographic interpretation by aerial photos, the south side of the Pearle Beach is stable. But the north side is erosion area with erosion rate of 12cm/year and scarps are observed in Manisa PB. In the area extending from Manisa to Villas Caroline, sand spit at the north end is on a sedimentation trend with a rate of 48 cm//year is. It seems that scarps easily occur on this coast. In the case of the cyclone in January 2013, a scarp of around 1.5m occurred.		
Coastal utilization characteristics	Beach utilization	Utilized as PB (public beach) as well as hotels. For tourism purposes most of the hinterland is a tourist spot where restaurants and shops are located. At its inland side, there are houses.		
General assessment		This coast is one of the most popular tourist spots on the island, and both beach and hinterland are intensively utilized. Countermeasures against scarps are important because of the troubles in utilization and safety. In light of these facts, a protection program should be considered for this coast.		

Source: JICA Expert Team

10.3 Coastal Process

10.3.1 Coastal Change

a. Shoreline Change

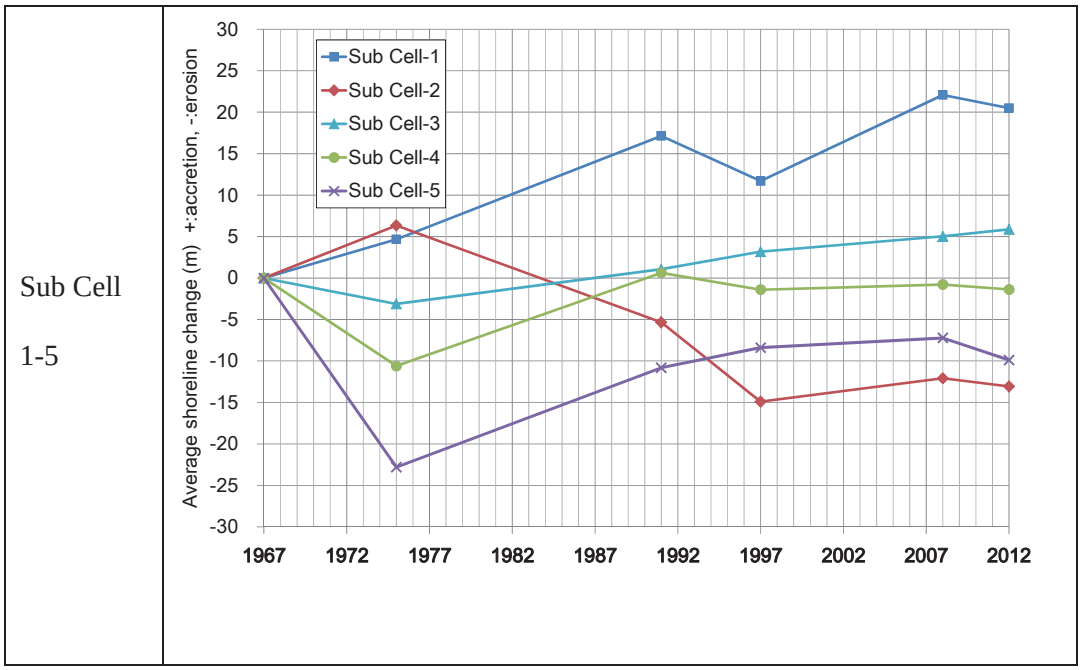
The coast is divided into 5 sub cells as shown in Figure 10.3.1 and the change of shoreline is shown in Figure 10.3.2. The beach was accreted at sub cell No.1 and eroded at No. 2 in the long term and others at the south were stable or accreted.

The temporal shoreline changes are shown in Figure 10.3.2. The sub cell No.1 at the north is accreted continuously and reached 20m of accretion. On the centrally the sub cell No.2 is eroded from 1975 and becomes over 10m erosion. The accretion at No.1 corresponds to the erosion at No.2. There is no large changes at No.3 and No.4 for a long term with small tendency of accretion. Sub cell No.5 at the south end shows erosion in 1975 and recovering tendency in the after. Though it not recovered to the shoreline of 1967.

The sediment budget is about 20,000m^3 of accretion within 45 years from 1967 to 2012. The accretion at No.1 is 60,000 m^3 and the erosion at No.2 is 40,000 m^3. The others are balanced.

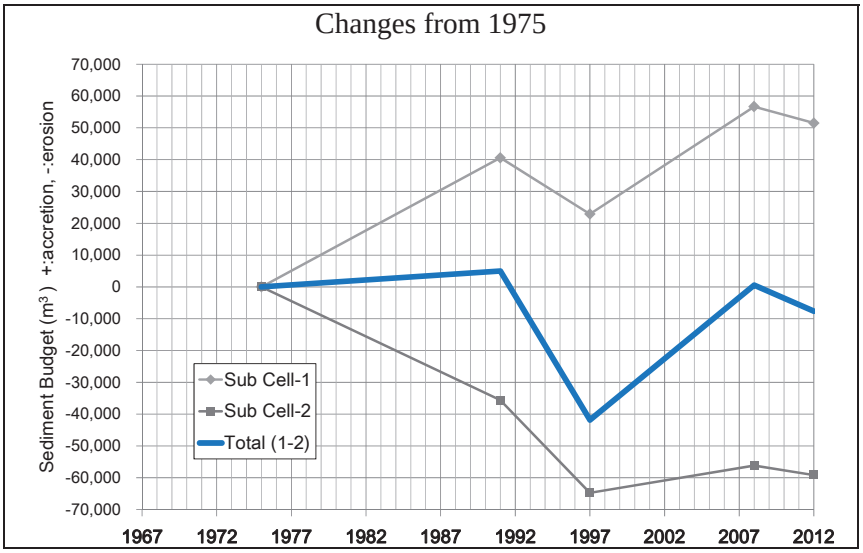
Source: JICA Expert Team modified based on the material from MHL

Figure 10.3.1 Study Area and Results of Shoreline Change at Flic en Flac



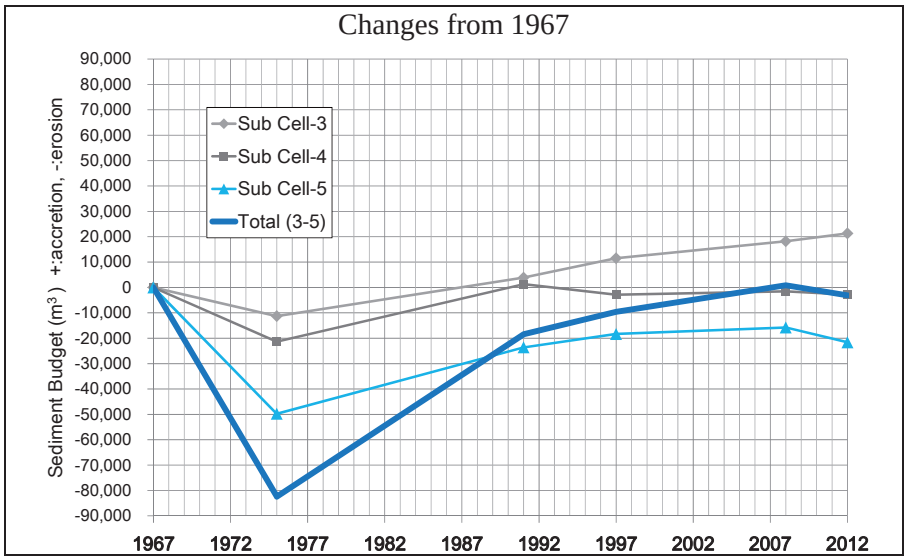
Source: JICA Expert Team

Figure 10.3.2 Shoreline Change at Flic en Flac



Source: JICA Expert Team

Figure 10.3.3 Sediment Budget (Sediment Cell No.11, Sub Cell-1-2)



Source: JICA Expert Team

Figure 10.3.4 Sediment Budget (Sediment Cell No.11, Sub Cell-3-5)

b. Beach Monitoring

The beach has been monitored regularly to know the beach profile changes. Eleven transects were set along the coast of 4.5km from the south of FEF-1 to the north of FEF-11 as shown in Figure 10.3.5. The beach was measures at about 3months interval.

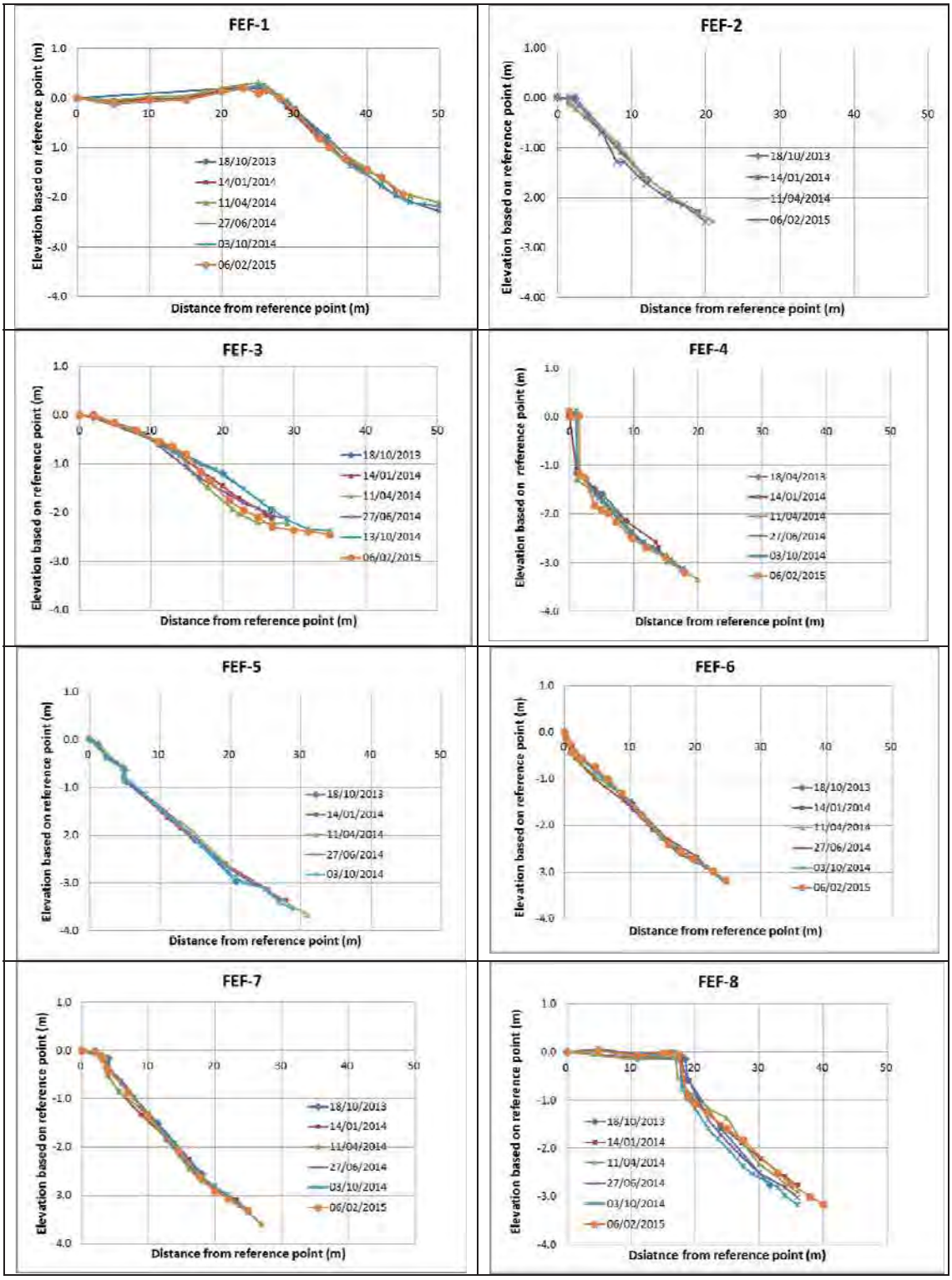
Source: JICA Expert Team modified based on the material from MHL

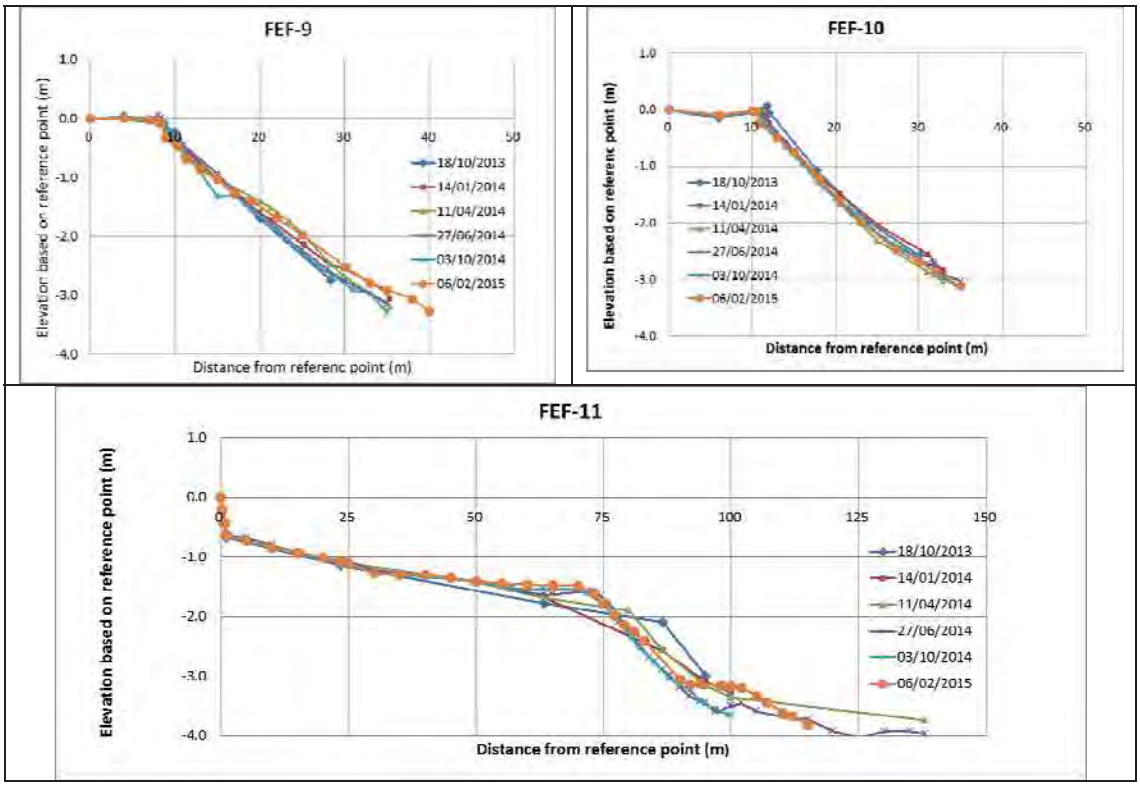
Figure 10.3.5 Arrangement of Transect for Beach Monitoring

The monitoring results of 6 times from November 2013 to February 2015 are shown in Figure 10.3.6. The transects from FEF-1 to FEF-3 are located in the stable site of long term changes, from FEF-4 to FEF-8 in the eroded site and from FEF-9 to FEF-11 in the accreted site. The profile at accreted site is gentle and steep at eroded site. The elevation is relative height and not the ground level above MSL.

The temporal changes of sectional area from the area at November 2013 as a baseline are shown in Figure 10.3.7. Here, the characteristics are the seasonal change and the difference of changes at each transect. The beach at transects FEF-3, FEF-7 and FEF-10 was eroded from October 2013 to May 2014 and accreted from May 2014 to October 2014. Reversely at transects FEF-5, FEF-8 and FEF-9 the beach was accreted from October 2013 to May 2014

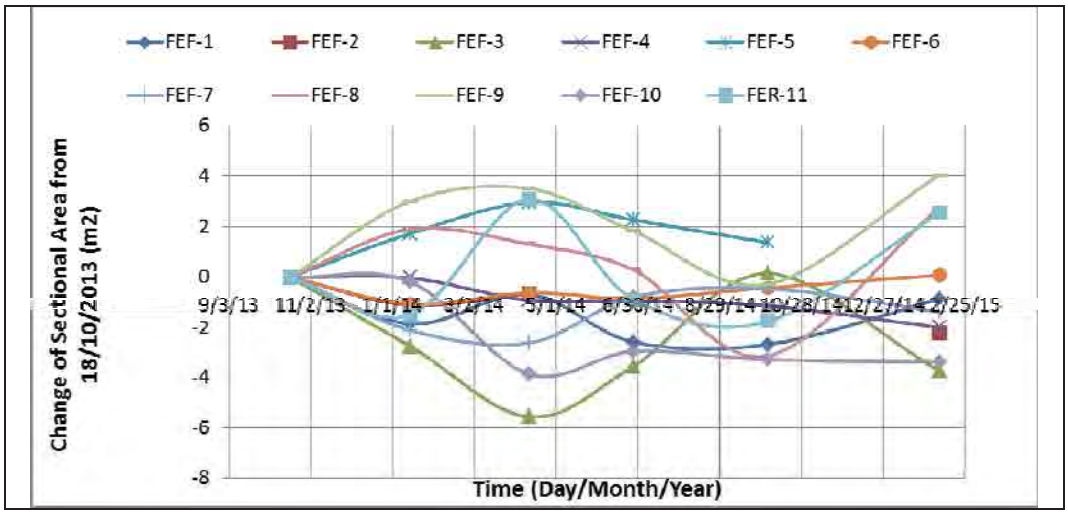
and eroded from May 2014 to October 2014. Then erosion and accretion were occurred alternately along the beach. It seems that the accretion corresponds to the stable site of long term change and the erosion to the eroded site. They are believed to correspond to the change in the wave conditions. However it is not clear since there is no wave observation data.





Source: JICA Expert Team

Figure 10.3.6 Beach Monitoring Results at Flic en Flac



Source: JICA Expert Team

Figure 10.3.7 Temporal Changes of Sectional Area at Flic en Flac

10.3.2 Sediment Transport

The coast is concave and waves comes right angles to the edge of the reef. Then reef current flows from the edge to the beach, along the beach and out at the both end of reef. The sediment moves according to the current. There is offshore movement through passes in the reef.

Already pointed out by Baired (2003) the erosion at the sub cell No.2 was caused by the coral

mining for raw materials of lime kiln and construction use.

The bathymetry is shown in Figure 10.3.8 studied by MOI. The ground level of lagoon in front of sub cell No.2 is -1.5m and deeper than the both side of -0.5m. Also the bottom is smooth. The coral sand is produced at the reef edge and deposited in the deep lagoon. Then the sand does not reach the beach. The alignment of the coast is convex and generates longshore current from sub cell No.2 to No.1. Then erosion happens at No.2 and deposition at No.1.

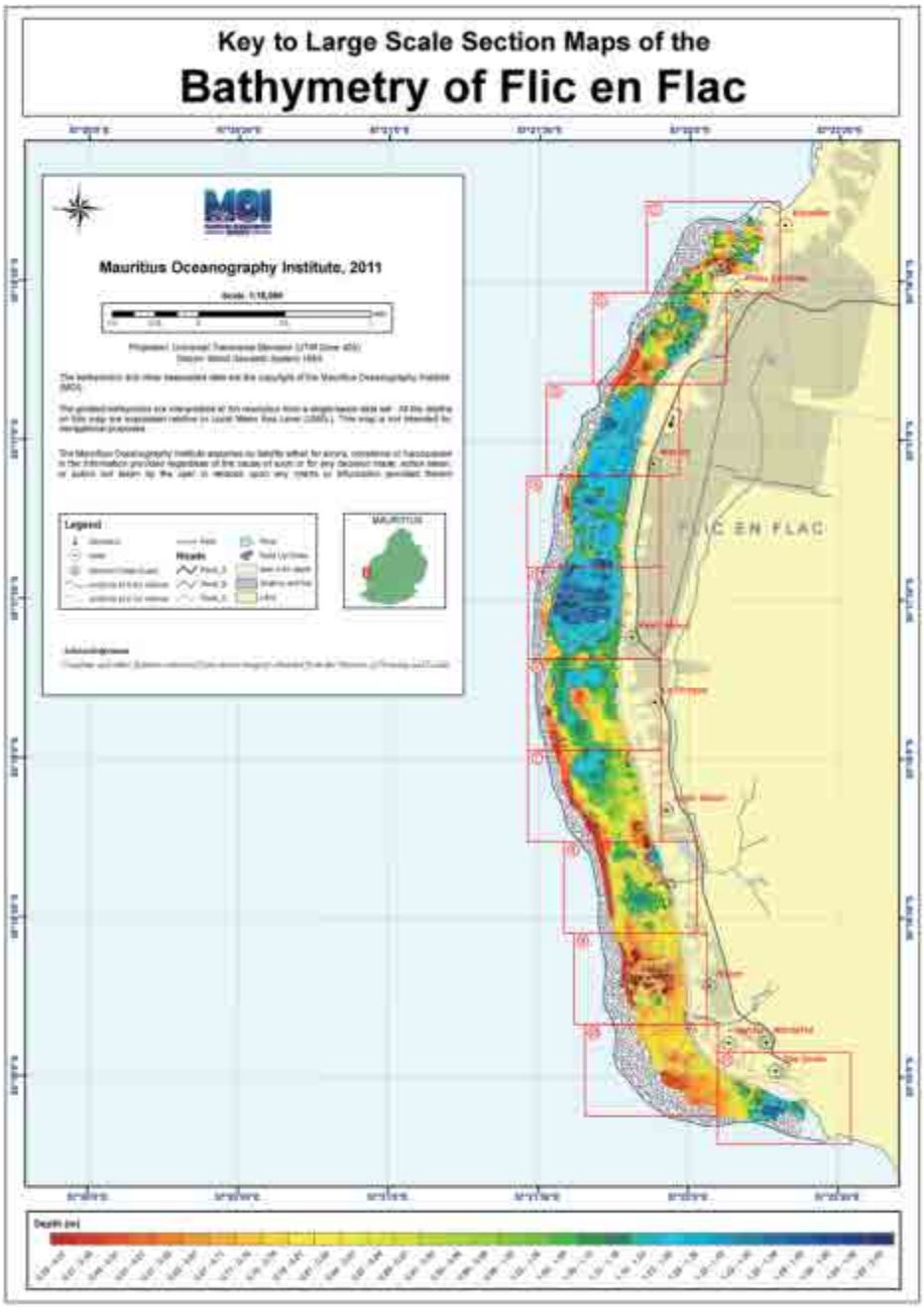
The accretion at No.1 is seems to be caused by the existence of coral patch in the lagoon. The beach is concave behind of the coral patch. It shows the dissipation of waves by the coral and the sedimentation caused by it.

There are some possibilities that the sand flows out through passes. The results of MOI for the deposition at the pass is shown in Table 10.3.1. (Assessment of Sand Accumulated at Reef Passes in the Region of Flic en Flac: MOI, 2010) In the table, the deposition at Pearl Beach is in inside of the reef and the other is outside.

From the result, the loss through the pass is estimated that it is smaller than the sediment transport in the reef. The accumulated volume at No.1 is 60,000m^3 within 45 years and offshore deposit is 10,000m^3 at the maximum within longer years.

Table 10.3.1 Sand Deposit at the Pass of Coral Reef

Position	Volume	Water Depth	Bed material
Pass Offshore of Pearl Beach	2,760m^3	3m	Mix of Coarse and Fine Sand
200m Offshore of La Pirogue Pass	12,240 m^3	14m~17.5m	Fine Sand
150m Offshore of Sofitel Pass	5,000 m^3	13m	Mix of Coarse and Fine Sand



Source: MOI

Figure 10.3.8 Bathymetry of Flic en Flac

The beach at sub cells of No.3 and No.4 receives sediment from offshore and accretes. The sub cell No.5 receives sand from No.4 by the longshore transport and shows accumulation recently.

The short term changes by cyclone is reported by MOI. (Bissessur, D. and O. Pasnin: Preliminary Report on the State of the Public Beaches of Flic en Flac and Mont-Choisy after Cyclone Event Giovanna, MOI, 2012) The beach change caused by the cyclone Giovanna in February 2012 was surveyed. The comparison between the profile in October 2012 and February to March 2013 shows $3m^2$ of accretion at sub cell No.1 and $4.5m^2$ and $3m^2$ of erosion at two sections at sub cell No.2.

The cyclone of January 2013 also caused beach scarp of 1m high as shown in Figure 10.3.9.

at the sub cell no.2.

Source: JICA Expert Team

Figure 10.3.9 Beach Scarp at Flic en Flac Produced by Cyclone January 2013(At Photo C of Figure 10.2.1)

10.4 Coastal Conservation Plan

10.4.1 Problems and Related Factors

The beach erosion has been caused mainly by the coral sand mining in front of the public beach though the beach is accreting in a whole. If structures are built in a dynamic zone, sometimes they cause beach erosion. Also the beach is stabilized by the coral and seagrass in the lagoon. Then the conservation of coral and seagrass is necessary. The regulation of nautical activities and large nets fishing is also required to prevent the degradation of them. The maintenance is also important factors to stabilize the beach.

Currents caused by incoming waves transport sediment to the north or the south from the center of concave reef and the beach at the center shows erosion though in total it is accreting. However at the center the lagoon is deeper than at other parts. The beach is eroded because the supplied sand deposits in the deeper parts and does not reach to the beach. Especially at the cyclone high wave caused beach scarp which makes troubles for beach use. In the past gabions were installed after the cyclone erosion of 1994 and removed by the recommendation of Baird (2003) in 2008 following the removal of the Pearl Beach wall and setback of the hotel from the HWM. At present beach scarp occurs during cyclone/storm events at some distance landward of the actual HWM and beach profile restoration has been carried out. However, daily maintenance of scarps as soon as it is occurring, is not being carried out by the beach contractors.

Adjacent to Villas Caroline, there is the Fish Landing station where sand has accumulated on the beach. Vehicles have direct access to the sea. Pleasure craft operators place and remove their boats at this location by making use of 4x4 vehicles. This activity would lead in the long run to the compaction of the sand on the beach and during heavy rainfall the permeability of the sand would be decreased thereby leading to erosion scarps on the beach and sand loss. At present, there is no slipway and no parking facilities such that everyday there are lots of 4x4 vehicles which park on that beach. In addition, trailers are also left on the beach. The track that the vehicles use to access the sea is also highly compacted and during heavy rainfall, gullys of quite deep are formed along this track. As a result of heavy use by vehicles, no grass/creepers or other vegetation grow in this beach.

On a daily basis, corals are being collected and used to level parking spaces or collected in bags. During surveys carried out by MOESDDBM, it was estimated that some 400m^3 of corals were being collected on a yearly basis and disposed away from the dynamic beach zone. It should be noted that yearly, the eroded beaches have to be replenished at the rate of some 400 -1000 m^3. Therefore if the collected corals, which are sand source for the beach, are buried at escarpments and within the dynamic beach zone, the amount of required beach replenishment may considerably reduce.

During daily maintenance of the beach, the sand dune is being raked to collect leaves and other garbage which are then collected and disposed away. Garbage such as plastics, paper, and cartons amongst others need to collected and disposed away. However, leaves and algae are organic biodegradable matters which are essential as food source to beach and marine organisms. Removal of these important food sources from the food chain affects the coastal ecosystems and health of the beach.

In 2008, Pearl Beach Hotel removed its vertical retaining wall and implemented setback from the HWM. However, Gold Beach Hotel which is located adjacent to Pearl Beach Hotel maintained the same setback of 15 m from the HWM. With time, the beach in front of Gold Beach Hotel is decreasing in width and the retaining wall, being within the dynamic beach zone, will interfere with the beach dynamic processes.

For the long term, measures are required to minimize degradation of coral which is the source of sediment and help in wave dissipation.

10.4.2 Short Term Plan

The maintenance of natural beach is taken as the course of action for the coast conservation plan because the coast is one of the major tourist resorts with public beach and hotels. In some area beach erosion and scarp have been caused. There are several measures as shown in the following Table 10.4.1. They are sand bypassing from accreted to eroded area, setback by accepting the erosion and dynamic beach changes, and the control of alongshore sediment transport by structures. The plan of sand bypassing is selected because the accumulated area of sand is clear, it is easy for dredge and possible to keep natural conditions of the beach. The structural measures are not appropriate because they cause sometimes erosion problems. The beach scarp can be coping with reprofiling.

Table 10.4.1 Alternative Measures at Flic en Flac

Measures	Sand By-pass	Setback	Construction of Facilities
Outline	Sand is accumulated at the northern area due to long-shore sediment transportation. Taking an advantage of the accumulated sand, the beach has a tendency of accumulation for the most areas and erosion at some points. Budget is requested by MOESDDBM for sand by-passing. Accumulated sand is precious resource and it is important to keep the same conditions. If accumulation becomes short, taking sand from the other resources will be considered.	Setback may expect minimizing long-shore sediment transportation for a long term measure.	Constructing the facilities will decrease long-shore sediment transportation and establish the stable beach conditions. Constructing an artificial reef is one of the measures, however, careful investigations and proper understanding of the existing phenomenon plus effects and impacts of such measures should be examined in advance. It will not so sure if this measure is the most appropriate one for the time being.
Advantages	Recycling sand will be conducted from the accumulated northern area to eroded areas. The distance between the accumulated and eroded areas is not long. Thus, it will be easier to carry out sand recycling.	The eroded area is in the public beach. It will be effective if sufficient space behind the beach is secured.	Immediate responses will be anticipated by the constructing facilities at the eroded areas.
Disadvantages	This measure will require periodical and continuous maintenance.	As the beach is the biggest public beach, many people and tourists come and enjoy at weekend. The issue is the decrease of such people owing to the setback.	There is a possibility that erosion will be induced just behind the groyne. Therefore, in-depth investigations will be necessary.

Measures	Sand By-pass	Setback	Construction of Facilities
	Sand by passing is recommended because to keep the natural beach		

Source: JICA Expert Team

The volume of sand bypassing, period and position is estimated by the mean volume to accretion and erosion of 2,000m^3 a year. Then the volume of every year or every five year can be bypassed from the accreted area to the eroded area according to the beach change. The effects and impacts will be monitored continuously. The works are executed by the Beach Authority because the public beach is located at the eroded area.

Source: JICA Expert Team processed based on the material from MHL

Figure 10.4.1 Arrangement of Measures at Flic en Flac

10.4.3 Long Term Plan

It needs to make coral reef conservation plan and to improve the environmental conditions because the coverage of coral varies from 1% to 30% and shows degradation. The coral is the source of sediment and long term measures are required. Especially at the deep area in front of eroded beach the recovering of bed is required by coral planting. At first the monitoring and analysis will be done of the coral, seagrass and water quality.

The coral area in the lagoon is decreasing and the seagrass at the south is increasing. Based on the monitoring of water quality, the treatment of domestic waste water and fertilizer is required because populated area and sugar cane field are extended at the hinterland. Coral is distributed at the north of the reef and increasing gradually. The conservation and protection of coral is necessary at the area. At the south there exist living coral and also protection is required. At the middle where coral is limited MOI and MOESDDBM has carried out experiments on coral plantation. The activity can be extended to the adjacent area because planted coral has survived

and recruitment was also possible. However, the lagoon has to be protected against impacts from nautical activities and fishing especially large nets fishing. Zones where corals are being restored should be declared as no activity zones for fishing and nautical activities. Fishing and motorized nautical activities have to be carried out outside the lagoon.

Concerning large nets, from information gathered from the Ministry of Fisheries there is a total of 14 licenses operating around the island and Flic en Flac is one of them. If the lagoon corals have to be restored, it is imperative that destructive fishing practices be prohibited within the lagoon. A large net fishing has to be gradually phased out. Presently there is a buy-back policy in place whereby the fishers can return their license to the government against compensation.

In order to create job opportunities for the fishers who are engaged in large nets fishing and for an effective management of marine protected areas, a Marine Protected Area (MPA) Authority may be created which will have the responsibility for the management and protection including enforcement of the protected areas. Regulations can be developed by the Ministry of Fisheries and Environment and these be enforced by the MPA Authority.

Alternatively, the management of the protected areas may be given to an NGO who can recruit large nets fishers as MPA rangers. For instance, the MWF has restored and is managing quite well Ile aux Aigrettes. The same principle may be applied for MPA's management.

Another option is to provide training for alternative livelihoods to those fishers who are presently engaged in large nets fishing.

As for the immediate efforts in the short-term countermeasures for the water quality at the coast, it is necessary to conduct the water quality monitoring with high precision analysis to grasp the detail conditions of eutrophication and the survey to understand the effects of the drainage from the houses, villas and hotels behind the coast.

Based on the these monitoring results, if necessary, it is necessary to promote the conversion of more efficient sewerage systems such as the improvement of wastewater treatment facilities as the medium and long term countermeasures.

Concerning the management of the beach at the Fish Landing Station, a slipway may be constructed with proper vehicle access to the sea on the public beach (PG Anna) located in between the Fish Landing Station and the Klondike Hotel. The shore is rocky and deep alters for boat access is found nearshore. Construction of the slipway would have least impact on adjacent beaches. In addition, the vehicles would be able to use the parking space already constructed at that beach. The beach at the Fish Landing Station may be vegetated as appropriate and closed for vehicle access.

10.5 Coast Maintenance Plan

10.5.1 Maintenance Problems

A lot of garbage and driftage are left on the beach at undeveloped area nestled between hotels. It is a problem from a standpoint of landscape and utilization.

Sandy beach hardly exists in front of the fence of the hotel. Gold Beach Hotel and Hilton Hotel face this issue. According to a manager of Gold Beach Hotel, the vertical revetment had already existed when owner purchased the existing hotel in 2004. It is assumed that the

revetment was built in 1970' to 1980'.

Grass and Garbage at Undeveloped Area between hotels

Narrow Beach in front of Hotel

Parking Vehicles in Public Beach

Source: JICA Expert Team

Figure 10.5.1 Beach Condition at Flic en Flac

10.5.2 Maintenance Plan

This section shows improvement plan against present beach management issues of the beach as follows.

a. Hotel Hilton

The part of walkway with base exists in front of Hilton Hotel on the beach. This structure is not in aerial photographs until 2000 but it can be seen in a satellite photograph in 2004.

A line of HWM is put on the satellite photograph in 2004 and then from a line of HWM as starting point, lines with 15 m and 30 m from HWM are added on the land side. As the result, it proves that this structure is located between HWM and setback line with 15m. There is the possibility that this was constructed without observing setback rule. It is necessary to carry out demolition or relocation of this deck through discussion between hotel and related institutions because this structure will block continuous sediment transport in and around the hotel in future.

Source: JICA Expert Team

Figure 10.5.2 Position of Setback Line and Facility of Hotel (Flic en Flac-1)

b. Gold Beach Hotel

The concrete deck exists in front of Gold Beach Hotel on this beach Tthis deck is located between HWL and setback line with 15m. In addition, a part of hotel facilities and swimming pool also are included in this area.

This deck was constructed following setback rule of 15 m which was in line with PPG at time of construction. It is to be noted that setback of 30 m came in 2004. It is necessary to carry out demolition or relocation of this deck through discussion between hotel and related institutions because this will block continuous sediment transport in and around the hotel in future.

Source: JICA Expert Team

Figure 10.5.3 Position of Setback Line and Facility of Hotel (Flic en Flac-2)

c. Beach cleaning issues

- Enhancement of awareness of beach cleaning to lessees by using leaflet, etc.
- Periodic inspection by local authority
- To establish a new beach cleaning system and/or add responsibility of beach cleaning in lease agreement

d. Vehicle access issues into public beach

- Step-by-step upgrading of parking space in the whole Mauritius
- Installation of sign and information board, shrubs and flower trees as boundary

e. Plantation issues on the beach

- To set up suitable arrangement and composition of beach vegetation
- Selection of suitable species of plantation (native species as much as possible)

f. Management and monitoring of beach nourishment issues

- To set up suitable foreshore slope and backshore crown height
- To set up suitable grain size such as equal to or bigger size at existing beach
- To set up suitable frequency of beach profiling survey and analysis

g. Formation of scarp issues

- Enhancement of monitoring system under cooperation with institutions concerned
- Management of plantation on the beach

10.5.3 Validity of Setback Amount

The setback amount for eroded sand beach is configured as summation of the amount of erosion during a certain period, the amount of erosion which is caused by strong wave such as cyclones in that period, and the erosion due to the SLR (sea level rise) is anticipated in future which is described as following.

Amount of setback = Amount of erosion for a long period + Amount of erosion by temporally event (i.e. extreme weather conditions such as cyclones) + Erosion amount due to SLR

There are several proposed equations to estimate the amount of erosion due to the SLR. Among these, the equation proposed by Per Bruun is applied generally. The equation is as follows.

E=C×S, where, E: erosion amount due to the SLR, C: coefficient of beach characteristic and S: amount of SLR.

The rate of the SLR from 1987 to 2011 is about 3.9mm/year in average, and the coefficient of C, which is related with the inverse of sea-bottom slope and transportation area of sediments, is set as 10 by the mean sea-bottom slope in Mauritius. The erosion amount due to the SLR, therefore, is calculated as 1.6 m by multiplying averaged erosion rate of 3.2mm/year, the coefficient of 10, and the period of 50years (E=10×3.9mm/year×50years=2m).

The amount of setback becomes 20m if the period is assumed 50 years, the erosion rate of 0.3m, and temporally erosion at the maximum caused by Cyclone Carol of 13m. (Refer Vol.1 Ch. 2). The amount is the same as the present value of 30m. Then it is necessary to monitor the beach profile changes and better to revise the new amount of the setback based on the analysis.

Amount of setback= 0.3*50+13+2=30m

Chapter 11

Albion (Beach)

11 Albion (Beach)

11.1 General

The coast of 1.5km long is located at the west of Mauritius as a pocket beach. It is located with a public beach of 300m long at the center, houses at the north, a research institute at the south, and hotels further south. A river flows into the coast with wetland behind.

11.2 Coastal Conditions

11.2.1 Waves and Tides

The coast receives waves from west. The strong waves which attack to Albion Beach occur during the cyclone season from December to March. The dominant wave direction at the offshore is from northwest. However, the waves are refracted by the existence of coral reef, and incidents almost perpendicular to the beach. The wave height on the reef is influenced by not only the offshore wave characteristics but also the tidal change on the reef. Thus, the high wave commonly occurs at high tide during the cyclone.

11.2.2 Beach Condition

Albion is a pocket beach enclosed by both basalt cliffs at the northern and southern tips with 1.5km of coastline. The lagoon exists with 400m width in average. However the coral reef disappears at the southern end of the beach due to inflow of the freshwater from a river. The reef gap forms deep channel. The river mouth use to be blocked by a sand bar due to littoral drift. However, the sand bar is sometimes flushed by floods due to the heavy rain. The tidal range at a spring tide is 0.50m estimated from the observation at Port Louise and others. (Refer Vol.1 Ch.2) The water level in a lagoon has to be considered the storm surge and the wave setup together with the tide.

Source: JICA Expert Team modified based on Satellite image obtained from MHL.

Figure 11.1.1 Topography of Albion

This beach can be divided into three areas, (1) northern area for private residence and villas (2) central area for public beach, (3) southern area for hotels. There is Albion Fisheries Research Center (AFRC) between the public beach at the central area and the hotel at the southern area. There are two outlets for the drainage from the AFRC constructed in 1980's.

Wetland with freshwater exists behind the AFRC. Normally, the wetland is blockaded by sand

bar due to wave action. However, heavy rains of once or twice a year flush the sand bar and fresh water flows into the lagoon.

Figure 11.1.1 shows the location of the photos shown in Figure 11.2.2 and Figure 11.2.3. The current condition of the beach is as follows.

Point A (north side)

Point A (south side)

Point B

Point C (northern outlet)

Between Point C (northern outlet) and Point D (southern outlet)

Source: JICA Expert Team

Figure 11.2.2 Beach Condition at Albion on January 2013 (1)

The photo of point A shows the beach condition at the northern residential and bungalow area. At the north from the point A, no sandy beach exists in front of the property. The coastal structures such as groynes and revetments were made to protect the property. From the interview and the past aerial photographs, it is confirmed the sandy beach existed previously. The photographs shows that the groynes and revetments were constructed from 1975 to 1991.

Point D (north side from the southern outlet)

Point D（south side from the southern outlet

Point E

Point F

Point G (small freshwater pond)

Sea side of Point G

Source: JICA Study Team

Figure 11.2.3 Beach Condition at Albion on January 2013 (2)

The photo of point B shows the public beach at the central area. The sand beach is foreshore slope of 1:8.5 and seems to be stable without beach scarp. The beach erosion was identified from the south side of this northern outlet, and significant beach scarp was observed between point C and D as shown in Figure 11.2.2. The height of the beach scarp becomes higher gradually toward the south, and about 1.5m height at the north side of the southern outlet at Point D. Due to the serious beach erosion at this area, the underground pipe which was installed by AFRC has been already exposed. The height of beach scarp decreased toward the south from the point D. It was completely disappeared at the point E and sand beach with mild

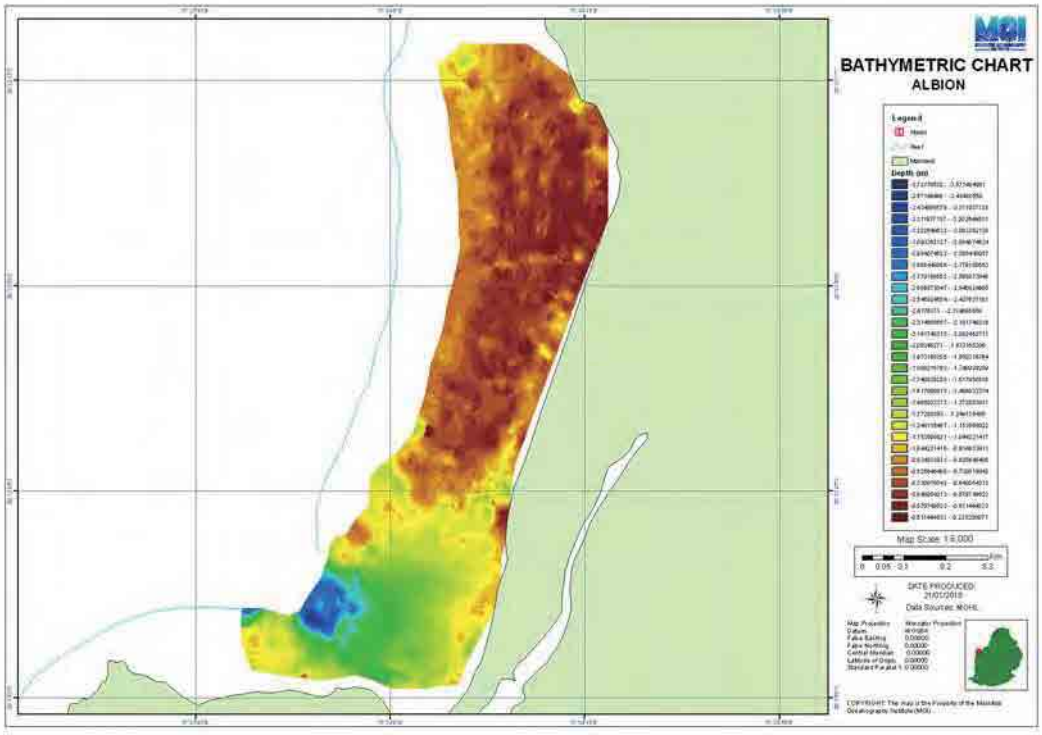
foreshore slope exists.

The point F is located in front of the reef gap. The local deformation of the beach due to existence of the reef gap was not observed. This area is utilized as private beach for the hotel which was constructed after 1997 in this area.

The small freshwater pond exists behind the point G. As mentioned before, this pond is normally blockaded by the sedimentation sand due to wave action from sea side. However, when the heavy rain occurred once or twice a year, the sedimentation sand is flushed and the freshwaters flow into the lagoon. According to the obtained information, the frequency of flushing tends to increase in recent year.

The average grain size at the foreshore was 1mm more or less and coarser comparing to that in other beaches. This is due to narrow coral reef with 400m in width.

The bathymetric map is shown in Figure 11.2.4 supplied from MOI. The ground height at middle and north in the lagoon is -1m (brown color) and shallow. At the pass of the south the ground height is -2m (blue color).



Source: MOI

Figure 11.2.4 Bathymetric Map at Albion Lagoon

11.2.3 Reef Environment

As shown in Fig.11.2.4, coverage of living corals dominated by massive and corymbose-type corals, was from 2 % to 33 % in this lagoon and density of juvenile *Acropora* was only 0.1/m^2. Branching *Acropora* dominated in this lagoon and coverage of living corals was 70 % in 1998, however the coral community completely disappeared. Coral coverage dominated by massive *Porites* was 33 % in the back reef. Juvenile *Acropora* was zero. Transparency was only 3 m and siltation was low. *Padina* and *Surgassum* were seen on the skeletons of branching

Acropora at the patch reefs in the lagoon. Seegrass of *Halodule* (partly *Syringodium*) spread out in the north of the lagoon. Fragments of branching coral covered in the area of lagoon off the seagrass bed. Massive *Porites* was scattered in the lagoon with the coverage of 5 %. Coral patch dominated by branching *Acropora* located at the center of the lagoon in the aerial photographs in 1996, but the patch disappeared at present. The seagrass bed of *Halodule* spreads to the offshore, but the area of the seagrass bed in front of AFRC shrinks in comparison with the aerial photographs taken in 1996. According to the long-term monitoring, the coverage of living corals in fore reef decreased from 60% to 0 % during the period from 2000 to 2010.

The investigation results on water quality and impacts to coral in the lagoon at Albion are shown in Table 11.2.1. Transparency is 3m and siltation is low. Chlorophyll a, turbidity and nutrients are respectively 0.51 ug/L, 0.95 NTU, 0.03 mg/L for NO_3 and 0.008 mg/L for PO_4 on an average and generally good level as habitat of coral (the coverage of living coral is 20 to 50%). According to the results of water quality monitoring by AFRC, high concentration of coliform with higher than 200 MPN/100ml was detected in 2010. The water pollution from domestic wastewaters is progressing. With respect to the water quality of the small river flowing into the south side of this coast, compared with that of lagoon, the nitrogen concentration (NO_3 in river: <0.005-4.60 mg/L) become ten times higher by time. The coast is an underdeveloped district of sewerage system. The most wastewaters are flowing into the coast through AP (absorption pit) and ST (septic tank) from houses. As the cause of the eutrophication, the effects of the drainage from the house and the pollution load from the small river are considered.

Source: JICA Study Team modified based on Google Earth

Figure 11.2.5 Coral and Seagrass at Albion by Spot Check

As the result of coral checking carried out in the basic study, the coverage of coral habitat was between 2 to 33%. On the other hand, from to the monitoring result carried out by AFRC, the coverage of coral habitat at nearby the reef edge significantly decreased from 60 % to 0% between 2000 and 2010.

As the result of water quality survey carried out in the basic study, the water transparency was measured to 3m and the silt contents were low. The water pollution became worse than before and the item of PO_4 and Escherichia coli exceeded over the coastal water quality guidelines in Mauritius.

Table 11.2.1 Investigation Results on Water Quality and Impacts to Water Quality in Lagoon

Check items		Conditions			
Water quality	Chlorophyll a (ug/L)	0.23-1.50(#) (Ave. 0.51)			
	Turbidity (NTU)	0.44-2.30(#) (Ave. 0.95)			
	NO_3-N (mg/L)	<0.01-0.04(#) (Ave. 0.03)			
	PO_4-P (mg/L)	<0.005-0.01(#) (Ave. 0.008)			
Population density behind coast(per km^2)		298			
Sewerage disposal behind coast	Status of development of sewerage facilities behind coast	Absorption Pit, Septic Tank, Pit Latrine			
	Present condition of sewerage disposal from houses (Sewerage system, Septic tank, Pending arrangement, etc.)	Albion VCA SS: NIL, AP: 754, ST: 1303, PL: 55			
	Present condition of sewerage disposal from hotels and restaurants (Sewerage system, Septic tank, Pending arrangement, etc.)	Hotels >75 rooms uses onsite treatment plants. Restaurant uses septic tanks.			
	Development plan of sewerage system for houses and hotels behind coast	In pipeline for development, Study stage			
Impact of pollution from sugarcane	Incidence of red-soil runoff from land side	Yes. River Mouth Lagoon Width: 483 m			
	Existence of sugarcane field behind coast. If there is it, area of the field behind coast.	Yes. Area: 2,907 Ha			
Relation between living coral and water quality**	Coral coverage	Chlorophyll a (ug/L)	Turbidity (NTU)	NO_3-N (mg/L)	PO_4-P (mg/L)
	>50%	<0.2	<0.5	<0.012	<0.007
	20-50%	0.2-0.6	0.5-1.3	0.012-0.051	0.007-0.016
	10-20%	0.6-0.9	1.3-1.9	0.051-0.081	0.016-0.023
	<10%	>0.9	>1.9	>0.081	>0.023

#: Observation for water quality and coral reef was conducted from the shore to the reef edge.
**: This relation was obtained by the water quality survey in this study. Refer to Table 2.6.3 in Vol.1.
SS: Sewerage Systems, Ap: Absorption Pit, ST: Septic Tank, PL: Pit latrine
Source: JICA Expert Team

The exchange of seawater at Albion beach is rather higher than that in other beaches due to narrowness of the coral reef. However, because of shallowness of the water depth on the reef, it is easy for coral bleaching to occur due to high water temperature at low tides.

11.2.4 Coast Use

Bungalows at the north, a public beach at the middle, the research institute at the south and hotels further south are located. The lagoon is used for the anchorage of pleasure boats and fishing boats. The public beach is crowded with many families at weekends. The beach, the coastal forest and the toilet are kept clean by the Beach Authority. Large net fishing is practiced in this lagoon.

The coastal conditions are summarized in Table 11.2.2.

Table 11.2.2 Coastal Condition and Problems at Albion (Beach)

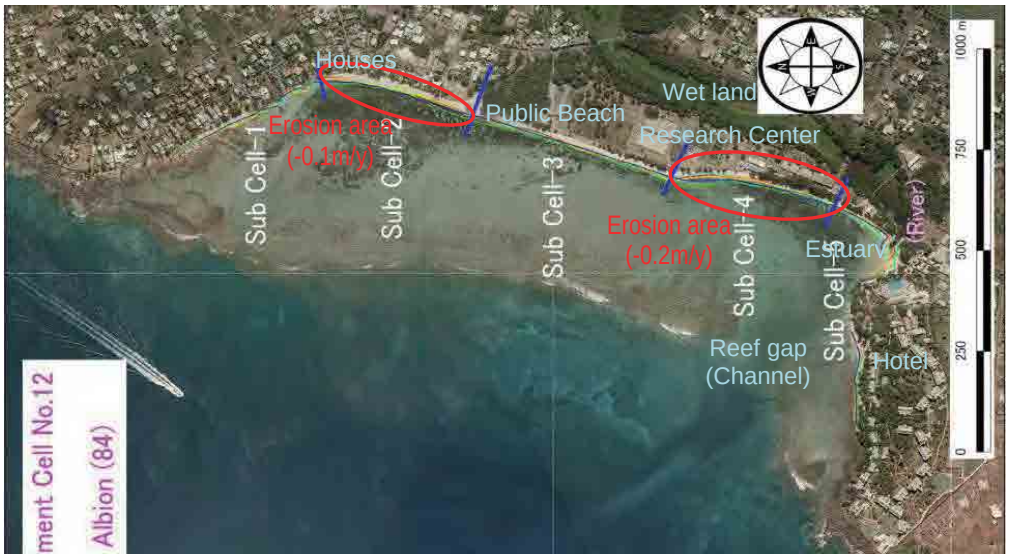
Basic investigation No.		No. 18 (Sediment Cell No.12)	PB No.	No.
Coast name		Albion		
Natural and topographic characteristics	Sea state	Located at the west side of the island, and affected by waves from the west as well as cyclones		
	Topography	Pocket beach with around 400m-wide reef on the front. Reef width is narrow compared with Le Morne, Flic en Flac and Pointe d'Esny. The medium diameters is around 1 mm and coarse relative to the other beaches		
Environmental characteristics	Coral reef	Coral reef coverage ranges from 2 to 33%, and it tends to become lower near the coast line. According to the results of coral reef monitoring by AFRC, coral reef coverage around the reef edge from 2000 to 2010 has been decline from 60% to 0%.		
	Water quality	Transparency is 3m, and siltation is low. Though water quality has been relatively good, PO4-P and fecal coliform bacteria above the environmental standards in Mauritius is detected. The water pollution is progressing. This coast is subject to coral bleaching because of the increased water temperature in the lagoon which is very shallow.		
Coastal transformation characteristics	Disaster and structures	Small retaining walls and fences have been installed, but some of which were damaged by scarps.		
	Coastal transformation	As a whole, this coast is an eroded area with the maximum rate of 0.2m/year. Though the public beach is stable, erosion at the front side of AFRC and scarps (1 to 2m) were observed between 2007 and 2008.		
Coastal utilization characteristics	Beach utilization	Utilized as PB (public beach), where Albion Laboratory (AFRC) is located. A hotel was built at the south end in 2008.		
General assessment		Since this coast is an eroded area as a whole, there is a fear that coral reef will be deteriorated. In light of the existence of scarps on the front of the laboratory and damaged fences, a protection program should be devised.		

Source: JICA Expert Team

11.3 Coastal Process

a. Shoreline change

Figure 11.3.1 shows the study area and the coastal change at Albion. It is divided into 5 sub cells from No.1 at the north to No.5 at the south. For the long term the sub cell No.2 and No.4 were eroded, No.1 and No.3 were stable and No.5 shows large fluctuation.

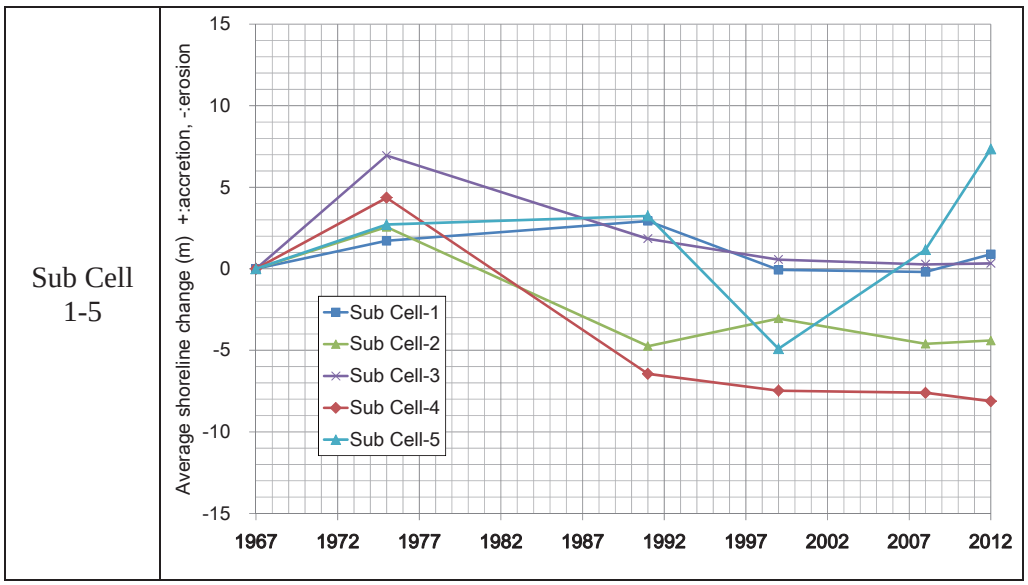


Source: JICA Expert Team

Figure 11.3.1 Study Area and Coastal Change at Albion

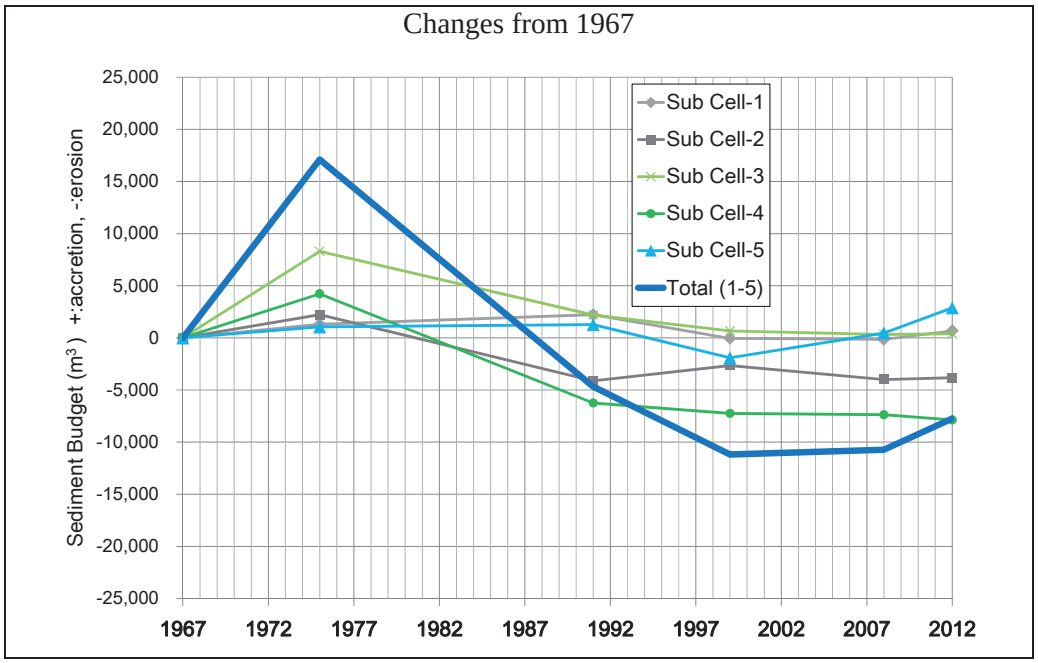
Temporal changes of shoreline are shown in Figure 11.3.2. The sub cell No.1 is stable, No.2, No.3 and No.4 was eroded from 1975 to 1991 with the maximum erosion of over 10m at No.4. At No.3 it was accreted from 1967 to 1975 and the erosion is not clear in long term. At No.5 it was eroded in 1999 and accreted in the after. The change is different from the other cells.

The sediment budgets are shown in Figure 11.3.3. In total the accreted volume becomes 15,000m^3 from 1967 to 1975 and from 1975 to 1999 the eroded volume is 25,000 m^3. After that the accreted volume is 3,000 m^3. From 1967 to 2012 within 45 years the total becomes 8,000 m^3 of erosion and 200 m^3 a year in average.



Source: JICA Expert Team

Figure 11.3.2 Shoreline Change at Albion



Source: JICA Expert Team

Figure 11.3.3 Sediment Budget at Albion (Sediment Cell No.12, Sub Cell-1-5)

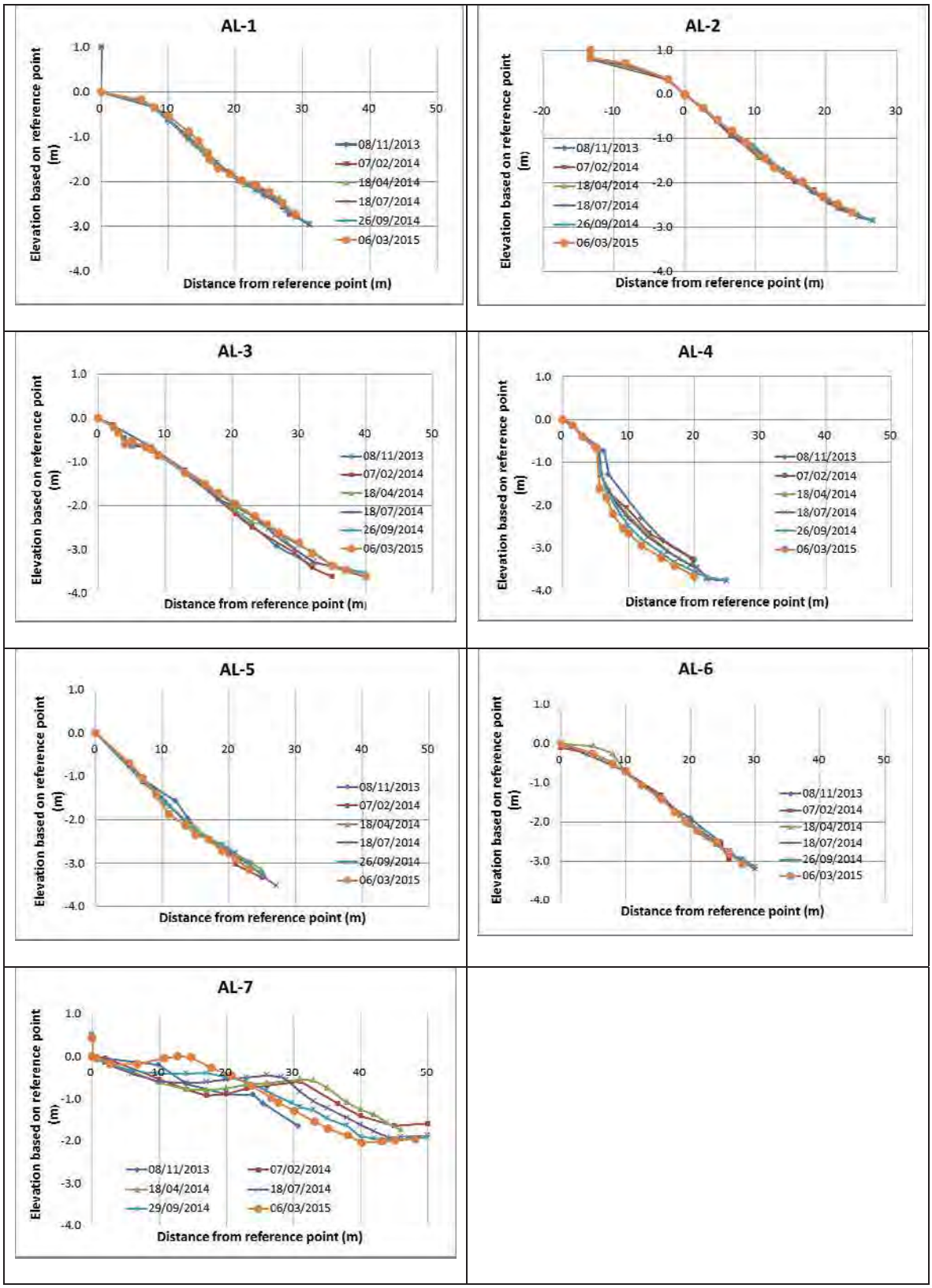
b. Beach Monitoring

The beach has been monitored regularly to know the beach profile changes. Seven transects were set along the coast of 1km from the north of AL-1 to the south of AL-7 as shown in Figure 11.3.4. The beach was measures at about 3months interval.

Source: JICA Expert Team modified based on the material from MHL

Figure 11.3.4 Arrangement of Transect for Beach Monitoring

The monitoring results of 6 times from November 2013 to March 2015 are shown in Figure 11.3.5. The transects from Al-1 to Al-2 are located in the eroded site of long term changes, at Al-3 is stable site, from AL-4 to AL-5 in the eroded site and from Al-6 to Al-7 in the accreted site. The profile at eroded site is steep. The elevation is relative height and not the ground level above MSL.

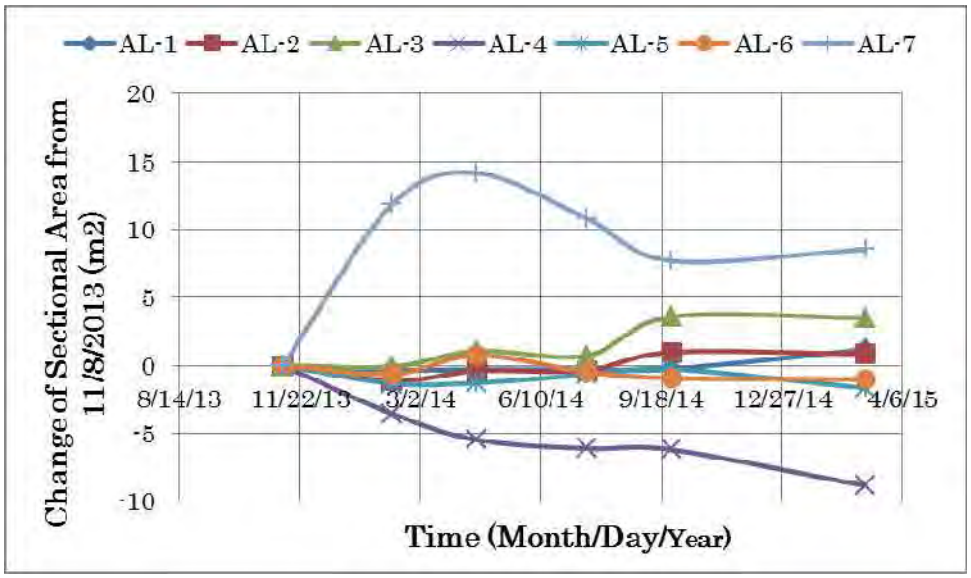


Source: JICA Expert Team

Figure 11.3.5 Beach Monitoring Results at Albion

The temporal changes of sectional area from the area at November 2013 as a baseline are shown in Figure 11.3.6. Here, the monitoring results are not always consistent with the long term change. Also the seasonal changes are relatively small. At the transects of AL-1 and

Al-2 the beach was eroded in long term. However it becomes stable or shows accretion recently. The beach of AL-4 located in front of AFRC was only eroded during the monitoring. The south beach of AL-7 located at the river mouth shows large changes with accreting trends as the same as long term changes.



Source: JICA Expert Team

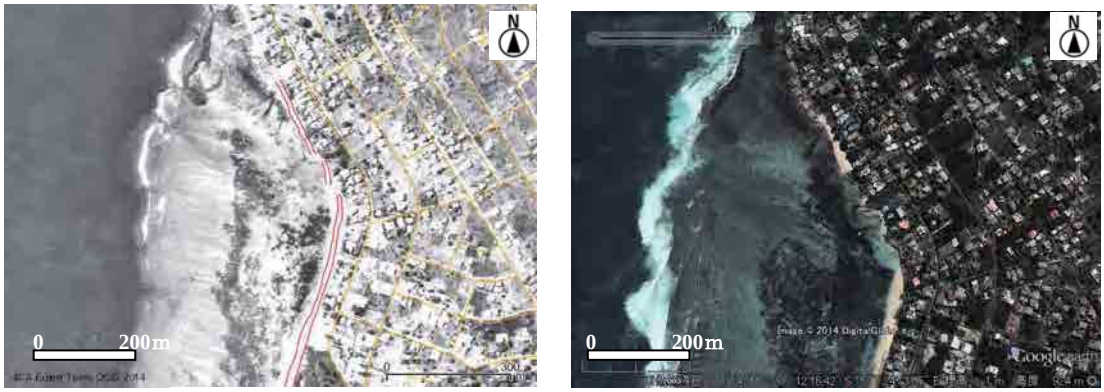
Figure 11.3.6 Temporal Changes of Sectional Area at Albion

11.3.2 Sediment Transport

The main sources of beach sand seems to be the sand broken by high waves at the reef because the coral reef exists in front of the beach and the beach sand is made of coral. The reef conditions of sub cell No.2 are shown in Figure 11.3.7 from 1967 to 2013 at the time of erosion.

The photo of 1967 in Figure 11.3.7 shows wide shadows in front of the eroded area and it is estimated coral offshore and seagrass near the beach from the present conditions. In the photo of 1975 the shadows changed to white in some part where the sand covered the seagrass by the cyclone of Gervaise in 1975. The area corresponds to the eroded area of sub cell No.2. The erosion was caused by the disappeared seagrass which protected the beach. After 1991 the erosion did not progress and the seagrass recovered in the photo of 1991. In the satellite image of 2013 the seagrass in front of the beach was continuous but narrow compared to the south. A revetment was constructed at the eroded beach and protected beach erosion (refer to Figure 11.2.2). Though there is a possibility to prevent the recovering of the beach. At present the seagrass is extended its area.

Change of Seagrass：Left 1967, Right Loss of Seagrass after Cyclone 1975



Recovery of Seagrass : Left 1991, Right 2013年

Source: JICA expert Team

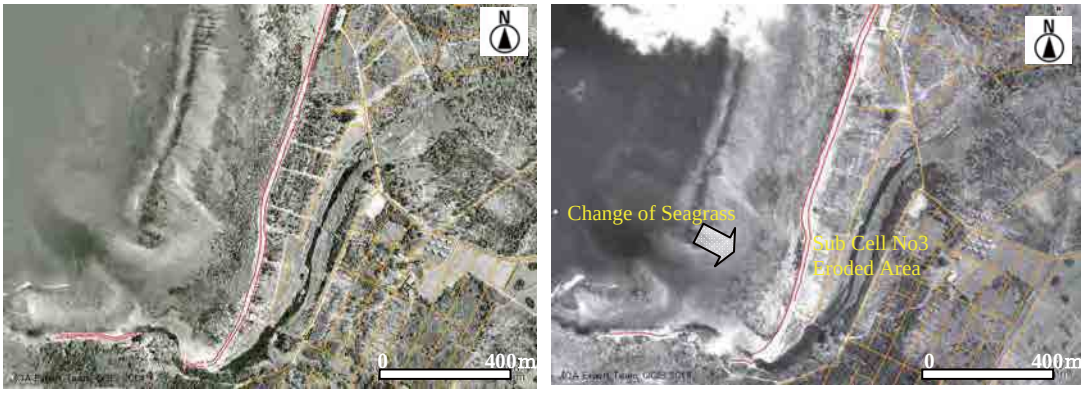
Figure 11.3.7 Loss and Recovery of Seagrass at North Albion

The reef conditions of sub cell No.4 are shown in Figure 11.3.8 from 1967 to 2013 at the time of erosion. The photo of 1967 shows wide seagrass in front of the beach. The seagrass existed but decreased in 1975 as shown in the photo of 1975. In 1991 the seagrass disappeared completely at the sub cell No.4 and the condition was continued in 2013.

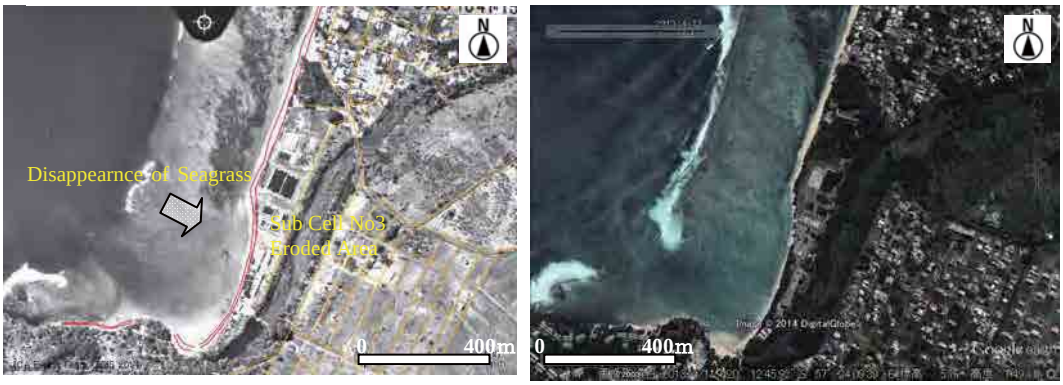
The current pattern from the trace of bed shows the change of direction in front of the seagrass to offshore because of the seagrass in front of the beach in the photo of 1967. On the other hand the current from offshore reached to the beach and changed its direction to offshore through the channel as shown in the photo of 1991. The current in 1967 was prevented by the seagrass and in 1991 the current was reached to the beach. The change of current pattern caused the change of sediment transport. The loss of seagrass increased the wave and current action together with the rate of sediment transport and caused erosion.

At the sub cell No.3 located between No.2 and No.4 the seagrass was kept and the erosion seems not severe.

From the alignment of the reef, it is estimated that the sand is transported by the onshore current to the beach. A part of sand is deposited on the beach. The other moves alongshore and offshore through the channel. On the basis of the movement the erosion was caused by the loss of seagrass and cyclones. The function of seagrass is large to keep the beach sand. The diffracted waves at the channel entrance has also contribute to decrease the sediment loss as shown in photo of 2013.



Change of Seagrass：Left Condition at 1967, Right Change after Cyclone 1975



Change of Seagrass：Left Loss of Seagrass 1991, Right No Seagrass at 2013
Source: JICA expert Team

Figure 11.3.8 Loss of Seagrass at South Albion

11.4 Coastal Conservation Plan

11.4.1 Problems and Related Factors

The beach has the tendency of erosion in a whole and the causes are estimated to be the loss of seagrass bed in front of the beach. The scale of the coral reef is small as 1.5km long and 300m wide. The forming of coral is poor because of the fresh water inflow of the river. The coral on the reef easily is impacted by the environment changes such as cyclones and floods.

Branching Acropora dominated in the middle to back reef of the lagoon until 15 years ago. However the coral community completely disappeared. The seagrass bed adjacent to the river mouth was almost disappeared though that of Halodule tends to increase in the north of the lagoon.

The coral and seagrass were damaged partly by the high waves of Cyclone Gervaise and the erosion started at the north by the loss of seagrass. At the south near the river mouth also the erosion started though the cause was not clear. From that several damages happen such as the generation of scarp in front of AFRC, falling of fence and damages to the pipeline.

The loss of coral and seagrass is estimated to be caused by the increase of sea surface temperature, the impact of cyclone, flooding and large net fishing. As the beach receded, the outlet in front of AFRC is now within the dynamic beach zone and is interfering with the coastal processes of the area. The beach adjacent the second outlet is not recovering and is

continuously eroding

The beach erosion is mainly caused by the loss of seagrass and coral cover. The erosion is recovering according to the recovery of seagrass and was small where the loss of seagrass was less.

11.4.2 Action Plan

The coast has tendency of erosion in general with the residential area and the fishery research center behind. Thus, coastal conservation measures will be needed for coastal protection in parallel with the conservation of seagrass for the stabilizing the beach, and with the recovery of coral, which becomes a source of sediment.

Measures against coastal erosion are shown in the Table 11.4.1, including setback which allows erosion, beach nourishment by sand and construction of groynes in front of the residences at the north. The comparison is shown in the Table and setback has been recommended for the time being.

The extent of setback has been defined at 30 m in general for coastal conservation measure and it is enough in Albion. The necessary setback is 26m which comes 10m of long-term erosion within 50 years, the change of 13m caused by the cyclone and the erosion of 3m by the sea level rise. At the river mouth, we have to consider the change of sand bar caused by flooding. Then it is necessary to evaluate the value by the accumulation of beach monitoring data.

Table 11.4.1 Alternative Measures against Coastal Erosion

Measure	Setback	Beach Nourishment	Groyne + Setback (Combination)
Outline	Considering the erosion rate during the target period (for example 50 years), shoreline change for this period due to cyclones will be a distance of setback. Then, the construction area from the high water level line to the setback distance will be restricted. In other words, the present situations will be kept.	Beach nourishment will be placed to the eroded places with the same eroded volume of sand. Finding a sand source is important as it would be difficult to find a new borrow pit.	A groyne will be constructed at the point where the directions of the shoreline are changed. Then, sediment moved to the channel will be trapped by the groyne for the eroded northern residential area, allowing erosion at the research center. As the research center is situated between the river and wetland, the location is not geographically suitable and it is better to designate the area as a natural reservoir.

Measure	Setback	Beach Nourishment	Groyne + Setback (Combination)
Advantage	Heavily eroded areas are in front of the fishery research center and the public beach. Setback is possible. Natural scenery will not be affected by this measure.	After the beach nourishment, the foreshore width will be wider. The shoreline change is 30 cm/y and the beach nourishment will be effective for a long period. Sand recycling from the reef gap will be available taking an advantage of such natural utilization.	Sediment supposed to move to the channel will be trapped by groynes and then sand recycle will be conducted. Maintenance is simple.
Disadvantage	Many local people and tourists come to the beach on weekends. Setback may reduce the space behind the beach and may restrict utilization.	Harmful impact on coral reef when collecting sand may be expected and dispersal of sediment may be anticipated. Proper investigations for taken sand will be necessary if the sand is suitable for beach nourishment in terms of quality and quantity.	Constructing groynes will contribute to stabilize the shoreline, but it will be needed to control erosions down-drift. In addition, it is against the method aimed by the country which is to utilize the natural resources in the countermeasure.
Evaluation	Recommended	As a result of further investigations, mechanism of littoral drift and possible measures will be confirmed.	As a result of further investigations, mechanism of littoral drift and possible measures will be confirmed.
Further Issues	Appropriate setback and adaptation	Mechanism of littoral drift and preventive measures	Mechanism of littoral drift and preventive measures

Source: JICA Expert Team

a. Coastal Constructions

It is necessary to monitor the constructions of coastal structures and enforce the regulations to include in beach management plan. At the sub cell No.2 in the past, a vertical revetment was constructed in the eroded area. It is better to reconstruct a gentle one or to remove for the recovering of the beach because the seagrass is recovering in front of the beach. The monitoring is also necessary for the analysis of the effect of seagrass on the beach stabilization. At the same time the impact of the revetment on the longshore sediment transport can be studied.

b. Setbacks

At the south of sub cell No.4 and No.5 there is a possibility of hotel construction. In this case the setback should be considered the changes of beach and sand bar at the river mouth caused by both waves and floods. It needs to decrease the risk in the changing area.

c. Rehabilitation of corals and seagrass

For the long term the rehabilitation of coral and seagrass will become the target of the coast. At the north the supply of the coral sand and the dissipation of waves can be expected. There is a possibility of the recovering of seagrass for the stability of the beach. At the south, the reef is not developed because of the fresh water inflow of the river. When incident waves

come from the north, littoral drift moves southward due to longshore currents and to the offshore by the flooding of the river. When incident waves come from the south, the diffracted waves causes littoral drift to the north. Those movement also impacted by the existence of seagrass. It is necessary to carry out further investigations as it is difficult to analyze in more details for the time being.

The coverage of corals ranges 2-33% and they are so sensitive to induce coral bleaching due to the increase of sea surface temperatures because of the shallow reef. It is necessary to establish a reef conservation plan and to implement.

The water quality is good for the living condition of coral. Also the AFRC has been tested coral plantation. As a short term action it is better to continue those activities and to regulate activities such as large net fishing by the monitoring. Given that this beach is highly eroded, should we ban large net fishing in the lagoon and promote coral transplantThe donor is necessary from the other reef because there is no blanching coral of Acropora genus. One of the measures is the distribution of slick taken at the time of spawning season from the reef such as the southeast part of Pte. d'Esny.

d. Countermeasures for the water quality

As for the short term countermeasures for the water quality in the lagoon, it is necessary to conduct the water quality monitoring with high precision analysis to grasp the detail conditions of eutrophication and the survey to understand the effects of the drainage from the houses and the pollution load from the small river.

e. Expansion of the coral transplanting scale

As for the long-term countermeasures, it is necessary to expand the coral transplanting scale, in order to rehabilitate the deteriorated corals due to rising sea temperatures. If the eutrophication is progressing further, it is considered necessary to promote the conversion of more efficient sewerage systems such as the improvement of wastewater treatment facilities and the development sewerage treatment plants in the basin and behind the coast.

For the plantation of seagrass, the necessary information is not sufficient. In a short term, the monitoring will be conducted to study the existing species and its living condition and the possibility of seagrass plantation. In a long term, the plantation can be started for selecting suitable species based on the study.

There is a possibility that beach sand goes offshore and, thus, if any deposit in the channel is identified, it will be possible to utilize it for beach nourishment. Also the accumulated sand at the mouth of the river will be used for beach replenishment if the flood causes loss of sand. Before that it is necessary to monitor the change of the beach and also the change of sand bar at the mouth for several years.

Removal of concrete structures within dynamic beach zone including the outlets from AFRC is necessary because those structures cause erosion at one side and accretion at the other side by the change of wave conditions.

To consider, in case sand is not available, to place pebbles at the eroded site covered with sand

11.5 Coast Maintenance Plan

11.5.1 Maintenance Problems

Present issue and points of concern for beach space management are presented below.

At the north beach there are vertical revetments without beach in front. They prevent the accumulation of sand by the reflected waves and work as groynes to control longshore sediment movement.

People cannot pass thorough the beach because large scarp is formed in front of the research center. There are some possibilities that plantings and fence will fall down and flow out due to erosion.

Beach cleaning is carried out by the Beach Authority every day at the public beach. On the other hand, lots of garbage and driftage are left on the beach in front of the fishery research center. Garbage accumulates in ditch faced to the beach. It might be flowed out to the sea after the rain. Those conditions are shown in Figure 11.5.1.

 Maintaining coastal forest and beach in good environment condition	 Erosion area in front of the research institute. Scarp with Approx. 1.7m was formed at this area.	 Collapse of fence and trees at erosion area in front of the research institute.
 Accumulated Garbage in drainage contacting with beach	 A lot of garbage is uncontrolled in front of the research institute which is continuing from the public beach.	 Accumulated garbage and seaweed in front of the research institute.

Source: JICA Expert Team

Figure 11.5.1 Beach Condition at Albion

11.5.2 Maintenance Plan

To the vertical revetment the response of the beach by cyclone and the change of seagrass will be studied and it the seagrass is recovered the vertical revetment may beremoved. The scarp can be improved by the beach reprofiling according to the beach change.

The beach in front of the research center seems to keep clean because it is connected to the public beach and residence is used. The responsible organization has to be cleared with the cooperation of the Beach Authority. The garbage in the channel has to be removed

continuously. The cleaning will be done by the responsible organizations. This section shows improvement plan against present beach management issues of the beach as follows.

a. Existing coastal facility issues

- Modification of revetment from vertical type to sloping permeable type with plantation
- Demolition and modification of groynes depending on effective

b. Formation of scarp issues

- Enhancement of monitoring system under cooperation with institutions concerned
- Management of plantation on the beach

c. Beach cleaning issues

- Enhancement of awareness of beach cleaning to lessees by using leaflet, etc.
- Periodic inspection by local authority
- To establish a new beach cleaning system and/or add responsibility of beach cleaning in lease agreement

11.5.3 Validity of Setback Amount

The setback amount for eroded sand beach is configured as summation of the amount of erosion during a certain period, the amount of erosion which is caused by strong wave such as cyclones in that period, and the erosion due to the SLR (sea level rise) is anticipated in future which is described as following.

Amount of setback = Amount of erosion for a long period + Amount of erosion by temporally event (i.e. extreme weather conditions such as cyclones) + Erosion amount due to SLR

There are several proposed equations to estimate the amount of erosion due to the SLR. Among these, the equation proposed by Per Bruun is applied generally. The equation is as follows.

E=C×S, where, E: erosion amount due to the SLR , C: coefficient of beach characteristic and S: amount of SLR.

The rate of the SLR from 1987 to 2011 is about 3.9mm/year in average, and the coefficient of C, which is related with the inverse of sea-bottom slope and transportation area of sediments, is set as 10 by the mean sea-bottom slope in Mauritius. The erosion amount due to the SLR, therefore, is calculated as 1.6 m by multiplying averaged erosion rate of 3.2mm/year, the coefficient of 10, and the period of 50years (E=10×3.9mm/year×50years=2m).

The amount of setback becomes 25m if the period is assumed 50 years, the erosion rate of 0.2m, and temporally erosion at the maximum caused by Cyclone Carol of 13m. (Refer Vol.1 Ch. 2). The amount of 25m is the below the present value of 30m.

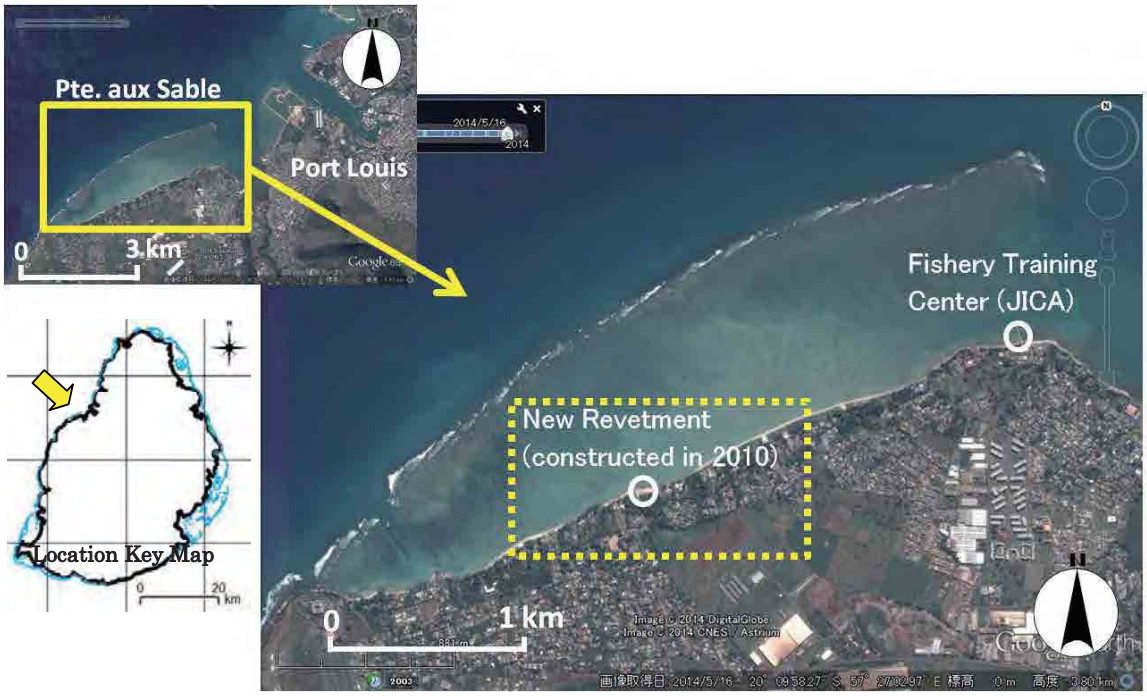
Amount of setback= 0.2*50+13+2=25m

At the river mouth the amount of setback has to include the change caused by flooding. At present there is not enough data and further investigation is necessary.

Chapter 12

Pte. aux Sables

12 Pte. aux Sables



Source: Edited by JICA study team based on the data from Google Maps

Figure 12.1.1 Pte. aux Sables Coast

12.1 Outline of Coast

Pte. aux Sables Coast, which is located around 5km to the southwest of Port Louis. It is a coral reef coastline of approximately 4 km. Most of the land along this coast is leased land, and there are private homes, holiday homes and small hotels dotted along the coast. The leased land area of this coast is categorized as a third grade area among five grades, meaning that it is a middle-class area. The coast has three public beaches. Among these areas, an approximately 216 meter-long slope revetment was built as a coastal erosion measure on the public beach in the central part of Pte. aux Sables in 2010. In addition, there is a fishery training facility, built in 2002 by Japanese government (JICA) grant aid, at the east end of the coast (Figure 12.1.1).

The reef width is approximately 400 m in the west and gets gradually wider to the east until it becomes approximately 900 m at the east end. The coast is comprised of white sand of coral reef origin.

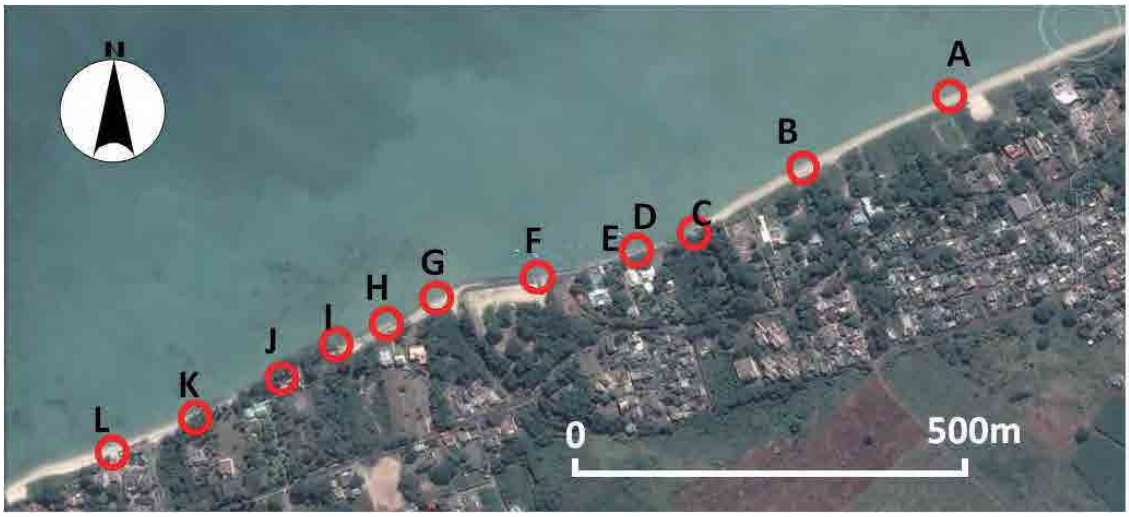
12.2 Present Condition

12.2.1 Site Reconnaissance

Coastal photos taken from the positions shown in Figure 12.2.1 in April 2014 can be seen in Figure 12.2.2 and Figure 12.2.3 .

- Point A is approximately 600 m to the east side form the new revetment of the public beach. A wide sandy beach exists here, and vegetation is seen in the backshore.

- Point B is approximately 250 m to the east of Point A. Beach width becomes narrow from this point, but the width of both foreshore and backshore still seems to be sufficient. Next point is Point C, and it can be seen in the far distance from this point.



Source: Edited by JICA study team based on Google Maps

Figure 12.2.1 Photo Positions

- Point C is approximately 150 m more to the west from Point B. In this coast, there is a the beach cliff of around 1m high and roots of some old trees have been washed bare (indicating erosion). There is an area of private homes fronting the coastline after this cliff.
- Point D & E are located in just front of the area of leased area. The new revetment is located at west-side of this area. There is a fence running along the seaward side of the land, and boulders have been placed in front of the fence by the residents of this area. The residents said in interviews that the coastline erosion was occurring before construction of the new revetment. However, erosion accelerated after the construction of the new revetment, prompting them to add more boulders recently.
- Point F is the new slope revetment at the public beach in 2010. The length of revetment is approximately 170 m long, and it is formed of 1 ton armor stone at a slope inclination of 1:1. In addition, aerial photo analysis of the alignment of the new revetment compared with aerial photos of the coastline before construction confirms that 10 to 20 meters of foreshore has be reclaimed when constructing the revetment, and sand has been filled in behind the revetment.
- Point G shows the western coast situation from the west end of the newly built revetment. Since the new revetment is located further off shore than the existing coastline, the littoral drift towards the east is stopped at the west end of the new revetment. Accordingly, some sand deposits are observed locally at this coast.
- Point H is located approximately 100 m to the west of point G. The coast condition gets worse again, and the sandy beach gradually disappears. There is much wreckage of a concrete revetment which is thought to have existed along this coast previously.
- At Point I, which is approximately 100 m west from point H, it is found that the ground is greatly washed away and tree roots and stumps are exposed. There are rubble stones,

of about the size of a person's head, in front of these trees, but they might have been put their artificially. There are no more rubble stones near point J, which is approximately 70 m to the west of point I, and the vertical retaining-wall continues after this point. Most of the sandy beaches disappear in this area.

- In point K which is approximately 150 m further to the west, the foundation of existing retaining-wall is exposed. It means that erosion still advances after the retaining-wall construction. And then, near point L, which is 150 m west point K, the sandy beach can be seen again. There are private homes and villas from point G to point K.

Based on the present site conditions, it is judged that the problem range of this coast is an approximately 900 m section of coastline (around 200 m section from the east end of the revetment, and around 500 m from the west end) on both sides of the newly constructed revetment.

Point A (Approx. 600m east from new revetment)

Point B (Approx. 350m east from new revetment)

Point C (Approx. 200m east from new revetment)

Point D (Boulder protection, approx. 100m east from new revetment)

Point E (Boulder protection, approx. 100m east from new revetment)

Point F (New revetment on public beach)

Source : JICA Study Team

Figure 12.2.2 Present Conditions of Pte. aux Sables (May 2014)

Point G (West side view from west end of new revetment)

Point H (Approx. 100m west from point G)

Point I (Approx. 200m west from point G)

Point J (Approx. 70m west from point I)

Point K (Approx. 150m west from point J)

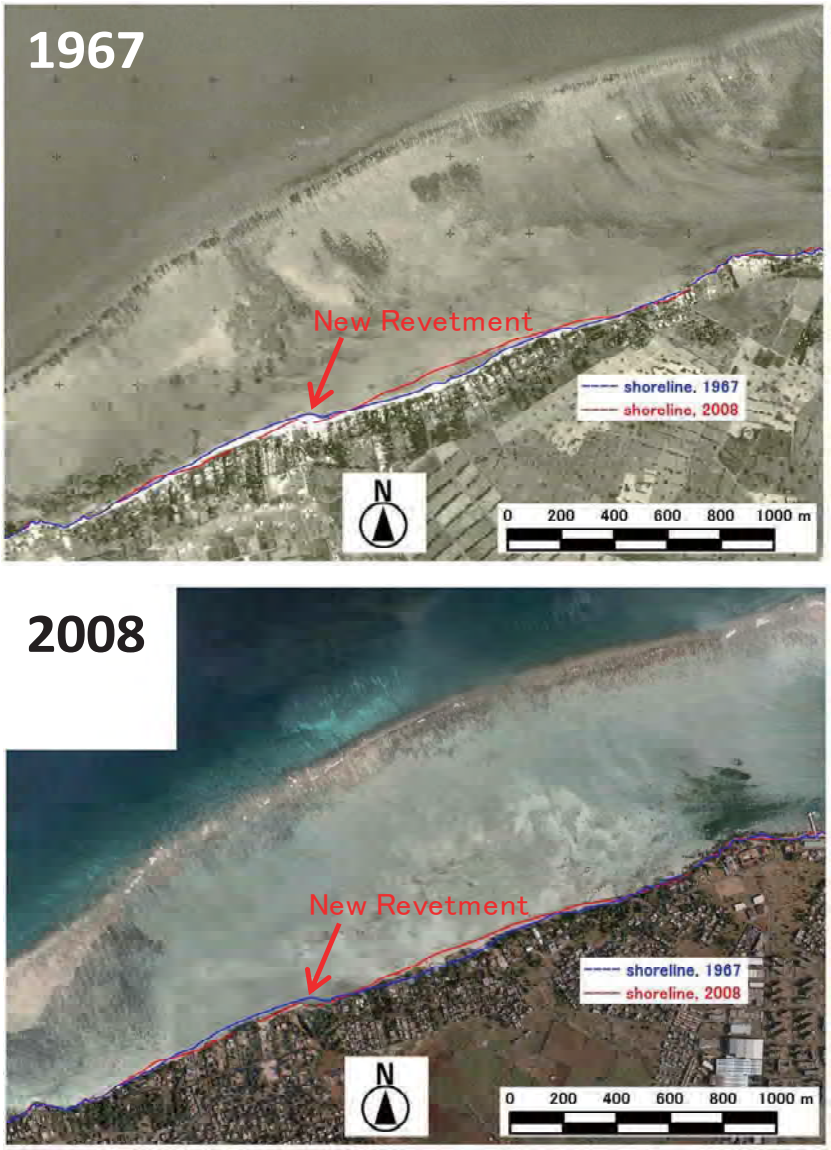
Point L (Approx. 150m from point K)

Source : JICA Study Team

Figure 12.2.3 Present Conditions of Pte. aux Sables (May 2014)

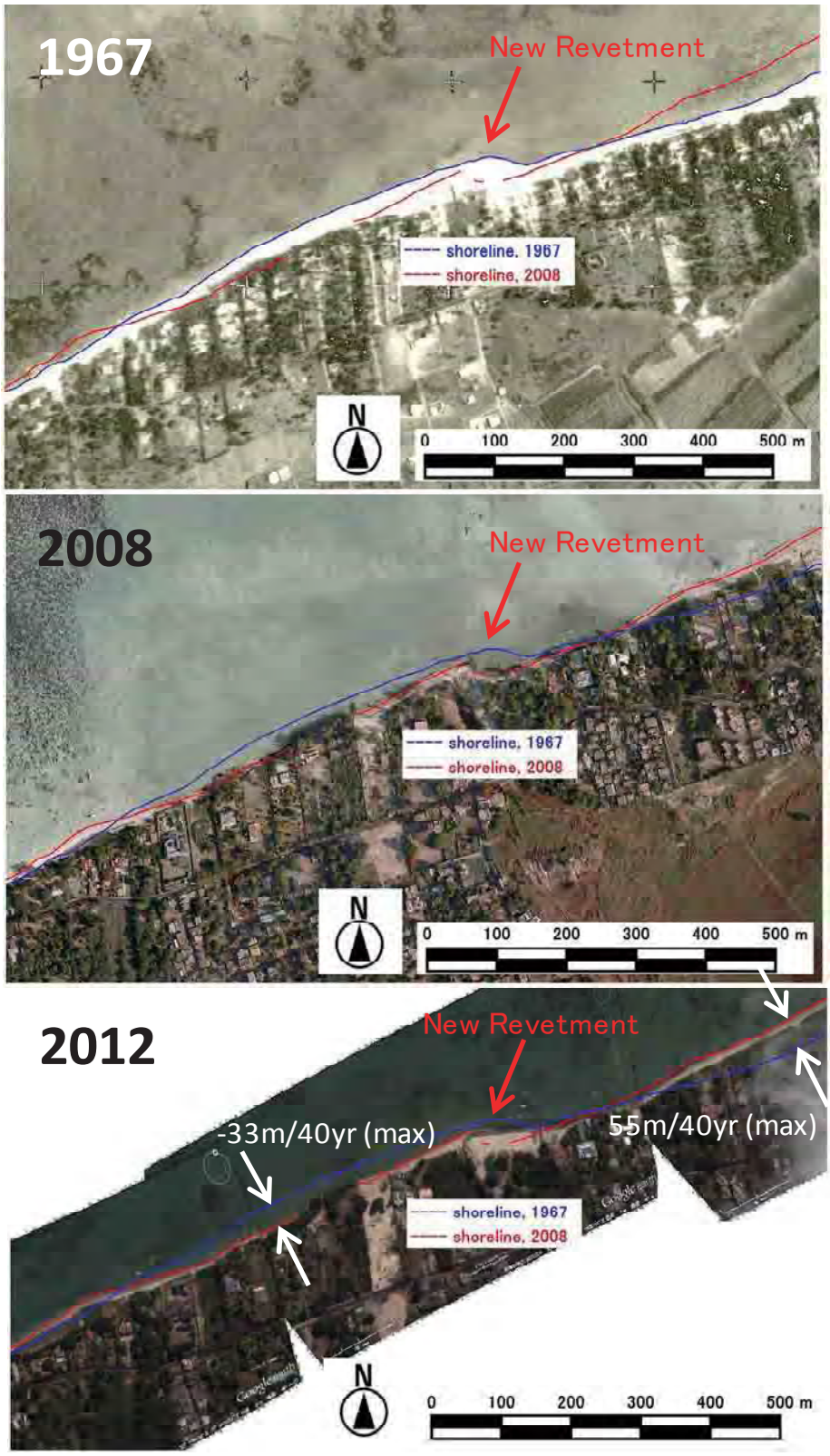
12.2.2 Long Term Coastline Change and Sediment Budget

Figure 12.2.4 shows the aerial photo of the wide area of the coastline in 1967 and 2008, and the coastline change that has occurred in between times. Also, aerial photos, taken in 1967, 2008 and 2012, of the approximately 1 km of public coastline in the central part that has experienced the severest coastline change and erosion issues are shown in Figure 12.2.5 . These images can be interpreted such as changes in the reef and the patterns of streak lines to roughly gauge the direction of currents and sand movements, and changes in coral and seaweed distribution. Figure 12.2.6 shows the change of the reef in 5 terms from 1967 to 2008. Two areas identified on the reef which are thought to affect coastline change are marked with red and blue frames. Figure 12.2.7 shows the change of sediment budget of each sub-cell in 6 terms from 1967 to 2012 and its gross change. Estimation of sediment budget is calculated by multiplying the movement height of 2.5 m (a 2.5 meter-high section of sand) by the area of coastline change as observed from the past aerial photos, in the same manner as at other coasts.



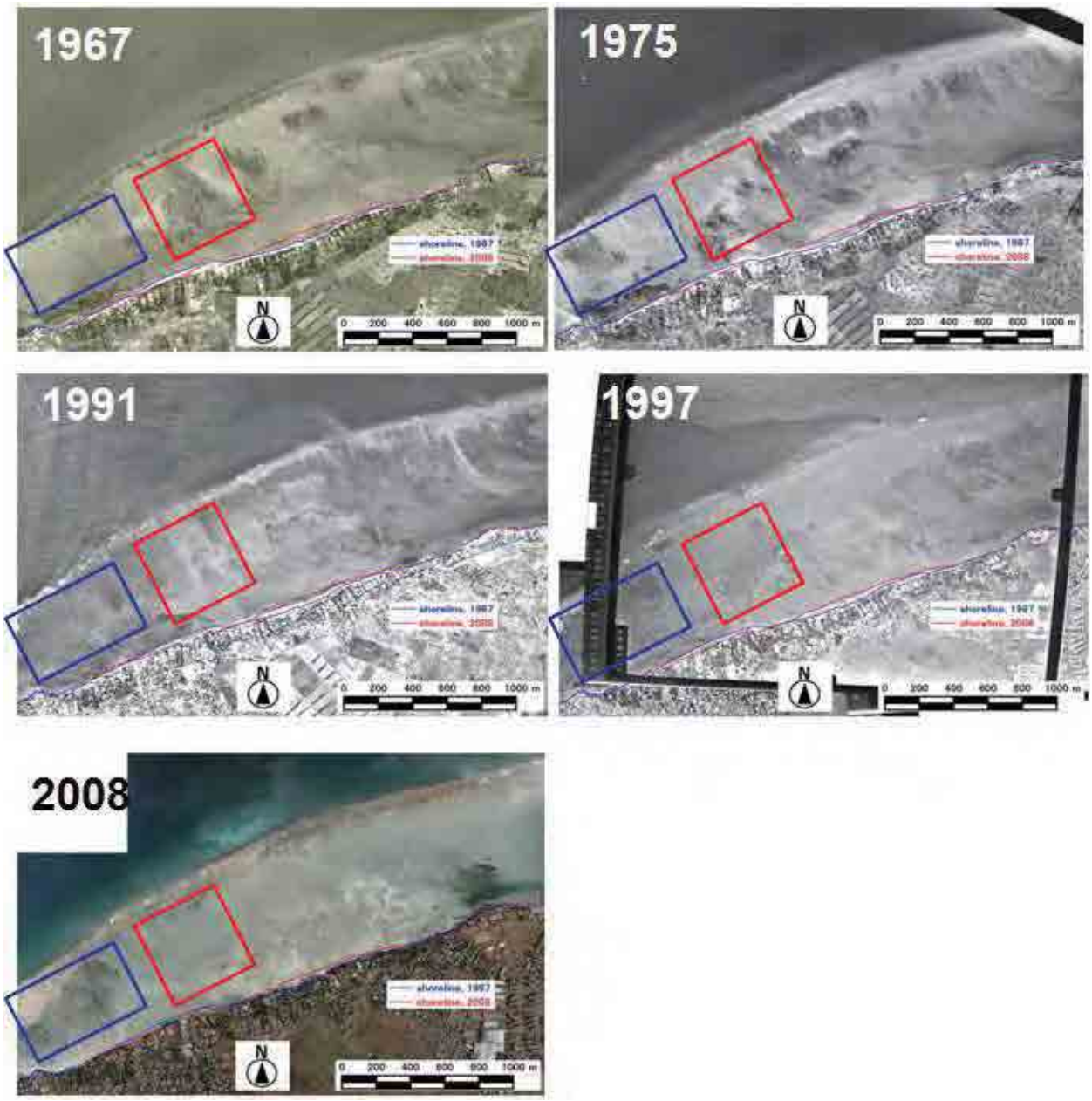
Source: Edited by JICA based on the satellite image from MHL

Figure 12.2.4 Comparison of Aerial Photo (Wide Area)



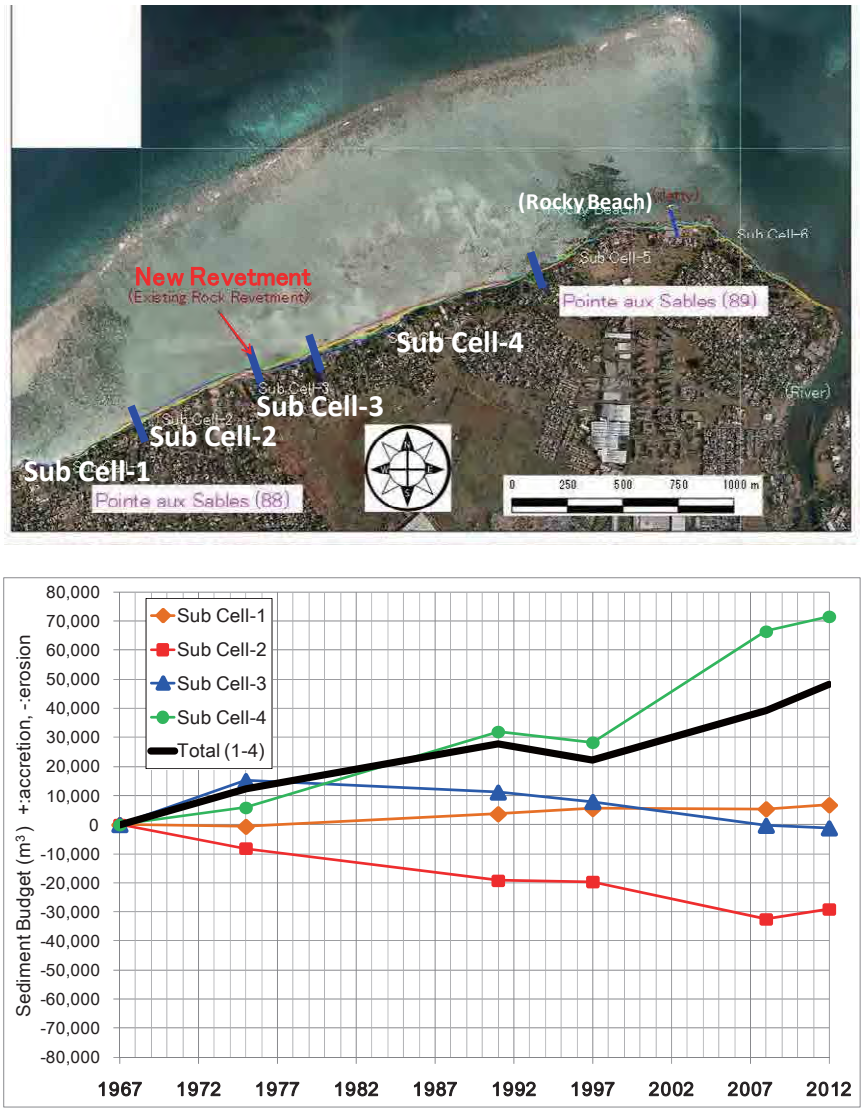
Source: Edited by JICA based on the satellite image from MHL

Figure 12.2.5 Comparison of Aerial Photo (New Shore Protected Area of Public Beach)



Source: Edited by JICA based on the satellite image from MHL

Figure 12.2.6 Reef Condition Change for 5 terms in 1967-2008



Source: Upper) Edited by JICA based on the satellite image from MHL
Lower) JICA Expert Team

Figure 12.2.7 Comparison of Sediment Budget in Each Sub-Cell

- As shown in Figure 12.2.4 and Figure 12.2.5 , the characteristics of the coastline change of this coast is that the coastline approximately 500 m west from the revetment in the public beach (Sub Cell-2) has almost constantly been in a state of erosion since 1967. Particularly, the tendency of erosion becomes remarkable from 1997 to 2008. During 40 years, the average coastline erosion for the section is around -20 m (-0.5m/year), and around -33m (-0.8m/year) at the maximum point. The location of the area of maximum erosion is nearby point I and point J in Figure 12.2.3 .
- On the other hand, it is seen that the coastline is likely to advance constantly in an approximately 1 km long section (Sub Cell-4) from a point which is around 300 m east of the revetment. Similar to Sub Cell-2, the tendency to increase becomes remarkable from 1997 to 2008. During 40 years, the average coastline accretion (advance) for the section is around 25 m (+0.6m/ year), and around 55 m at the biggest point (+1.4m/ year). The location of the area of maximum coastline advance occurs nearby point A and point B shown in Figure 12.2.2 .

- A hook-shaped coastline was formed in the vicinity of the revetment from 1967 to 1976. However, after 1991, it gradually decreased and adversely become concave in 2008. It is thought that such local coastline change is connected with changes in the reef in front of this coastline. As for the reef condition in the front area, the color difference because of coral colonies was seen from 1967 to 1976 when the hooked coastline was still seen in this area. But it is not seen thereafter. It means that the disappearance of the reef-formed coral colonies might have an influence on the change of the coastline. On the other hand, in the blue framed area (Petit Verger) in the figure, the color difference because of coral colonies is seen remarkably in 2008. As the result of reef investigation described hereafter, it is confirmed that tree coral (*Acropora genus*) is inhabiting in this reef at high coverage-rate (60%).
- At the east end of the reef, there are clearly visible streaks or lines toward the east from an off-shore direction. This shows that the current goes through from off-shore to the east since the reef is not present at the east end due to influence from GRNW.
- The general sediment budget shows +50,000 m^3 (1,250m^3/ year) in 40 years and it tends to increase remarkably. The tendency to increase almost maintains constantly except for the period from 1992 to 1997. In the remarkably eroded area, Sub Cell-2, it is -30,000 m^3 (-750m^3/ year), and in sedimentation area, Sub Cell-4, it is 70,000 m^3 (1,750m^3/ year) as shown in Figure 12.2.7.

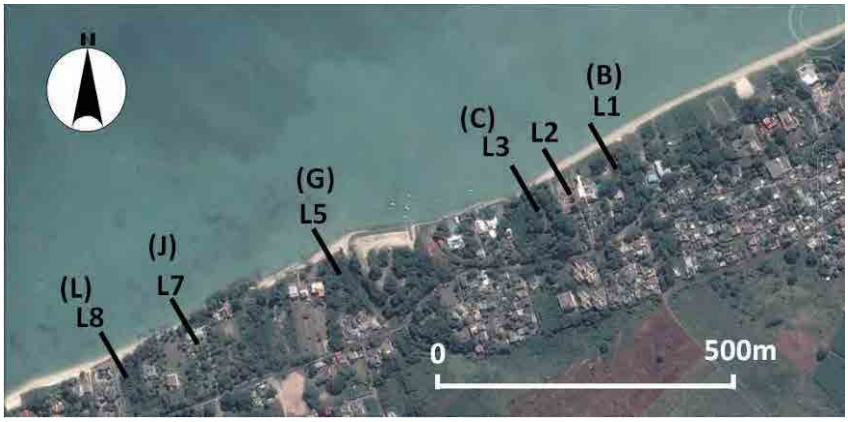
12.2.3 Short Term Coastline Change (continuous monitoring results)

This coast is one of the targeted coast for continuous monitoring in this project. Ten survey lines have been established along a 1.5 km-long section of coast including the public beach, and coastal monitoring surveys have been carried out approx. every 3 months from November 2013. As the monitoring for around one year, Figure 12.2.9shows the results of representative 6 points mentioned in Figure 12.2.8. In addition, Figure 12.2.8 also shows the photo positions which are close to each survey point (refer to Figure 12.2.1).

- In L1 - L3 to the east side of the revetment, remarkable section changes have not been observed at L1 point, but constant coastline erosion is apparent at L2 and L3. The coastline erosion occurred during about a year from November 8, 2013 to October 31, 2014, reaching around 3 m in L2 point, and around 4-5 m in L3 as well. Since such coastline erosion is not seen in the long-term coastline change from 1967 to 2008, it may be said that these changes have occurred after this period.

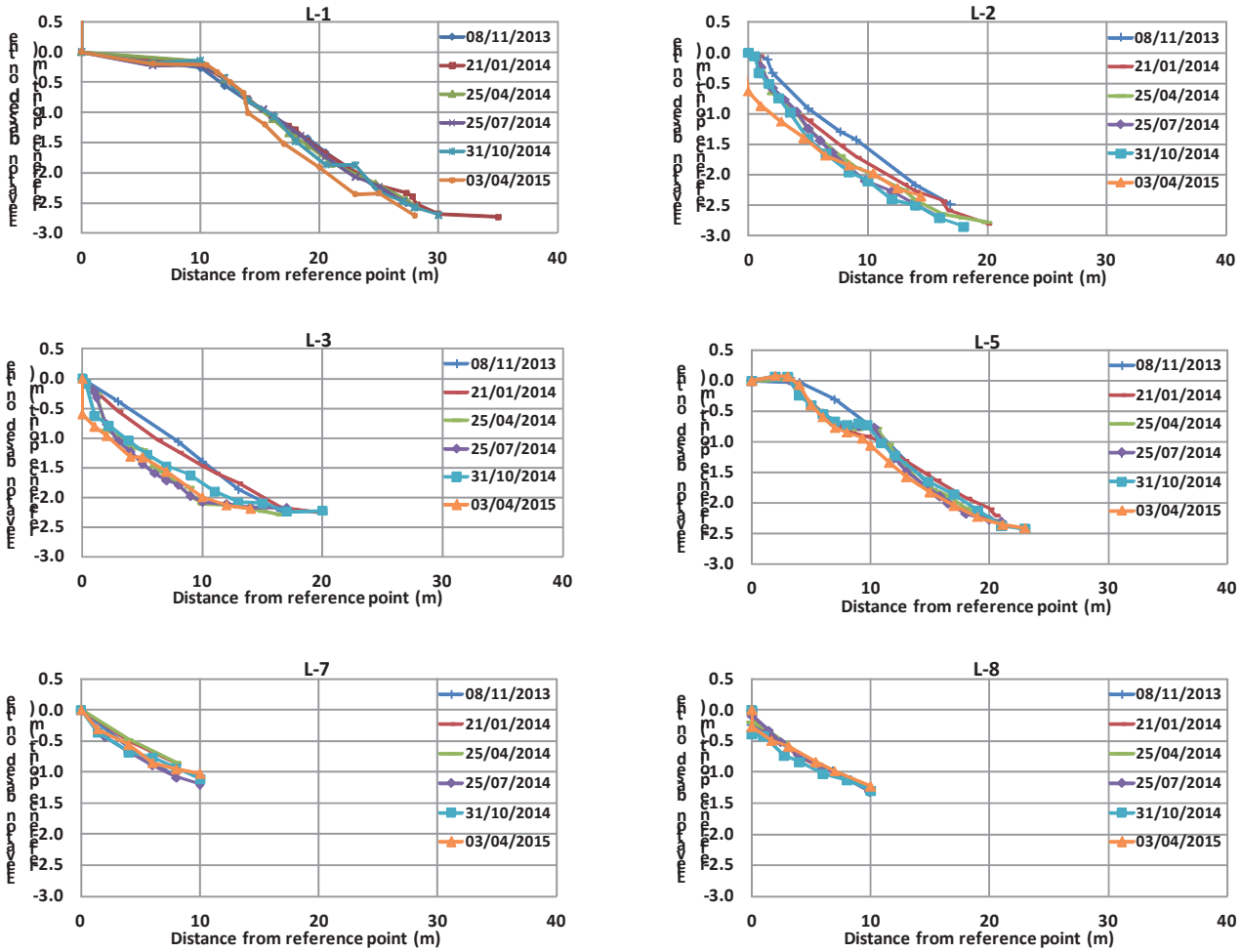
- In L5 - L8 points to the west side of the revetment, remarkable section change is not seen at the L5 spot, but the tendency of erosion is seen in L7 and L8 points. But, the erosion is around 1-2 m and it is smaller than that of the east side. Coastline is not eroded uniformly, and the seasonal change can be seen. In addition, it is almost the same level as the biggest erosion (-0.8m/ year), which is estimated by a long-term coastline change.

Accordingly, despite the fact that erosion is only occurring in a limited area, there is remarkable and on-going erosion on the east side of the revetment. Since it seems remarkable after 2008, it is thought that the revetment built in 2010 is influencing this erosion. On the other hand, it is shown that the coastline erosion on the west side of the revetment, which is distinguished by long-term coastline change, is continuing until now.



Source: Edited by JICA Expert Team based on Google Maps

Figure 12.2.8 Coastal Survey Points



Source：MOESDDBM and JICA Expert Team

Figure 12.2.9 Result of Continuous Coast Monitoring in Representative 6 Points

12.2.4 Characteristics of Wave, Water Level, Current, Topography, Bed Material and Reef Environment

a. Meteorological and Hydrological Conditions

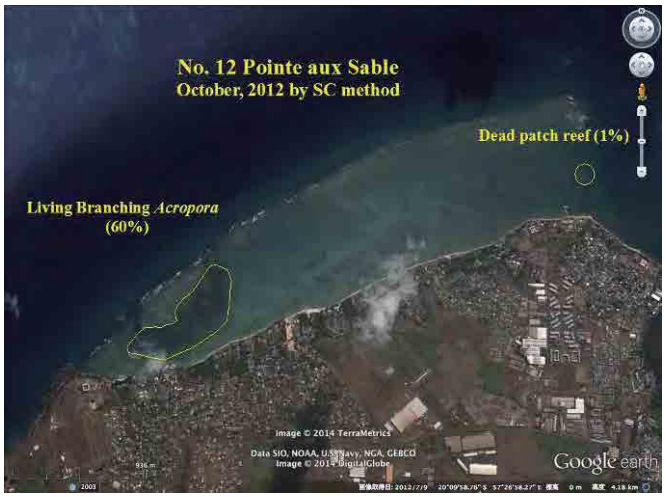
This coast is located on the northwest side of the main island of Mauritius, and the coastline extends in an east-west direction. In this regard, it is thought that the high waves during cyclones greatly influence the coastal change of this coast. Also, the height of waves propagated off-shore is small because the reef width is wide along the coast located in the northwestern part of the island. Therefore, it is thought that the influence of the wind and waves in the reef also affect the beach behavior. As distinguished from the aerial photos of 1991 in Figure 12.2.6, the incident direction of off-shore waves is predominantly from a northwest to west-northwest direction.

b. Coastal Topography and Sediment Material

Most of coast area is sandy beach of the coral origin, but several rock reefs exists at the east end. The cape with the reef is located at the west end, and the reef continues around 4 km to the east side from there. The reef width becomes gradually wider from west to east, being around 300 m at the west end to around 1 km at the east end. The river (Black River) flows into the east end, and the reef suddenly disappears. The incline of foreshore is almost 1:8. Since no particle size analysis has been done, there is no fixed-quantity data about the particle size. But it seems relatively coarse at around 0.3-0.4 mm by observation.

c. Reef Environment and Water Quality

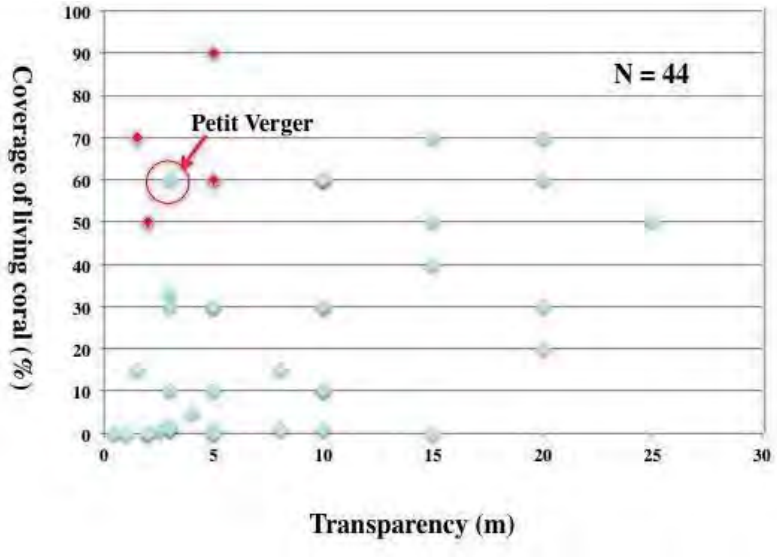
According to the monitoring survey by spot check (SC) method in 2012, coverage of massive and corymbose-type corals was only 1 % at the patch reef off Pointe aux Sables, and fragments of branching *Acropora* scattered around the patch reef. There were no Juvenile *Acropora*. Seagrass and seaweed beds were not seen in this area. Transparency was only 3 m and siltation was high. However, transparency was 3 m and siltation was high in the west lagoon off Petit Verger and coverage of corals dominated by branching *Acropora* was estimated to be 60 %.



Source: JICA Expert Team modified Google Earth.

Figure 12.2.10 Monitoring Results of Spot Check Method in Pointe aux Sables and Petit Verger

According to the aerial photographs taken in 1996 and its analyzing results, living corals covered in the west half of back reef and macro-algae seemed to grow thick in the east half of back reef. And, the seagrass bed also seemed to be located in front of central coast. And, living corals covered the patch reef off Pointe aux Sables at the time. Area of coral community off Petit Verger gradually increased in these 18 years. Generally, coverage of living corals has a positive relationship with transparency and has a negative relationship with degree of siltation. However, this coral community is plotted out of the relationships, so there is a possibility that this coral community has a tolerance to pollution (Figure 12.2.11).



Source: JICA Expert Team

Figure 12.2.11 Relationship between transparency and overage of living coral

The investigation results on water quality and impacts to water quality in the lagoon are shown in Table 12.2.1. The water quality in vicinity of the coast is affected by GRNW River. Turbidity and siltation is high. Chlorophyll a is 0.63 ug/L on an average and at a level that it is not well suited as a habitat of coral (the coverage of living coral is 10 to 20%.). According to the results of water quality monitoring by AFRC, coliform is always high (higher than 500 MPN/100ml). With respect to the water quality of GRNW River, compared with that of lagoon, the nitrogen concentration (NO_3 in river: 1.09-2.10 mg/L) is become ten times higher by time. This coast is a densely populated areas (population density: 2,946 /km^2) and sewerage system nearly maintenance. However, still a considerable number of households are using AP or ST. As the cause of the eutrophication, the effects of drainage from the houses not connected to the sewerage system and the pollution load from GRNW River are considered. At this coast, the sewage water which had drained to the inside of the reef became to be drained to the outside of reef by the water quality improvement project in 2007. The water quality in vicinity of this coast is likely to be improved in the future. However, the upstream side of GRNW River basin has still many underdeveloped districts of sewerage system.

Table 12.2.1 Investigation Results on Water Quality and Impacts to Water Quality in Lagoon

Check items		Conditions			
Water quality	Chlorophyll a (ug/L)	0.33-1.20(#) (Ave. 0.63)			
	Turbidity (NTU)	1.07-9.05(#) (Ave. 2.28)			
	NO_3-N (mg/L)	<0.01-0.07(#) (Ave. 0.04)			
	PO_4-P (mg/L)	<0.005-0.01(#) (Ave. 0.007)			
Population density behind coast(per km^2)		2,946			
Sewerage disposal behind coast	Status of development of sewerage facilities behind coast	Sewerage Systems(Trunk Sewer), Absorption Pit, Septic Tank, Pit Latrine			
	Present condition of sewerage disposal from houses (Sewerage system, Septic tank, Pending arrangement, etc.)	Town of P Louis VCA SS: 2215, AP: 997, ST: 236, PL: 33			
	Present condition of sewerage disposal from hotels and restaurants (Sewerage system, Septic tank, Pending arrangement, etc.)	Septic tanks, Absorption pits			
	Development plan of sewerage system for houses and hotels behind coast	NIL			
Impact of pollution from sugarcane	Incidence of red-soil runoff from land side	None			
	Existence of sugarcane field behind coast. If there is it, area of the field behind coast.	None			
Relation between living coral and water quality**	Coral coverage	Chlorophyll a (ug/L)	Turbidity (NTU)	NO_3-N (mg/L)	PO_4-P (mg/L)
	>50%	<0.2	<0.5	<0.012	<0.007
	20-50%	0.2-0.6	0.5-1.3	0.012-0.051	0.007-0.016
	10-20%	0.6-0.9	1.3-1.9	0.051-0.081	0.016-0.023
	<10%	>0.9	>1.9	>0.081	>0.023

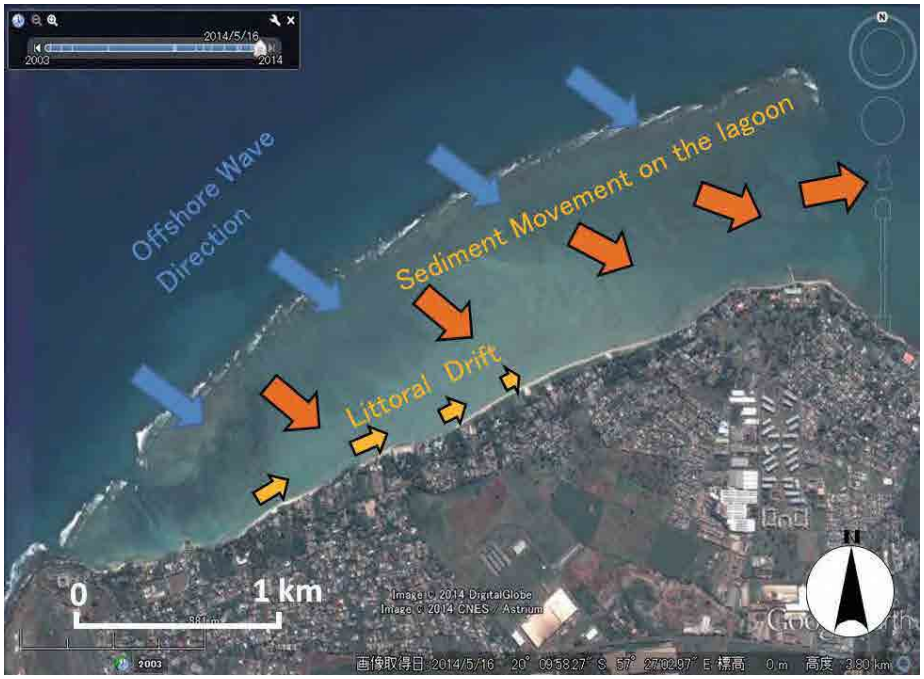
#: Observation for water quality and coral reef was conducted from the shore to the reef edge.

**: This relation was obtained by the water quality survey in this study. Refer to Table 2.6.3 in Vol.1.

SS: Sewerage Systems, Ap: Absorption Pit, ST: Septic Tank, PL: Pit latrine
Source: JICA Expert Team

12.3 Littoral Drift and Cause of Erosion

12.3.1 Littoral Drift



Source: Edited by JICA Expert Team based on Google Maps

Figure 12.3.1 Wave and Littoral Drift Pattern at Pte. aux Sables

Figure 12.3.1 shows the incidence direction of the waves, the sand movement direction on the reefs and the littoral drift along the coast as estimated from the above-mentioned various approaches. It is thought that the sediment may move to the land side from the off-shore on the reef by the incidence of westerly waves in this coast. And then, it may gradually move to the east, as a whole, by the littoral drift facing east. The volume of drift sand as the whole coast is estimated to be 1,000 - 1,500 m^3/year as the result of a long-term sediment budget (Figure 12.2.7). Since there is the difference in the drift sand volume locally, the erosion area and sedimentation area is seen in this coast.

12.3.2 Causes of Erosion

The problems and causes of erosion on this coast are as mentioned below.

a. Long-term Coastline Erosion in West Side of Public Beach

The 500 m-long stretch of coast (Sub Cell-2) from the western end of the new revetment at the public beach has experienced constant coastline erosion since 1967. The coastline erosion in 40 years is around 20 m (-0.5m/year) on average, and a maximum of 33 m (-0.8m/year). In addition, from one-year coast monitoring results, it is confirmed that this erosion is still in progress. However, since it is seen that littoral drift facing east is prevented in the west end of the new revetment, the erosion speed may fall as a result of the construction of the new revetment (compared with that of before construction). The causes of this erosion may be the change of seaweed habitation on the reef, and the decrease of the sand supply from the reef with the coral environmental degradation. Other possible contributing factors to the erosion

may include the disappearance of the foreshore and the construction of the vertical retaining wall, which was carried out after a period of significant erosion.

b. Local Coastline Erosion on the East Side of the Public Beach

Remarkable coastline erosion occurs in the range of approximately 200 m from the east end of new revetment of the public beach since its construction in 2010. The coastline erosion amount is up to 4 – 5 m/year at the maximum point from the coastal monitoring results. The new revetment seems to be causing the erosion to the east side of the public beach because it's construction extended the coastline 10 to 20 meters in a seaward direction, thereby obstructing the eastward littoral drift. It is thought that the coastline erosion will continue in future and it may be enlarged little by little to the east side although the erosion volume is thought to gradually decrease.

c. Deterioration of the Habitat of Coral & Seaweed due to Waste Water

In this coast, eutrophication which is caused by the turbidity of water and waste water is advanced in comparison with other coasts in Mauritius and the deterioration of water quality is seen remarkably. In addition, distribution level of the coral decreases on the reef compared to the past, and seaweed bed close to the land of the central part has now disappeared. As a whole, even though the sediment budget is positive and there is an accretion trend at this coast, the deterioration of the habitat of coral and seaweed may cause the decrease of the sand source of supply in the long term future. Furthermore, eutrophication may cause the increase of the littoral drift because the wave reduction effect by such as coral and seaweed decreases.

12.4 Coastal Conservation Measures

12.4.1 Outline

In this coast, the coastline erosion between 500 m west and 200 m east of the public beach is a problem which requires urgent measures. This problem area is personal leased land area, so that it is necessary for individuals to take the protection measures basically. However, as the protection measures that can be carried out by individuals, it is limited mainly to the structural measures such as revetment and/or small groyne and so on. On the other hand, the increase in total sediment budget is relatively remarkable in this coast. In other words, coastline erosion is a problem where the hinterland has been developed, because of the change of the balance of the littoral drift, but erosion is not an issue affecting the whole coast. With such a background, the measures to protect personal land will not solve this problem. Meanwhile, in the east side of the problem area, the remarkable sedimentation occurs adversely. Accordingly, it is necessary to make the short-term measures in the comprehensive viewpoint which considers continuity of the littoral drift and the overall coast situation in this coast.

Furthermore, in this coast, the deterioration of the water quality caused by the artificial influence and also the associated deterioration of the reef environment are seen. Thus, it is necessary to come up with long-term measures to tackle these problems.

12.4.2 Principle of Measures

a. Short-term measures

- As long as there is littoral drift in this area of coastline the current problems cannot be solved with merely structural measures. Also, the total sediment budget in this coast tends to increase remarkably relative to other areas. Accordingly, the sand recycling from the sedimentation area on the east side is a basic short-term measure for the problem area.
- In accordance with the basic policy of the proposed coastal conservation plan, artificial (physical) structures should not be constructed as much as possible. On the other hand, the sand recycling to be recommended requires periodical maintenance (sand filling) basically. If the remaining ratio of the sand after sand filling is possible to be improved in order to decrease of the maintenance cost, additional structures such as groyne and so on shall be considered.

b. Long-term measures

- The water quality improvement to improve the habitat of coral and seaweed as well as increasing the recreation value of the reef shall be planned.
- The setback of houses shall be recommended at the time of the updated lease contract in the next term. It is necessary in order to reduce the inundation risk at residential areas which is caused by the reduction of medium-and-long term maintenance on sandy beach and the water level rise with the future climate change.

12.4.3 Short Term Measures

a. Preconditions

Preconditions to study sand recycling are described as below.

- Area to be filled with sand (sand nourishment) are two stretches of coast with no dry beach, namely 350 m of the 500 m long beach on the west side of revetment, and 150 m of the 200 m long section to the east of the revetment. The dry beach does not exist in front of the new revetment either, but the recovery of the sandy beach in this area is not considered since it was built for the protection of the community area in its hinterland.
- The new revetment is one of the factors causing the local coastline erosion in the east side of the new revetment recently. As a way of reducing the coastal erosion on the east side of the new revetment it is recommend that the revetment be removed or setback. On the other hand, the new revetment is now acting as a control point of the littoral drift, and it may be reducing the speed of erosion that has been occurring over the long term on west side of the revetment. Basically, this revetment was built for creating the public area as the citizen's oasis in the limited space in this coast. Accordingly, the removal of revetment or the setback shall not be included in the short- term measures.
- It is not realistic from the stability aspect of the beach nourishment to revive the coastline to the same as that of 1967. Based on the recent land use as the residential area in the hinterland, the plan is to revive the foreshore at an incline of 1:8 in off-shore from the border line of the revetment. As a result of coastal monitoring, assuming that the

average inclination is 1:5 and berm height is 2.5 m in the current eroded area, it is estimated that the required initial sand volume is about 3,300 m^3 in west side, while about 1,400 m^3 in east side of the revetment.

- By the long-term sediment budget, the average volume of sand loss in the west eroded area is estimated at around 750 m^3/ year. It is thought that the speed of sand loss in the east eroded area may be faster than this from the coastal monitoring results. The frequency of the sand recycling considering cost as the coast maintenance is assumed one time a year with around 2,000 m^3/time (1,000 m^3 each on the west and east sides). In addition, the sand accretion in the sedimentation area is estimated at 1,750 m^3/year, and the sand recycling from the sedimentation area of around 2,000 m^3 every two years is judged sufficiently enough.

b. Comparison for Filling Area of Sand Recycling

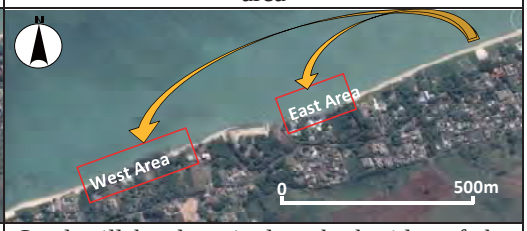
It is thought that there are two methods for sand recycling.

1) Method to handle the problem areas from the west side to the east side of revetment as a continuous area.

2) Method to handle the separate area, the west side and the east side of the revetment, and to cast respectively into two sides.

Table 12.4.1 shows the comparison of those two methods.

Table 12.4.1 Comparison of Sand Recycling Filling Method

Method	(Case-1) Handle west side & east side as one area	(Case-2) Handle west side & east side as separate two area
Outline		
	Sand is filled into only the west side, upper side of the littoral drift, and it is expected that the sand will move naturally downdrift to the problem area (west side) by the easterly littoral drift. In this case, consecutive littoral drift movement beyond the new revetment is the premise.	Sand will be deposited on both sides of the new revetment, the west and the problem area of the east side separately. In this case the revetment becomes the control point of the littoral drift.
Achievability, certainty	Since revetment is constructed protruding onto the foreshore, sand movement to the downdrift side of the revetment is not currently observed. If sand movement beyond the revetment is required, it needs the period for the sand to pass the revetment as well as enough sand supply on the 'up-drift' side. Dynamic management is a must in non-uniform coastlines; therefore achievability cannot be guaranteed.	Sand will need to be deposited in two areas, but certainty is higher than case-1. On the other hand, it is required that the outflow of deposited sand by the littoral drift to the east shall be reduced in both west and east side as well. If the revetment can be used as control point, the additional groyne which can reduce the outflow of deposited sand shall be constructed. It is possible to maintain the sandy beach in the west side.
Workability/work Cost	Two filling areas in case-2, workability and cost are not significantly affected by these two areas.	
Utilization aspect	No difference in both case	
Environ-mental Aspect	No difference in both case	
Evaluation	Not recommended	Recommended

Source：JICA Expert Team

Accordingly, as the method of sand recycling, and depositing of sand in two places of the west side and east side of the revetment (case-2) is recommended.

c. Measures at West Area

It is thought that there are two methods for sand recycling at the west side area.

1) Sand filling only. It allows sand movement (dynamic measures)

2) Sand filling and construction of groyne for preventing sand movement (static measures)

Table 12.4.2 shows the comparison of those two methods.

Table 12.4.2 Comparison of Measures in West Area

Method	Case-1 : Dynamic Measures (Sand Filling only)	Case-2 : Static Measures (Sand filling + groyne construction)
Outline		
	Sand filling only. Drift sand movement to the east is allowed.	Sand filling and construct groyne to prevent the sand movement/outflow.
Initial Cost(Direct Cost only)	Sand filling from the sedimentation area. Cost is cheaper than Case-2 (Sand filling; 3,300 m^3, unit price of sand; 550MUR/m^3, accordingly initial cost: 1.8 million MUR)	To keep the stable shape, sand volume increase by 30%. Also including groyne construction cost, cost is higher than Case-1. (i.e. It need additionally 2.6 million MUR for 2 groynes (L=50mx2), 26,000 MUR/m, additional sand volume of 1,000 m^3 needs additional cost of 0.5 million MUR)
Maintenance Cost (for 10 years, Direct Cost only)	Periodical sand filling is necessary (once per 2 years) and maintenance cost is required. In case of sand recycling from sedimentation area with 1,000 m^3 per 2 years, 2.8 million MUR is necessary for 10 years (unit price of sand; 550MUR/m^3).	Due to prevention of the sand movement/outflow, periodical sand filling is less of a necessity. Sand filling may be required around every 10 years. In case of sand filling with 1,000 m^3 after 10 years, 0.6 million is necessary (unit price of sand; 550MUR/m^3).
Total Cost (for 10 years)	4.6 million MUR/10 year	5.5 million MUR/10 year
Utilization aspect	Sand always moves/outflows at the measures area. On the other hand, the sandy beach will be expectedly developed in front of groyne by the moved sand.	Stable maintenance is expected at the measures area. There may be no beach in front of revetment at backside of groyne.
Environmental aspect	Natural coastal view is maintained.	Artificial structures (groyne) stands in the coastal view.
Evaluation	Recommended if priority is place on the view	Recommended if priority is placed on reducing management requirements

Source: JICA Expert Team

From the comparison mentioned above, dynamic measures of Case-1 is cheaper. On the other hand, the dynamic measures of Case-1 needs the appropriate management based on the monitoring result and the cost is largely dependent upon the actual outflow volume of the sand.

Measures are chosen from the perspectives of utility, environmental and total cost of each case. In this study the dynamic measures of Case-1 will be applied.

d. Measures at East Area

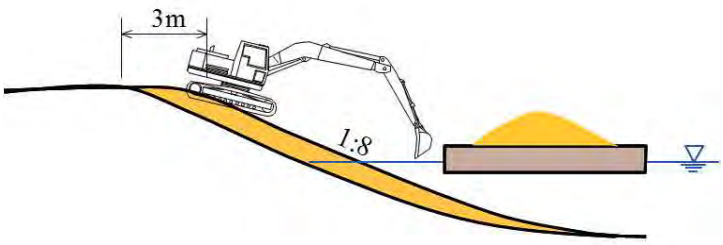
In the east eroded area unlike the west area, the consecutive sandy beach continues at the east side which is located on the down-drift side. Since the static measure using a groyne which is shown as one of the substitute plans in the west area, is likely to produce more erosion in the other area of down drift side, it cannot be recommended. Accordingly, it is solely applied in the east side area that the sandy beach is maintained by the periodical sand filling dynamically.

e. Practical Sand Recyclying Method

Excavation from Accumulation Area

The estimated sand excavation area is Sub Cell-4 (Figure 12.2.7) which has had the coastline expansion with average of around 25 m wide and sand increase of approximately 70,000 m^3 on the costal line of around 1 km long in the past 40 years. It is planned that the initial filling of 4,700 m^3 for coastline sedimentation area will be acquired in the area shown in Figure 12.4.1. The sand acquisition can be considered from the surface layer of backshore, but the particle size is generally smaller than in the foreshore. Therefore, it is planned that the sand will be acquired from the foreshore while maintaining the current beach incline. Since this coast area has been already used as personal residential land and for villas, the securing of access road for transportation of sand is difficult. It is thought that marine transportation using small pontoons is most realistic.

Source: Edited by JICA Expert Team based on the satellite image from MHL



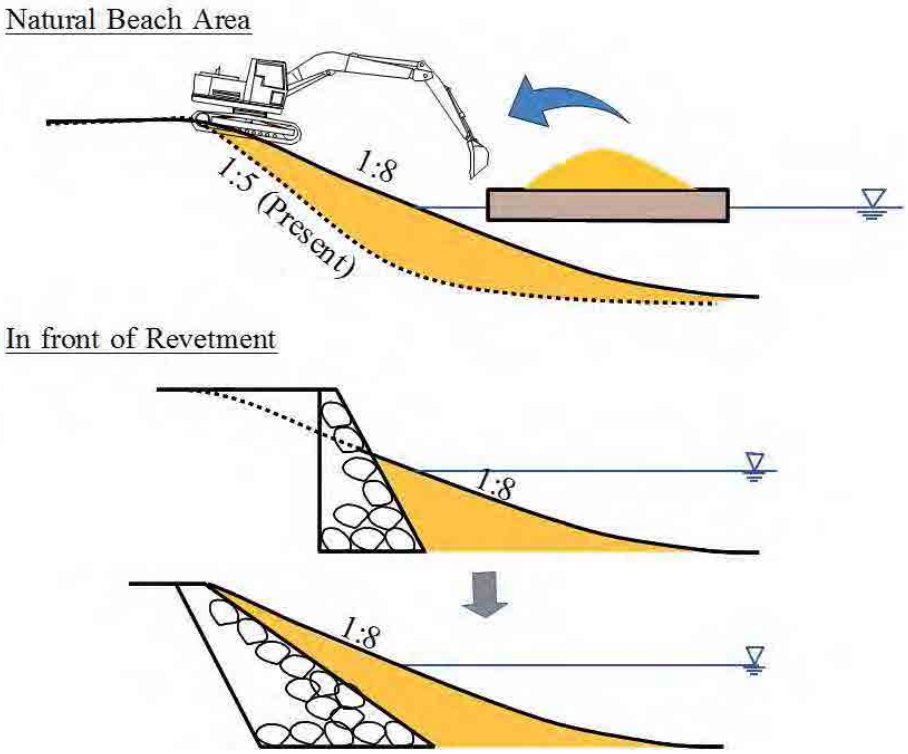
Source: JICA Expert Team

Figure 12.4.1 Sand Excavation from East Sedimentation Area

Sand Fill to East Eroded Area

From the precondition, it is assumed that initial filling volume is 1,400 m^3, the periodical filling volume is 1,000 m^3/2 years as the maintenance for the east eroded area. Filling area and sloping image is shown in Figure 12.4.2 . Here, the existing revetment is located further off shore than the present surrounding coastline (Figure 12.2.2 , point E). In order to improve the maintenance of the sand after sand filling, it is expected to do setback to the existing boulder revetment with 1:1 of slope inclination as much as possible and to make a more gentle slope than that of the existing one.

Source: Edited by JICA Expert Team based on Google Map



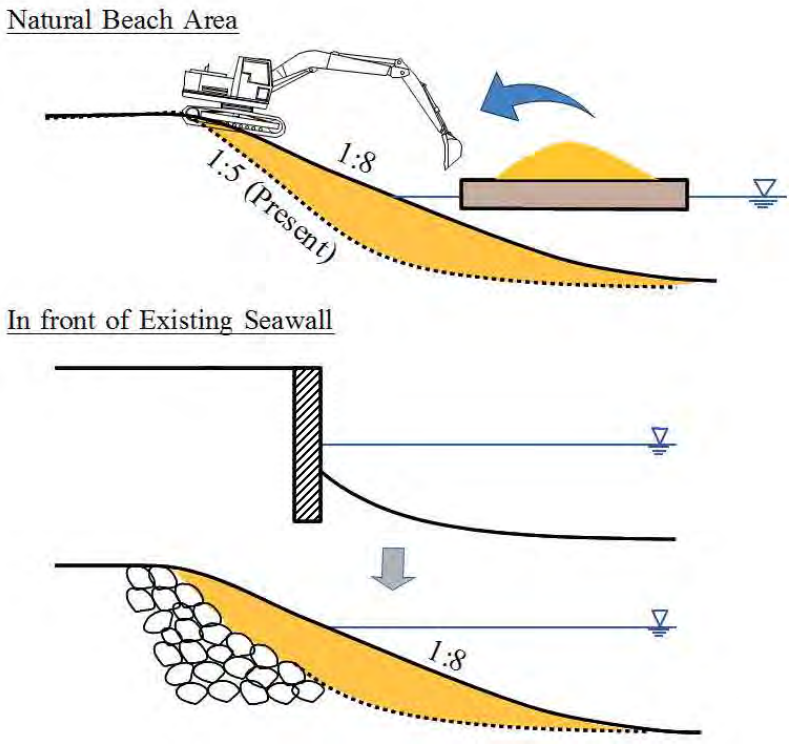
Source: JICA Expert Team

Figure 12.4.2 Typical Image of Sand Filling and Sloping at the East Eroded Area

Sand Fill at West Eroded Area

From the precondition, it is assumed that initial filling volume is 3,300 m^3, the periodical filling volume is 1,000 m^3/2 year as the maintenance for the west eroded area. Filling area and sloping images for the dynamic measures (Case-1) is shown in Figure 12.4.3. Also, in the west side of the sand filling area, the land is protected by the existing impermeable vertical retaining-wall made of concrete (Figure 12.2.3 point K). It is recommend that the existing impermeable vertical retaining-wall will be improved to the permeable boulder type revetment with gentle slope. Furthermore, the alignment of revetment is expected to be at least the same line of the surrounding natural beaches since it is confirmed that there is the space in the hinterland by the site survey.

Source: Edited by JICA Expert Team based on Google Map



Source: JICA Expert Team

Figure 12.4.3 Typical Image of Sand Filling and Sloping in West Eroded Area

f. Summary of Short Term Measures and Rough Cost Estimation

Recommended short-term measures and cost estimates are summarized at Table 12.4.3 below.

Table 12.4.3 Recommended Short-term Measures & Project Cost for Pte. aux Sables

Item	Description
Coverage Area	Eroded areas to the east (150 m long) and west (350m long) of the revetment on the public beach
Measures	・Sand recycling from east sedimentation area, ・Improvement of existing revetment（gentle slope, permeable revetment＋proper setback）
Initial Sand Filling Volume	East eroded area : 3,300 m^3, West eroded area : 1,400 m^3
Periodical Sand Filling Volume	East eroded area : 1,000 m^3/2years, West eroded area : 1,000 m^3/2years
Estimated Cost (as reference) (Note：direct cost only, excl. VAT）	Initial sand fill：2.6 million MUR（assuming 550MUR/m^3） Periodical sand fill for maintenance：1.1 million MUR（assuming 550MUR/m^3)

Source: JICA Expert Team

12.4.4 Long Term Measures

a. Enforcement of the Water Quality Improvement Measures based on the Water Quality Monitoring

At this coast, as mentioned above, the sewerage treatment plant was constructed in 2007 to improve the water quality on the coral reef. However, it is insufficient to evaluate the improvement effects because of the problems on the analytical precision for water quality monitoring and so on. In future, it is necessary to conduct the water quality monitoring with high precision analysis and the survey to understand the effects of the pollution load from the river and the drainage from the houses in the hinterland. Based on these monitoring results, if improvements are not observed, then it will be necessary to work to connect to the sewerage system those houses that are as yet unconnected.

b. Setting of Conservation Area on the Reef

Since the coral colony mainly consisted of the *Acropora genus tree coral* is distributed in the off-shore of Petit Verger at the west end of this lagoon, this area shall be set as the conservation area, and it is wished to be conserved. This colony may be the contamination-resistant colony, and it can be used as a donor coral when trying to transplant to the back-reef in this lagoon in the future.

c. Recommendation of Setback when the Next Lease Contract is Updated

There is the area where the buffer zone of 30 m from HWM does not meet setback requirements due to the construction of coastal revetments by the lessees and the retreat of the coastline due to erosion. The setback is difficult to enforce practically because of existing lease contracts, but it is recommended that the setback meets the 30 m buffer zone when the

next lease contracts are updated. In this way, it will lead to a reduction of the inundation risk at the residential area caused by the reduction of medium-and-long term sandy beach maintenance and by the rise of water level with the future climate change as well.

12.5 Beach Operation and Maintenance Plan

12.5.1 Improvement Plan against Present Beach Management Issues

In regard to the Beach Maintenance and Land Utilization for Pte. aux Sables, the present issues and the improvement plan are described in Chapter 5 in the Volume 1. The issues and the improvement plan for the system and implementation which common to the most of the target beaches are described in Chapter 5 as well. This section shows improvement plan against present beach management issues of the beach as follows.

a. Existing coastal facility issues

- Modification of revetment from vertical type to sloping permeable type with plantation
- Demolition and modification of groynes depending on effective

12.5.2 Beach Management Plan for Coastal Conservation Plan

In this section, several concerns on management for beach conservation are specified. The Beach Conservation Plan of Pte. aux Sables recommends a Sand Recycle from the accumulated sand in Eastern area to the eroded area around newly built revetment as a short-term measures.

As for the extraction of accumulated sand, there are resident in the backland of the area. So it is necessary to confirm the boundary of the lease-lands in the first place. Then implementation plan including the method for an extraction and transport of the sand and environmental impact assessment should be elaborated in agreement with the residents. Further, it is necessary to discuss between the public and the private sectors on the implementation of the Sand Bypass in the lease-land area. The joint implementation with cost sharing under the cooperation between the public and the private sectors is preferable. Even so, the regular monitoring and planning for implementation should be prepared by the MOESDDBM.

12.5.3 Validity Setback Amount

The setback amount for eroded sand beach is configured as summation of the amount of erosion during a certain period and the amount of erosion which is caused by strong wave such as cyclones in that period, which is described as following.

Amount of setback = Amount of erosion for a long period + Amount of erosion by temporally event (i.e. extreme weather conditions such as cyclones)

In addition, the erosion due to the SLR (sea level rise) is anticipated in future. There are several proposed equations to estimate the amount of erosion due to the SLR. Among these, the equation proposed by Per Bruun is applied generally. The equation is as follows.

$E=C\times S$

Where, E: Erosion amount due to the SLR, C: coefficient of beach characteristic and S:

amount of SLR. Therefore, the amount of setback needed is described as follows.

Amount of setback = Erosion amount for a long period + Erosion amount by extreme weather conditions + Erosion amount due to SLR

The rate of the SLR from 1987 to 2011 is about 3.2mm/year in average, and the coefficient of C, which is related with the inverse of sea-bottom slope and transportation area of sediments, is set as 10 by the mean sea-bottom slope in Mauritius. The erosion amount due to the SLR, therefore, is calculated as 1.6 m by multiplying averaged erosion rate of 3.2mm/year, the coefficient of 10, and the period of 50years (E=10×3.2mm/year×50years=1.6m).

12.6 Issues on Implementation

a. Conducting Continuous Coastal Monitoring and Adaptive Management based on its Results

The timing and volume of the sand recycling recommended for this coast has to be managed depending on the continuous coast monitoring results in an adaptive way. Accordingly, a system for managing and implementing the above needs to be established.

b. Formulation of Inhabitants Consensus for Use of Sand in Sedimentation Area and Improvement of Revetement

The consent of the local residents will be needed in order to use the sand from the sedimentation area. Therefore sound technical evidence as well as persistence will be needed to gain the residents' understanding. If the sand from this area of sedimentation (in front of the residents' houses) is not usable, the sand will have to be purchased from elsewhere at more than three times the cost.

In addition, each lessee will basically be responsible for the upkeep of their existing revetments together with the sand recycling. The consensus to proceed is also necessary. Furthermore, in order to gain the understanding of the residents regarding the necessity of the long-term setback, the continuous information sharing about the coast and reef changes to promote the understanding of inhabitants will also be necessary.

c. Information Sharing with other Related Organizations about Water Quality, Coral Environmental Monitoring and Cooperation

In this coast, the contamination of the water quality and the coral environmental degradation due to wastewater are apparent. Although the water quality monitoring seems to be carried out, the information sharing is not enough. The information sharing and the cooperation with the related government organizations (ministry of fisheries, ministry of housing & lands) are indispensable in order to maintain the coast well through the improvement of the medium-and-long term water quality and reef environment.

Chapter 13

Grand Sable

13 Grand Sable

13.1 General

Grand Sable is 3km long beach between Pte. aux Feuilles in north and cape-type shaped Pte du Diable in south located in south east of Mauritius. It has been chosen as a representative of the eastern coast from Bois Des Amourrettes to Deux Freres. In this study northern part of beach in its length of 400m located between two small rivers where a mass of residential area exists was selected as the planning site. Flexible revetment was placed at Grand Sable to demonstrate its effectiveness in preventing wave overtopping there by protecting the low lying areas. Flexible revetment is an alternative to other coastal protection measures such as gabion and rock revetment. During the study development of construction plan for the flexible revetment was carried out and the construction of the half in south part was implemented. (see the Volume 1, Chapter 8)

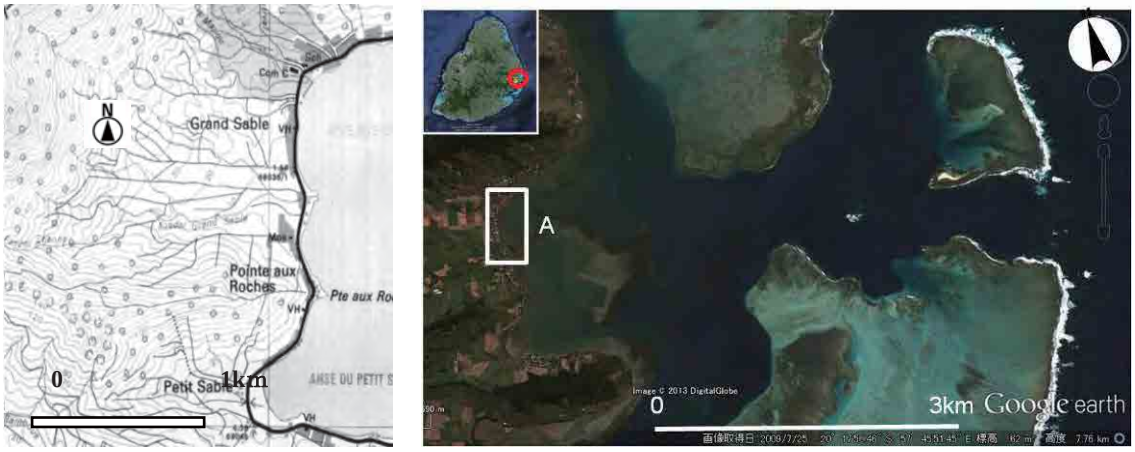
13.2 Coastal Conditions

13.2.1 Waves and Tides

The projected beach is located on southeast of Mauritius and waves generated by trade wind from southeast wind hit the beach. The beach encounters seasonal cyclone. Height of stormy wave is decreased by the front reef and the bottom friction. There is conspicuous wind generated wave in the lagoon generally. The tidal range at a spring tide is 0.86m estimated from the observation at Blue Bay and others. (Refer Vol.1 Ch.2) The water level in a lagoon has to be considered the storm surge and the wave setup together with the tide.

13.2.2 Coast Condition

The coast shown as Figure 13.2.1 is located on the north of estuary sandbar formed by the river and outer part of the bay surrounded by the plateaus formed by lava. The coral reefs spread to about 6km offshore and are formed by the width of 1 to 2km in the coastal front. A water channel is formed between the reefs. Silt and gravel flows out from the river, the gravel is deposited in the estuary and mangroves are growing the estuary. The bed of the coast is filled with silt or gravel, but volume of sand is small.



Source: left/MHL, right,/prepared by the Study Team based on Google Map

Figure 13.2.1 Land and Coastal Terrain of Grand Sable (‘A’ shows projected area)

13.2.3 Coastal Environment

Lagoon seabed consists of sand or mud with low transparency of below 1m, which is not suitable for coral habitat environment. Additionally, a large number of areas have sedimentation of silt and no sea grass beds and seaweed are found in these areas as shown in Figure 13.2.2. However, many leaves of *Halodule* are washed up on the beach and for this reason it is assumed that a mass of seaweed beds spread in the offshore. Aaccording to the analysis of aerial photo in 1996, distribution area of coral can be found in far back side of offshore and edge of reefs. Due to poor visibility in the lagoon, presence of corals could not be confirmed in these areas.

Source: JICA Expert Team modified based on Google Earth

Figure 13.2.2 Study Area of Coral Condition at Grand Sable

13.2.4 Coast Use

In terms of land use around the project area, one main coastal road traverses along the coast and residential area and agricultural land are settled in the land side of coastal road. A few bus stops as public transportation are properly facilitated along the coastal road and one community center where local residents gather to socialize is located on the clustered residential area. Since the shoreline reaches close to the coastal road, the area for recreation activity is limited to the spotted small space under trees and north public beach park of 700m^2. Additionally, the coastal area is used as mooring place for fishing boat and the slipway adjacent to the north public beach park is used for setting sail by local residents and fishermen. Moreover, around the estuary sandbar of the small river, a mass of mangrove vegetation in the sand sediment area are scattered and it would be possible for this areas to form diverse ecosystem. Regarding to drainage from the land side, since several drains are connected from the road and residential drainage directly to the beach, untreated wastewater brings about unpleasant odor near the beach. Furthermore, solid wastes can be seen along the shore. These arise from littering and also include marine litter that is being brought by the sea. It is to be noted that the east coast receives fresh water from 2 major rivers, namely GRSE and Riviere des Creoles. Driftage from these rivers ends up on the coast.

Coastal Conditions are summarized in Table 13.2.1.

Table 13.2.1 Coastal Conditions at Grand Sable

Basic investigation No.	No. 11	PB No.	No.
Coast name	Grand Sable		
Coast location			
Coast photo Coast situation	1 	Coast photo Coast situation	2 
Natural and topographic characteristics	Sea state	Waves due to south east trade winds are arriving from the south, but attenuated by wide reef (around 2km-wide).	
	Topography	Reef attenuates waves in a wide area with 5km-wide, leading to silt sedimentation. Especially in the wide reef in the southeast area, there are native mangroves. There are some gravel beaches. The medium diameter of sea bed material (under water) is within a range of 0.5 mm to 0.7 mm. The medium diameter from beach berm is around 8 mm partially.	
Environmental characteristics	Coral reef	The south part is affected by river (fresh water), where is unsuitable for coral habitat and seaweeds flourish. Coral reef coverage near beach is 0%.	
	Water quality	Transparency is 1m or less, and siltation is very high. The hinterland (beach berm) is a mangrove forest. Water quality at the south part is affected by fresh water and is polluted due to the domestic wastewater.	
Coastal transformation characteristics	Disaster and structures	Since waves are attenuated, a small damaged structure is observed. The impact to hinterland by storm surge is concerned. Only the public space located further north of the site (La Grotte) was badly damaged. The vertical impermeable retaining wall has cracked and is collapsing.	
	Coastal transformation	The results of the analysis through the aerial photograph and field work show this coast is stable.	
Coastal utilization characteristics	Beach utilization	A coast road was built and has been fully utilized as a community road. The importance of this coast seems high.	
General assessment		Since the widely used road was built at a low altitude,	

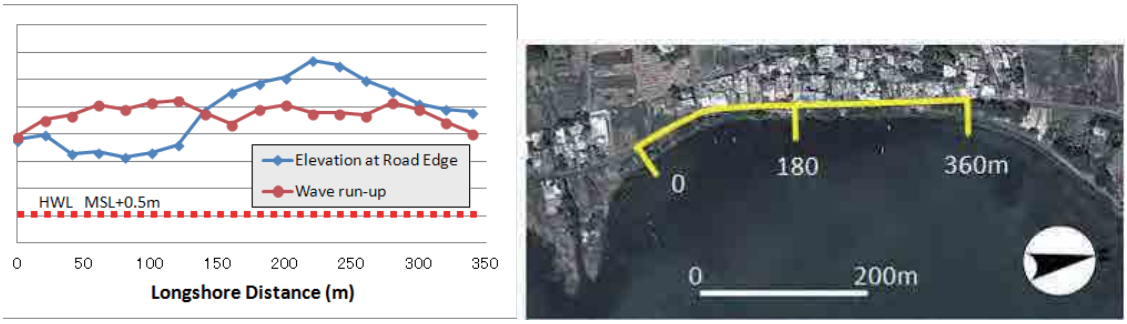
	countermeasures against overtopping waves are required. A protection program such as bank rising of road and implementation of protection measures should be considered.

Source: JICA Expert Team

13.2.5 Problems and Related Factors

In terms of the terrain of projected beach, both side of the beach is formed by discharge of sand from the rivers and in the middle it has weathered landform of volcanic rock and eroded by wave. Since the impact of the coastal erosion is just degradation of escarpment, the study found that there is no significant problem on this beach. However, there would be overtopping problem because the coastal road, which is considered as primary road from the airport to southeast tourism area, is established at low elevation land.

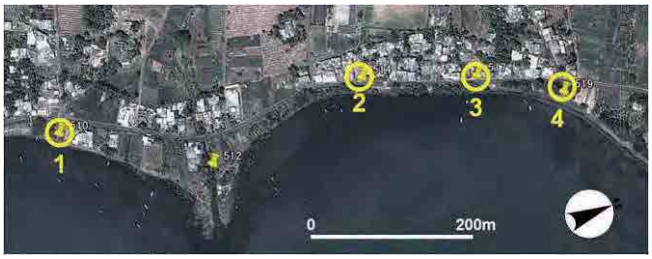
Figure 13.2.3 shows current situation of the coast to clear that it would be a problem in the road traffic when sea level rise occurs in the future due to the climate change. Especially, the impact would appear in the section of the lower elevation of 1.5m comparing to the higher elevation section.



Source: JICA Expert Team

Figure 13.2.3 Coastal Road Elevation in the Area 'A'

In the aspect of environment, shown as Figure 13.2.4, the problems of scattering garbage including littering from road side, deterioration of landscape value and having unpleasant odor can be notified in the beach. In the south estuary area effectiveness of plantation of mangrove has not been demonstrated because implementation of the activity has just started.



Location 1: Road elevation MSL+2.0m

Location 2: Road Elevation MSL+1.6m

Location 3: Road ElevationMSL+3.0m

Location 4: Road ElevationMSL+2.4m

Source: Upper Figure:/JICA Study Expert Team modified based on the Google Map, Lower Photos/ JICA Expert Team

Figure 13.2.4 Current Situation of the Area 'A'

13.3 Coastal Conservation Measures

13.3.1 Basic Policy

For the area of demonstration project for physical measure on Grand Sable, the basic principles is to apply coastal conservation with the method concerning the aspect of disaster prevention, coastal use and environment since the area has erosion and overtopping problems caused of coastal road and residential housings locating on low elevation area. Following items explain basic principles for coastal conservation measure on the projected area.

- Disaster Prevention: The facility development requires having adequate disaster prevention function against disasters caused by wave run-up and overtopping etc.
- Use: The method needs to keep the concept of nature friendly as well as functional to coastal use as one of the general ideas of coastal protection in Mauritius, although revetment construction for coastal protection measure against high wave and wave over-topping is common in Mauritius

- Environment: The facility development requires harmonization with surrounding environment and landscape with mitigating negative impacts of natural and social environment around Grand Sable
- Applicability: The idea of regenerative design needs to be sustained with the consideration of future project implementation by Mauritius. Therefore the proposed method would be implemented with available materials in Mauritius as well as economically efficient. Additionally, no specialized and difficult method would not be proposed

13.3.2 Basic Plan

As the basic plan for the coastal conservation measure of the demonstration project for physical measure on Grand Sable, Considering three applicable methods of coastal facilities, Rock armoring, flexible revetment and detached breakwater, and with the categorized evaluation analysis based on the basic principles mentioned above, the study confirmed that the flexible revetment would be most applicable for the coastal conservation measure on Grand Sable. (see Volume 1, Chapter 8)

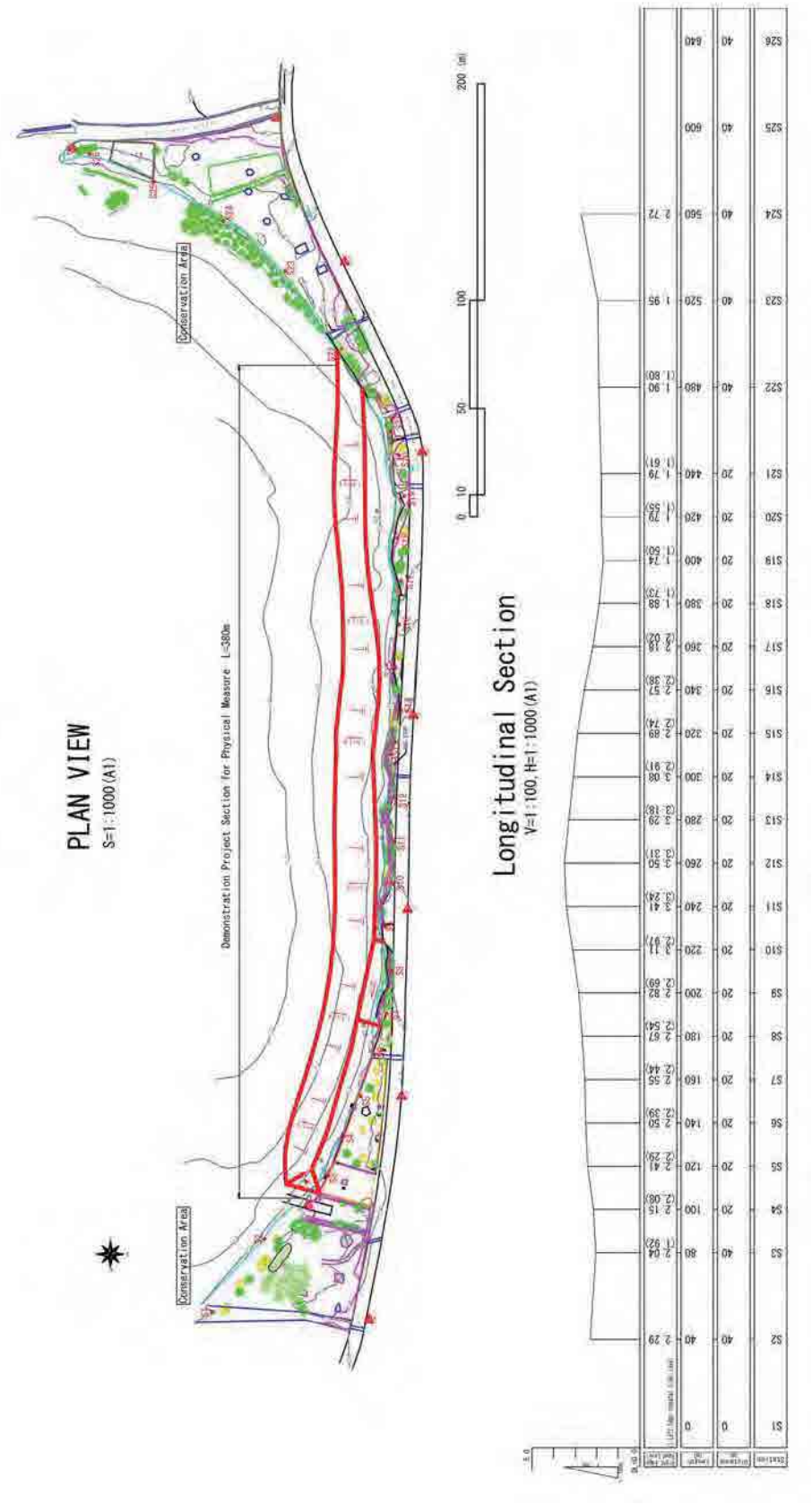
Followings show overall provisional basic plan and plan view led from the four categories, disaster prevention, use, environment and applicability, on Grand Sable, focusing on the flexible revetment as a main coastal facility.

Table 13.3.1 Proposed Basic Plan for the Coastal Conservation Measures on the Demonstration Project Area

Category	Description of Plan	Remarks
Disaster Prevention	Applying construction of flexible revetment with adequate disaster prevention function to protect from disasters caused by wave run-up and over topping	Already implemented on the demonstration project for physical measure
	Ensuring drainage facility with adequate drainage function to avoid flooding on roads as of heavy rain and structuring effective maintenance organization	
	Installing facilities along the border of road and beach for vehicle control, such as bollards, planters and curbs, to ensure the safety of the beach area	
	Rising road elevation to improve disaster prevention function in a long term aspect	
	Establishing watching or patrol system on the flexible revetment to avoid from illegal taking gravels from the beach	Non-physical measure
Use	Applying adequate crest width for the flexible revetment to encourage coastal use of the flexible revetment for recreation	Already implemented on the demonstration project for physical measure
	Improving conformability by creating shaded rest space under trees with avoiding from cutting existing trees	

Category	Description of Plan	Remarks
	Carrying out rehabilitation of the north public beach park to raise the recreation function with establishment of unification and network between beach use and park use	
	Applying gentle slope gradient for the flexible revetment to improve accessibility to the sea for mooring and lifting boat activity by local fishermen	Already implemented on the demonstration project for physical measure
	Encouraging community activity using beach area by managing beautification program of collecting garbage and festivals by the local residence	Non-physical measure
Environment	Applying the flexible revetment expected to see improvement of water quality and odor nuisance resulted from the filtration by gravels forming the revetment body	Already implemented on the demonstration project for physical measure
	Carrying out beach greenery along the boundary of road and beach by planting native plants to provide endemic coastal vegetation	
	On the estuary area, setting out the area as nature conservation area and creating variety of biodiversity space by promoting restoration of natural environment with planting appropriate vegetation to the area such as mangrove	
	Promoting people’s concern to natural environment of the area by carrying out monitoring activity for current ecosystem situation of conservation area and growing condition of planted vegetation as well as information communication to the community	Non-physical measure
Applicability	Establishing maintenance system and information network for preparation of revetment rehabilitation previously concerning deterioration of disaster prevention function resulted from deformation of the flexible revetment caused by natural phenomena such as cyclone	Non-physical measure

Source: JICA Expert Team



Source: JICA Expert Team

Figure 13.3.1 Master Plan for Coastal Conservation of Demonstration Project (Physical Measure)

13.3.3 Basic Design

Followings show general items of basic design for the flexible revetment on projected area of the demonstration project as physical measure. Basic design covers for the both section s, the section which the flexible revetment has been already implemented as the demonstration project located on the southern half of total projected section and the section where the study is proposing development for short term coastal conservation measure as future development section located on rest of northern half of total projected section.

a. Design Condition

The crest height and width for the flexible revetment is set to ensure that the predicted wave run-up doesn't exceed the existing elevation of the coastal road. The calculation of wave run-up is conducted using a virtual gradient method proposed by Nakamura (1972). The design condition is shown on Table 13.3.2. As required function, the design height (H=0.4m) at the place where the road elevation is MSL +1.6m doesn't run-up under the design tide condition with MSL+1.34m.

Table 13.3.2 Design Condition

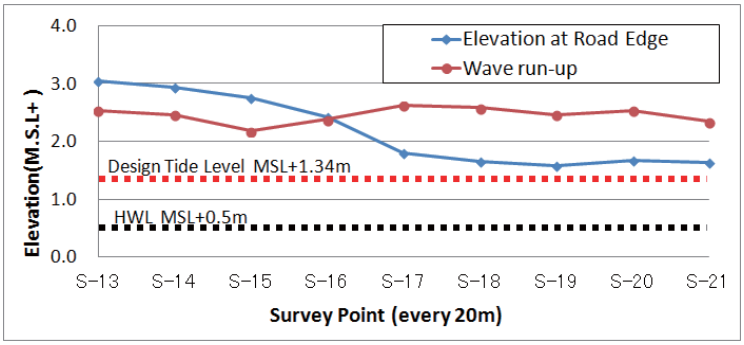
Profile	Design Condition	Remarks
Tide level with return period of 30 years (a)	MSL+0.67m (CD+1.04m)	From extreme statistics analysis using tidal data for 30 years
Wave set-up (b)	0.55m	From calculation result for design wave height with return period of 30 years
Predicted Sea level rise (c)	0.12m	0.39mm/year×30years
Design tide level	MSL+1.34m (CD+1.71m)	= (a) + (b) + (c)
Design wave height $(H_{1/3})_{30yrs}$	0.4m	Wave height with return period of 30 years
Design wave period$(T_{1/3})_{30yrs}$	8.0 s	
Topography		Survey results on August 2013

Source: JICA Expert Team

b. Sectional Design (Implementation Section)

b.1 Crest Height

Figure 13.3.2 illustrates the relationship between estimated wave run-up under the condition of Table 13.3.2 and elevation at the edge of the coastal road in the demonstration project area. It is inferred from the calculation of the wave run-up that it will be raised out about +2.5 m MSL in the current state. Basically the higher the crest are and the wider the crest width is, the more decrease the wave run-up. However, it is important to consider not only the functional point of view, but also beach utilization for the determination of crest height. Moreover, from the results of interview survey from the residents, the flood by running water from the hinterland in the heavy rain has been reported. Therefore the crest height is set as MSL+2.0m at the seaside edge of the crest so as not to interfere the existing drainage systems.



Source: JICA Expert Team

Figure 13.3.2 Elevation at Edge of Coastal Road and Calculated Wave Run-up

b.2 Crest Width

The crest width was examined to ensure to keep the wave run-up lower than the setting crest height (MSL+2.0m) using a virtual gradient method described above. Based on the analysis, in order to satisfy its function, it is found that the crest width needs to have more than 7.6 m. Taking into account the deformation of the section due to wave action, the crest width is set to keep more than 10 m from the road edge.

b.3 Slope

It is generally known that the gradient of gravel beach becomes 1:3 to 1:5 from the other examples and research works of flexible revetment. In this project, the gradient of the flexible revetment is set out about 1:5 for stable coastal gradient referred to other similar gravel coast in Mauritius. Additionally the gradient of the section which use mixed materials of gravels and rock sand applied for the comparison study is set out about 1:8 by referring to other similar coastal condition in Mauritius.

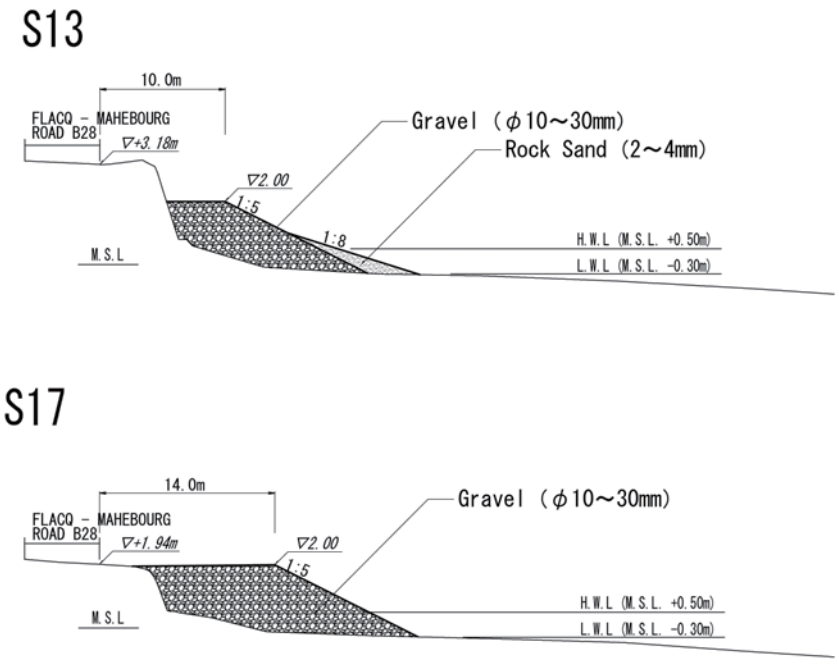
b.4 Specification of Gravels and Sands

Considering the applicability of the construction in Mauritius, it is recommended that a large amount of the materials, gravels and rock sand can be prepared easily with low cost. Diffent from white sand originated from coral which can be seen at other resort areas, the projected coast is comprised of dark color sand. Therefore there is no restriction against protection of exsisting landscape interms of color of materials. For the material of flexible revetment, crushed basaltic rock as the gravels which can be provided easily with low cost is applied. The size of gravel is set out as 10 to 30 mm, and 2 to 4 mm for rocksand based on available side of existing stonecrusing plant.

b.5 Extension of Existing Drainage

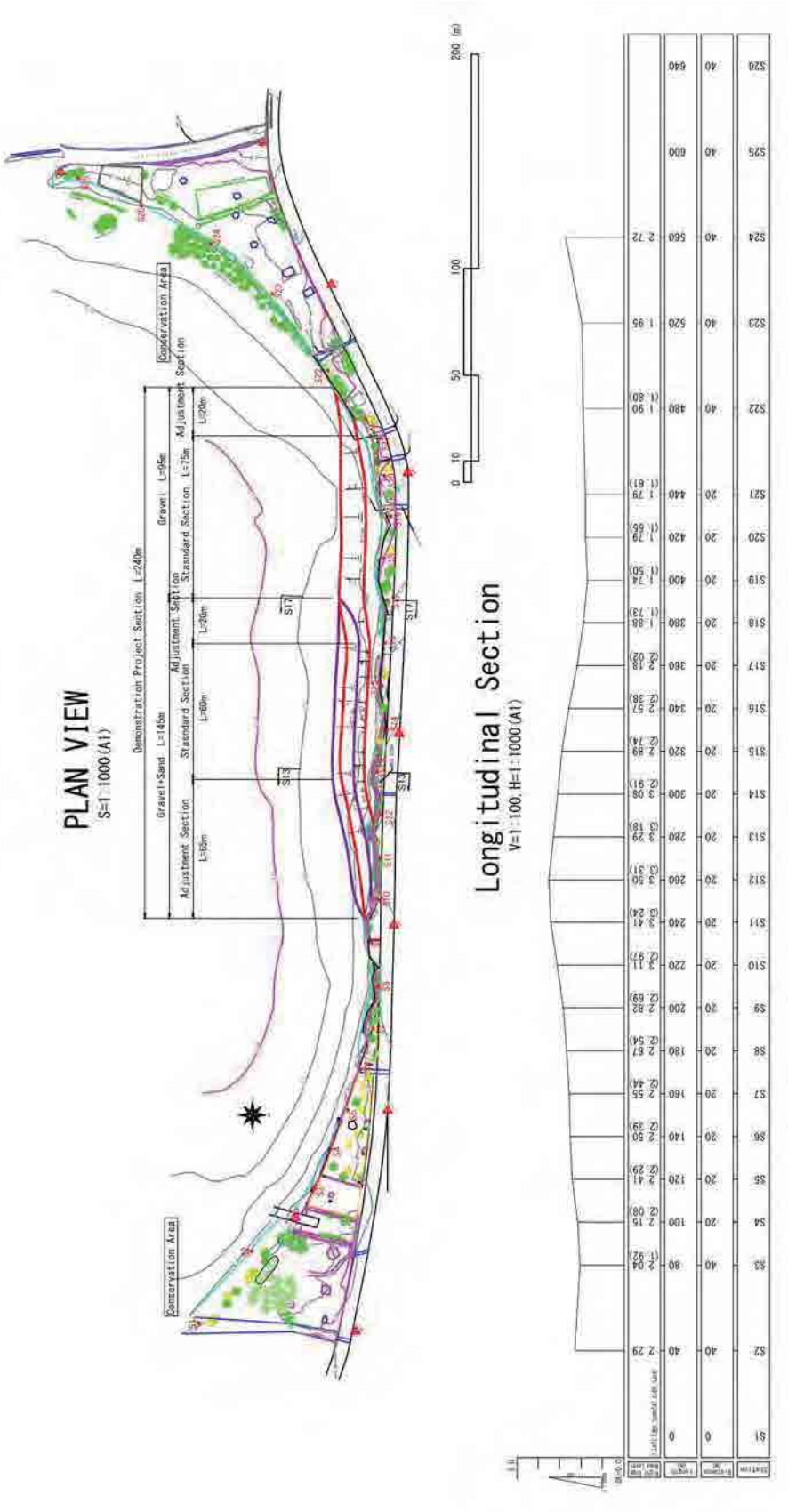
With the stretching in the direction off the coast of waterfront line, existing drainage is to extend with its length of the drainage (eight in the whole of Grand Sable, four locations in the demonstration project section). The extension work is conducted by connecting new Hume concrete pipes to the existing drainage and installing the pipes in the section of flexible revetment. The inside diameter of the pipe is same or larger than areal section of exiting drainage and can be selected from the size of a pre-cast concrete pipe. Three of the extended pipes sized as 533 mm of inside diameter for two location and 685 mm for one location in the demonstration project area.

The pipes used during the demo project did not perform well. It was obstructed with pebbles and driftage. Cleaning and maintenance is not easy. Alternatives such as open drains are to be considered for easy maintenance. The flexible revetment to be placed sloping towards the drains being highly permeable does allow for free passage of water. Even in case of presence of the pebbles at the outlets of the drains, water would continue to percolate through the flexible revetment. In so doing it is also filtering the water from pollution. Some regular maintenance may be required to remove garbage and silt that accumulate at the outlet. This may be done during everyday cleaning.



Source: JICA Expert Team

Figure 13.3.3 Standard Section(Implemented Section)



Source: JICA Expert Team

Figure 13.3.4 Plan View (Implementation Section)

c. Section Design (Future Development Section)

c.1 Crest Height

The crest height of future development section is designed as MSL+2.0m at the top edge of revetment slope as same as the section which has been constructed, however the it is only the connecting part of implemented and future section considering continuity of whole coastal area without any level awkward elevation differences between two. On the other hand, around the north public beach park, beach area is having enough distance due to the existence of the park, which can be determined that there is no need to have continuing elevation setting for the revetment because the height of wave run-up can be reduced. Additionally, setting the elevation of MSL+1.5m leads to not only deterioration of existing natural landscape but also convenience of use between the park and beach area due to the elevation differences. Therefore, the crest height of future development section is set as MSL+1.5m around the north public park area.

c.2 Crest Width

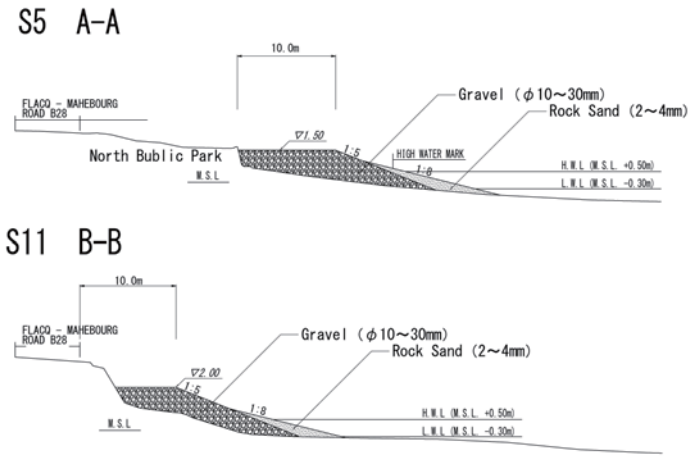
Followed by the identical consideration of implemented section in south part of demonstration project area, crest width is designed as 10m and basically required to sustain its smooth coastal line.

c.3 Slope Gradient

Followed by the identical consideration of implemented section in south part of demonstration project area, the gradient of the flexible revetment is set out about 1:5 for gravel part and 1:8 for rock sand part.

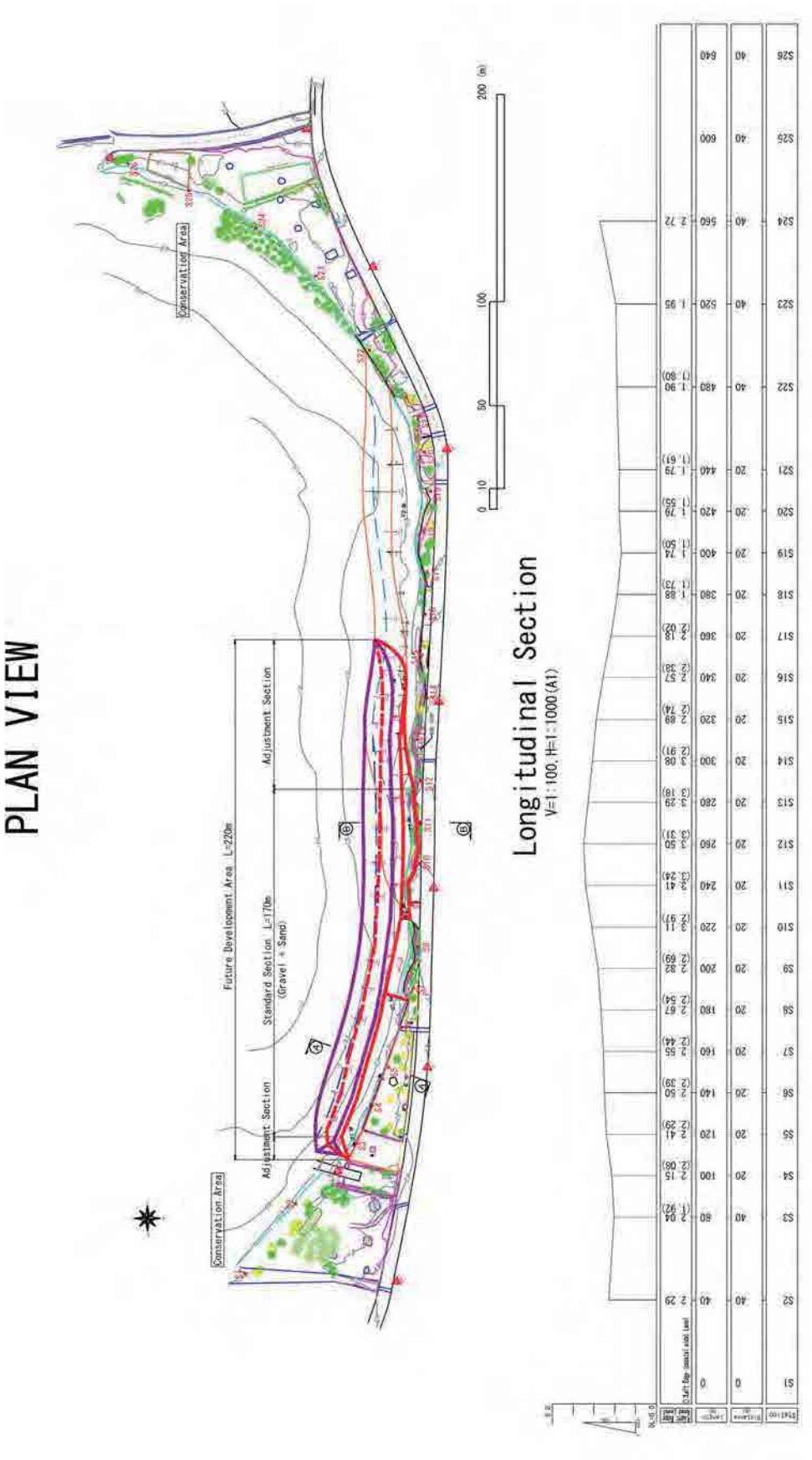
c.4 Specification of Gravels and Sands

Followed by the identical consideration of implemented section in south part of demonstration project area, The size of material is set out as 10 to 30 mm for gravels, and 2 to 4 mm for rocksand in its diameter.



Source: JICA Expert Team

Figure 13.3.5 Standard Section (Future Development Section)



Source: JICA Expert Team

Figure 13.3.6 Plan View (Future Development Section)

13.4 Long Term Plan

The ground level is low and there is a road passing along near the coast. Sea level rise would have impacts on the low lying land. Since the sea level rise is uncertain, it is necessary to consider the response. Measures can be defined as enlarging revetment, raising road elevation and limiting use of low land area. Figure 13.3.2 illustrates that some section of road elevation is comparatively low. It would be required to apply a raising road elevation when the road reaches rehabilitation period.

Although there would be issues such as accessibility to housings and drainages as the raising road measure is carried out. Originally this district is used for low land agricultural field and is not suitable for dwelling area. The study of ground height and inundation risks will be carried out. It is possible to implement with taking necessary action such as land use regulation at the high risk area. If necessary the raising housing elevation and resettlement area also applicable.

The demonstration project was carried out as a protection measure for the low land coast with wide reef extending at the south coast in Mauritius. The flexible revetment is not large scale and has advantages to correspond to the coastal use and future sea level rise. It is required to improve its technology based on the natural and social conditions in Mauritius.

At the north of the demonstration site, the revetment of public area and coastal road is partly damaged by the scouring of the foundation. The flexible revetment with gravel is one of suitable measures. However at the site there is a possibility of the gravel movement by the longshore transport caused by the oblique waves to the coast. It is recommended to examine the applicability of the flexible revetment at the site in considering future application to other coasts.

13.5 Maintenance Plan

13.5.1 Maintenance Issues

Before the implementation of the demonstration project, a large number of garbage, seaweed and tires were disposed with unpleasant odor in the projected beach. Beach environment was extremely deteriorated due to the littering addition to the decomposition and inflow of untreated gray water from housing as shown on Figure 13.5.1. These present health hazards.

A large amount of trash and seaweed are deposited on the coast

Tires and trash are disposed with unpleasant odor

Source: JICA Expert Team

Figure 13.5.1 Coastal Situation before the Implementation

On the other hand, situation of the implemented area in June 2014 after the project, as shown on Figure 13.5.2, water quality, deposition of garbage and unpleasant odor have been significantly improved. It can be noted that voluntary clean-up activity on the beach by local residence is one

of the reasons for the improvement. Otherwise, in the non-implementation project area, deposition of garbage, seaweeds and water turbidity is still noticeable.

Photo from the north to south on implemented area

Trash and seaweed are disposed on the future development area

Source: JICA Expert Team

Figure 13.5.2 Coastal Situation after the Implementation

13.5.2 Future Maintenance

In the area where the construction of flexible revetment was carried on as the demonstration project, deterioration of water quality and littering of garbage tend to be improved. One of the main reasons is that local resident began to clean the beach regularly and voluntary. Therefore, expansion of clean-up area for future implementation area will be required.

- To propose that the M/Local Government/ District Council to set up a dedicated team with necessary logistics (vehicles, materials) for regular collection of garbage (including marine litter on the shore and plastics within the mangrove areas) from the shoreline and its appropriate disposal.
- The Beach Authority would ensure clean-up of public beaches within the area.
- Concerning the seaweeds and algae, these shall not be removed from the beach. In case it is present in large quantities, then it can be collected and buried within the gravel beach on the upper reaches (near the coastal road). This would contribute to the moisture content and nutrient (humus) of the beach thereby promoting growth of grasses and trees. In addition, the algae and seaweeds also form part of the marine food chain.
- The Ministry of Environment to carry out regular sensitisation not to litter the environment and to inculcate a sense of belonging.
- The local residents to voluntarily carry out regular cleaning of the shoreline located in front of their village. They can also help the authorities to keep a watch on the gravel beach in order to prevent vandalism (removal of pebbles, removal of vegetation, damage to amenities amongst others).

In addition, the following items should also continuously carry out for future maintenance.

- Bathymetry survey carried out by MOI
- Beach profile monitoring
- Evaluation of shoreline change

Chapter 14

Albion (Cliff)

14 Albion (Cliff)

14.1 General

The cliff coast of Albion is selected as the representative coast of cliff. The coastal cliff is continuously eroded and not accreted naturally unlike the sandy beach. The development along the coastal cliff has to be considered the erosion. However the erosion speed is not fast compared to the sandy beach, the plan will be long term.

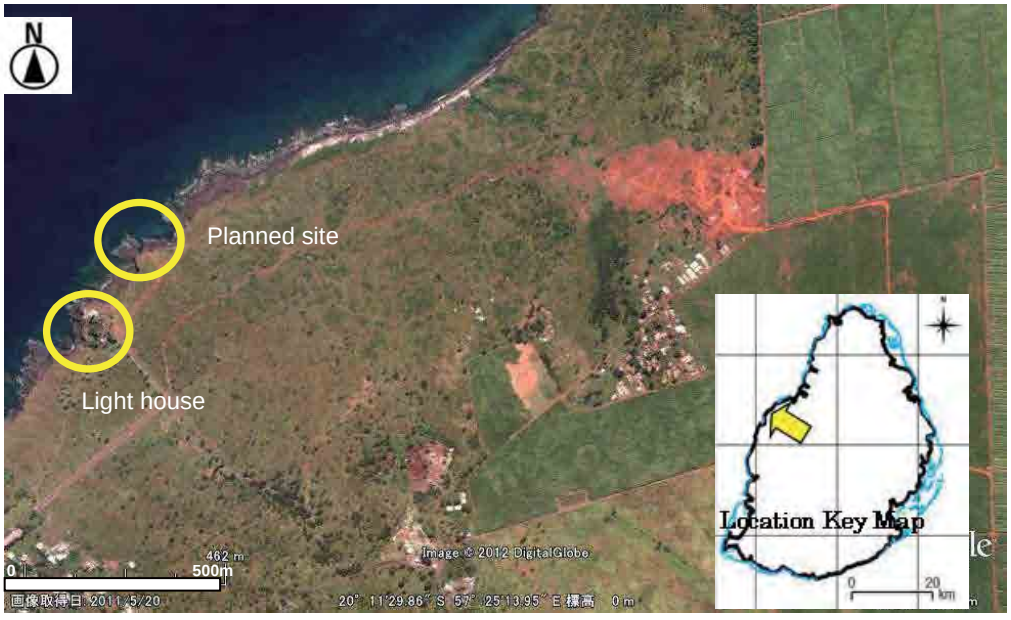
At Albion the development of the plateau is planned for future development. Then it is suitable to study of this kind of erosion problems. The results can be applied to the similar cliff coasts.

The measures for the cliff coast are mainly setback and the protection at the cliff base by structures. The setback is adequate and the method to estimate the setback limit is proposed.

14.2 Coastal Conditions

14.2.1 Topography of Coast

The coast is located on the west of Mauritius at the south of Port Louis without coral reef and receives waves wind wave from west and cyclone waves from northwest. The cliff of 30 m high is situated on the north of the existing lighthouse as shown in Figure 14.2.1. The highland behind the cliff coast has been used for a sugarcane field and residential area. The cliff is made of basalt having irregular cracks. There are also caves and over-hangs, and crashed rock is scattered at the base as a terrace.



Source: JICA Expert Team modified based on Google Earth

Figure 14.2.1 Study Area at Albion(Cliff)

The conditions of the coast are summarized in Table 14.2.1.

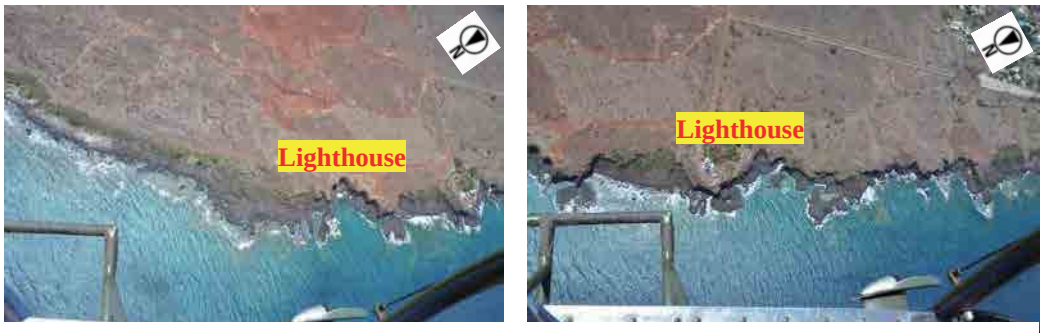
Table 14.2.1 Coastal Condition at Albion (Cliff)

Basic investigation No.		No. 19	PB No.	No.
Coast name		Albion(Cliff)		
Natural and topographic characteristics	Sea state	Located at the west side of the island, and affected by waves from the west as well as cyclones		
	Topography	A coast consisting of rocky shore and there is a sandy beach at Albion Public Beach, but a few at the south side.		
Environmental characteristics	Coral reef	No data available for site		
	Water quality	Fringing reef is inexistent offshore. Coastal water is affected strongly by open sea, and water quality is relatively good.		
Coastal transformation characteristics	Disaster and structures	No structures are constructed		
	Coastal transformation	This coast consists of rocky shore without any remarkable transformation observed. Slope failure occurs partially.		
Coastal utilization characteristics	Beach utilization	Site is used by public as viewpoint – for recreational purposes.		
General assessment		This coast is one of typical coast as cliff coast in Mauritius. Since the site has been earmarked for future, it will be important to establish the setback line taking into account long-term erosion of cliff.		

Source: JICA Expert Team

14.2.2 Coastal Cliff Characteristics

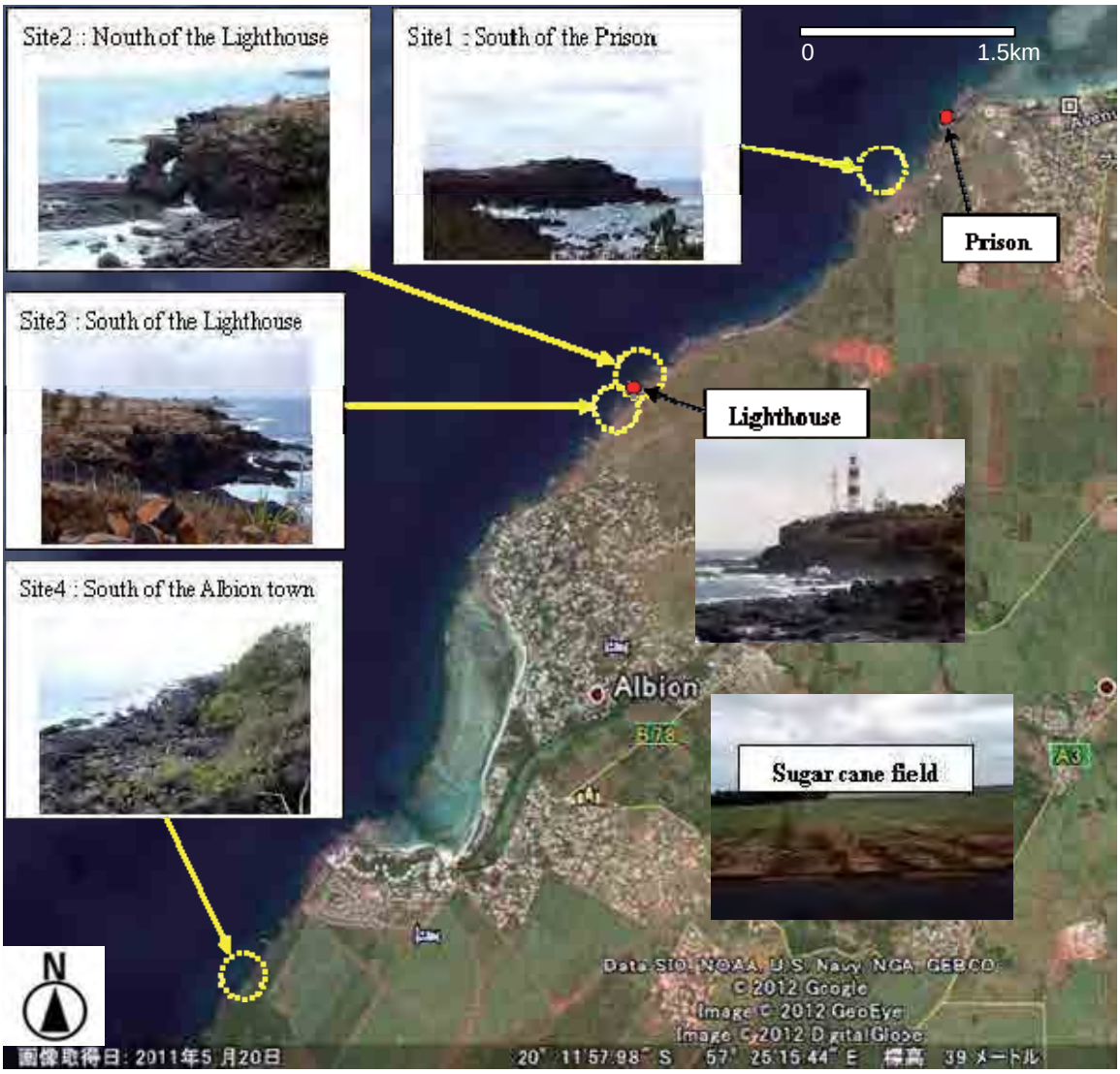
The aerial photo of the study area is shown in Figure 14.2.2 taken by a helicopter. The cliff was not eroded uniformly. The fluctuation is large and reached 30m in width. At the base collapsed rock is deposited 50m wide in its maximum. Future development is planned at the north of the light house.



Source: JICA Expert Team

Figure 14.2.2 Aerial Photo of Albion Left：North, Right: South of Lighthouse

The condition of cliff at Albion was surveyed and four location of the survey is shown in Figure 14.2.3. The height and slope of cliff and the status of the cliff behind, such as the location of the house were sketched and photos were taken. The degree of weathering and cracking of rock and the characteristics were confirmed.

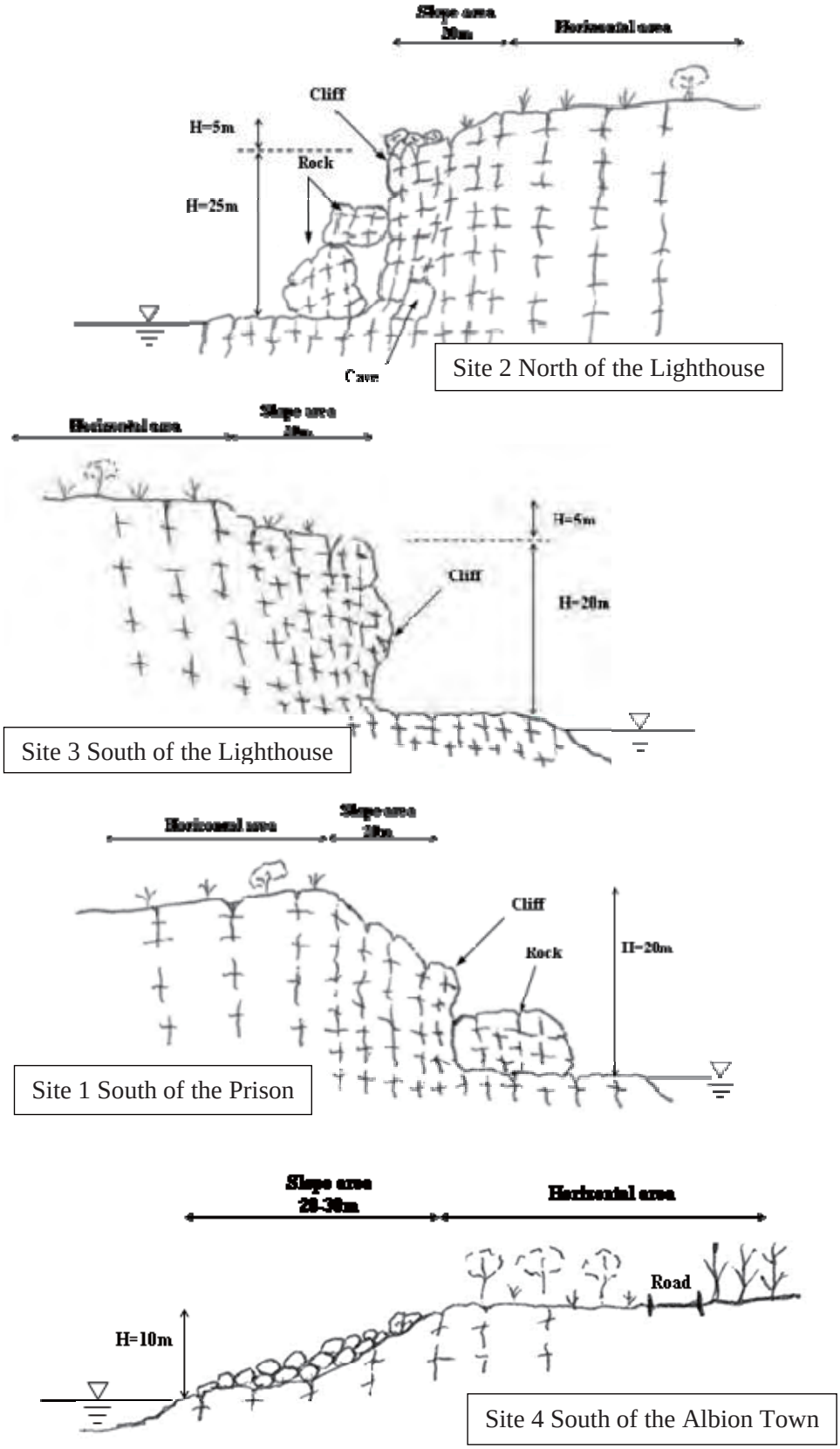


Source: JICA Expert Team processed based on Google Earth

Figure 14.2.3 Location of Survey at Albion Coast

The sketch of cliff is shown in Figure 14.2.4 and the results are as follows. Residential development has progressed in Albion area and the development is in progress. Geology of the coast is mainly composed of basalt and the terrain behind the coast is relatively flat and smooth. The coasts of Site 1 near the prison at Pte. aux Sables and Site 2 and Site 3 near the lighthouse at Pte. aux Caves are cliff of around 20 to 25m high with vertical slope. Basalt rock at the cliff surface is a pretty hard lithology itself and irregular cracks have developed in the vertical and horizontal directions with caves and overhang. The surface rock is seems to be weathering with topsoil. The bedrock is slightly larger and stable and the basalt rock has eroded away with gullies formed. There is a possibility that the rock of the upper portion collapse or fall down if the overhang progresses.

The coast of Site 4 at the south of Albion Town is about 10m high and covered by cobbles of 20 to 30m of width.



Source: JICA Expert Team

Figure 14.2.4 Sketch of Survey Points

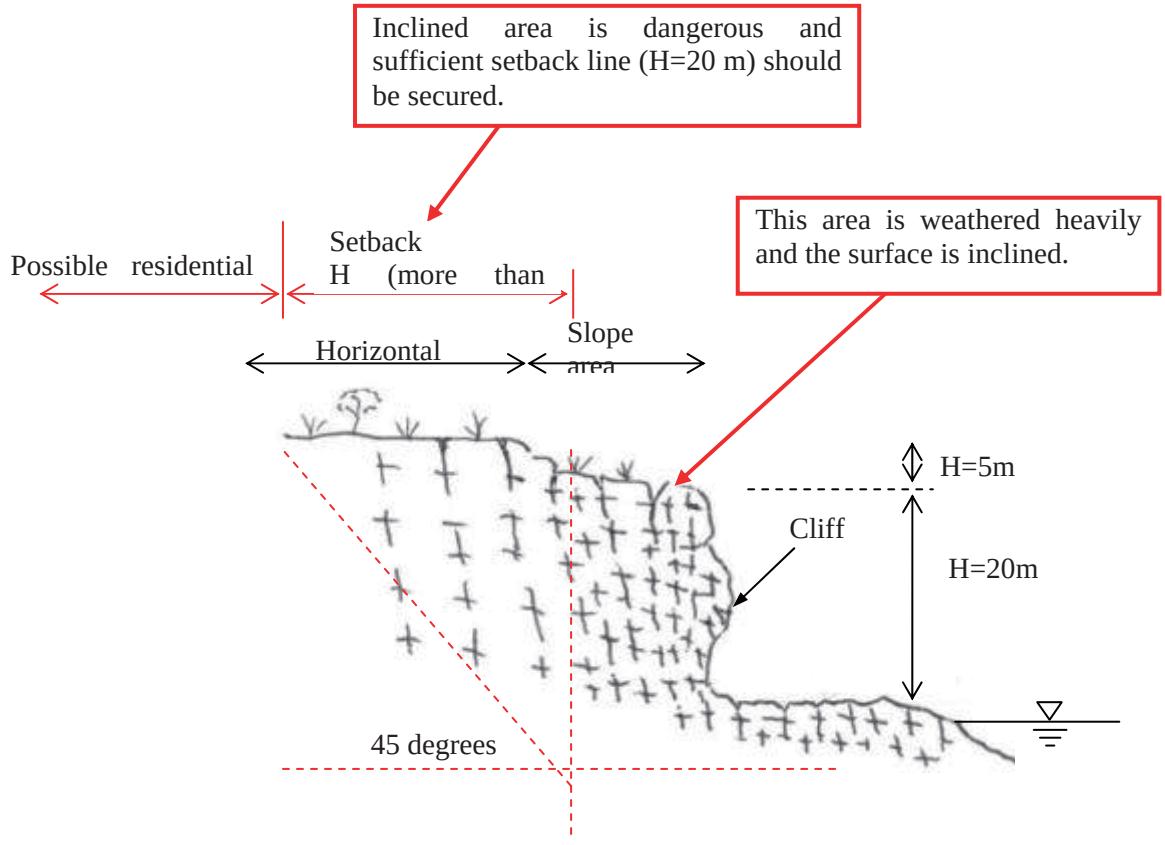
14.3 Coastal Conservation Plan

14.3.1 Problems and Related Factors

The cliff itself is strong enough to protect against attacking waves. The erosion speed of cliff is 5 cm per year according to a study in Oregon of the United States of America. Thus, erosion of cliff by waves might not be a big issue. However actually at site there are caves and possibly wave attack causes landslide and cliff erosion. It is necessary to estimate an affected on-land area considering the land utilization plan such as future land development. The possible measures are protecting cliff or determining a setback line. For the time being, setback is the most appropriate measure, but it needs to establish the setback distance with a proper justification.

14.3.2 Conservation Measures

The setback line will be determined considering the estimation of cliff erosion speed, the life time of houses or structures, the slope area of the cliff and horizontal area. The most important is the slope area and it should be analysed based on the site inspection and aerial photos. From the preliminary site investigation, two areas can be taken as shown in Figure 14.3.1. The first is the slope area where the rock is weathered and the cave is formed. The second is the horizontal area where estimated from the slope stability.



Source: JICA Expert Team

Figure 14.3.1 Image of the setback line (draft)

Based on the site inspection results, a preliminary examination of the setback line was conducted considering the facts that the existing cliff has been weathered, forming some caves, and the maximum stable degree (45 degree). A supplemental investigation will be conducted to

analyze the existing conditions in details and then the final setback line will be determined. Figure 14.3.1 illustrates the image of the setback line.

Plateau behind coastal cliff behind has been used as a residential area and sugar cane fields mainly. There is a plan for future development in the hinterland at the north of lighthouse. The setback line of important public facilities has to be decided in considering the long term cliff erosion and corruption. The long term erosion is estimated 5m if the erosion speed is assumed as 5cm/y of basalt from experience and 100 years of service period. Then the setback line becomes as follows.

Recommendations: use 5cm /yr as an example. Further investigations required for Mauritius, to define parameters required-to elaborate

Minimum Setback Line = Slope Area + Horizontal Area + 5m

The minimum setback is estimated from the limited information at present. It becomes 65m in total if the slope area is 30m, the horizontal area is 30m of 30m high cliff and erosion is 5m. It is comparable to the Pas Geometriques of 81m if a margin is considered.

The actual figure can be decided from the precise topographic map. At present the contour interval of the map is 10 in Mauritius. It is difficult to estimate the ground height of the cliff and the survey is necessary along the coast.

14.4 Coast Maintenance Plan

14.4.1 Maintenance Problem

The main problem is there is no suitable information for the management and setback. They include the geography and geology of cliff and its changing pattern in a long term. The monitoring for the future can contribute to decrease the risk because the coastal change is slow at the cliff coast.

14.4.2 Maintenance Plan

On the cliff coast the conservation plan is based on the setback. Then the management will become the regulation of structures in the setback area in a short term and the monitoring of the cliff erosion for the revising the setback line in a long term.