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

TECHNICAL GUIDELINE

(Volume 3)

June 2015

JAPAN INTERNATIONAL COOPERATION AGENCY

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

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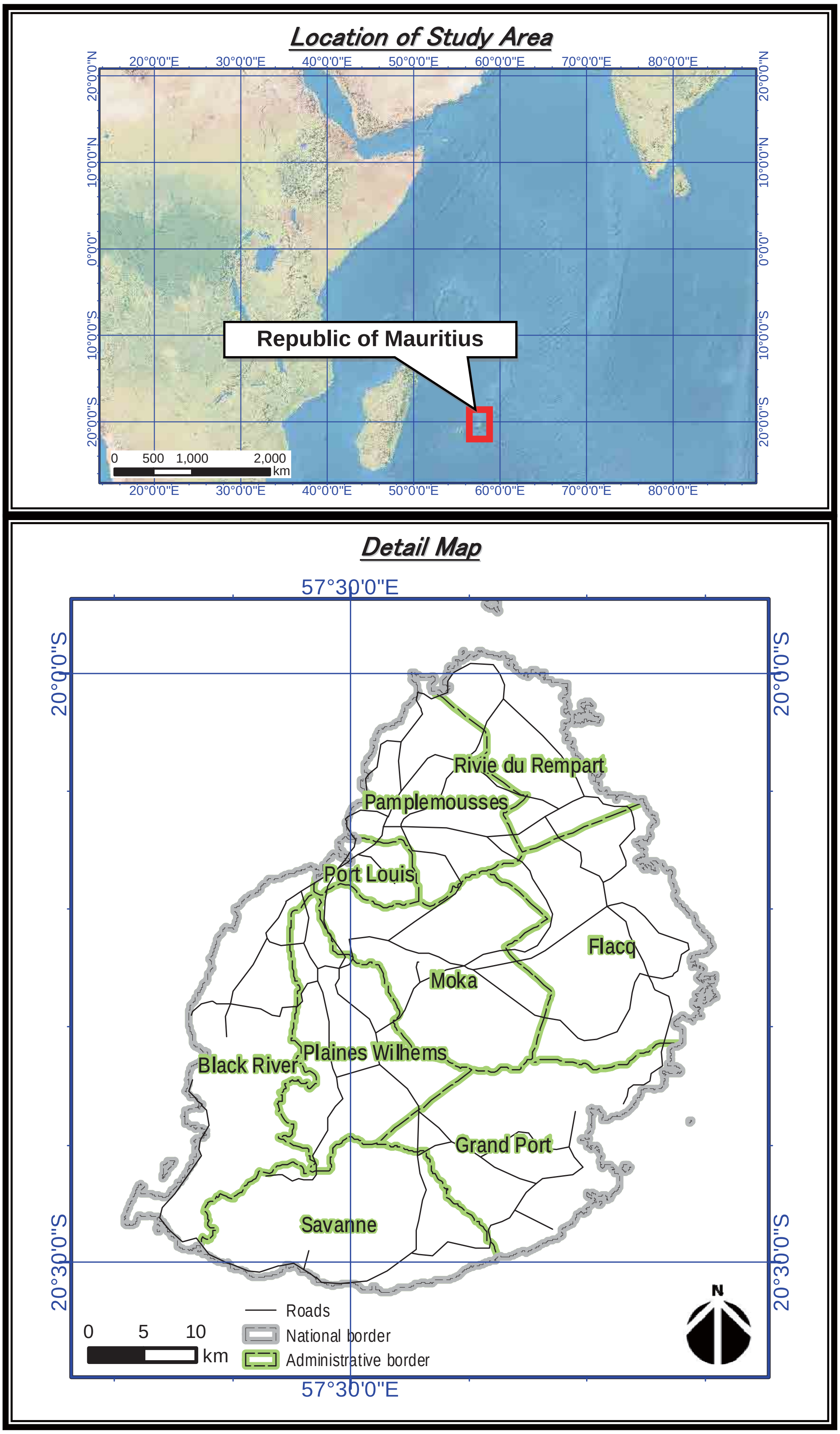


Location Map

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

Table of Contents

II. Technical Guideline for Beach Monitoring

IV. Technical Guideline for EIA on Coastal Conservation Project

Figure List

Table List

Photo List

Abbreviations

Abbreviations	English
AAP	Africa Adaptation Programme
AC	Advisory Committee
ACB	Acropora Branching
AF	Adaptation Fund
AFD	Agence Française de Développement
AFP	Adaptation Fund Programme
AFRC	Albion Fisheries Research Centre
AP	Absorption Pit
APHA	American Public Health Association
BA	Building Act
BA	Beach Authority
BLUPG	The Building and Land Use Permit Guide
BOD	Biochemical Oxygen Demand
C/P	Counterpart
CA	Capacity Assessment
CAB	Cabinet
CACI	Compact Airborne Spectrographic Imager
CADMAC	Climate Change Adaptation and Disaster Management Committee
CBR	Cost Benefit Ratio
CC	Crisis Committee
CCD	Climate Change Division
CACI	Climate Change Information Centre
CD	Capacity Development
CD	Chart Datum
CEB	The Central Electricity Board
CDEMA	Caribbean Disaster Emergency Management Agency
CF	Coral Foliose
CIRIA	Construction Industry Research and Information Association
CM	Coral Massive
COD	Chemical Oxygen Demand
CONDC	The Cyclone and Other Natural Disasters Committee
CONDS	Cyclone and Other Natural Disasters Scheme
CSO	Central Statistics Office
CVM	Contingent Valuation Method
CWA	The Central Water Authority
DB	Data Base
DC	District Council
DC	Dead Coral
DEM	Digital Elevation Model
DFR	Draft Final Report
DL	Datum Line
DO	Dissolved Oxygen

Abbreviations	English
DRR	Disaster Risk Reduction
ECMWF	European Centre for Medium-Range Weather Forecasts
E.Coli	Escherichia coli
EIA	Environment Impact Assessment
EIRR	Economic Internal Rate of Return
EMoP	Environment Monitoring Plan
EPA	Environment Protection Act
EPZ	Export Processing Zone
ESA	Environmental l y Sensitive Area
EU	European Union
F/S	Feasibility Study
FAS	First Aid Service
FC	Feacal Coliform
Fs	Safety Factor/Factor of Safety
GDP	Gross Domestic Product
GIS	Government Information Service
GIS	Geographic Information System
GL	Ground Level
GPS	Global Positioning System
GR	Grand River
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
JBIC	Japan Bank for International Cooperation
JCG	JICA Coordination Group
JET	JICA Expert Team
JICA	Japan International Cooperation Agency
JICE	Japan International Corporation Center
JTWC	Joint Typhoon Warning Center
K	Potassium
K-N	Kjeldahl Nitrogen
LEU	Living Environment Unit
LIT	Line intercept transects
LGA	Local Government Act, 2003
LMHTF	Le Morne Heritage Trust Fund
LMU	Landslide Management Unit
LWL	Low Water Level
M/M	Minutes of Meeting
Mauritius	The Republic of Mauritius
MBC	Mauritius Broadcasting Corporation

Abbreviations	English
MEHR	Ministry of Education and Human Resources
Mg	Magnesium
MGCW	Ministry of Gender Equality, Child Development and Family Welfare
MHL	Ministry of Housing and Lands
MHQL	Ministry of Health and Quality of Life
MID	Maurice Ile Durable
MLG	Ministry of Local Government & Outer Islands
MMS	Mauritius Meteorological Services
MoAFS	Ministry of Agroindustry and Food Security
MoESD	Ministry of Environment and Sustainable Development
MOESDDBM*	Ministry of Environment, Sustainable Development, Disaster and Beach Management (*Former MoESD)
MoF	Ministry of Fisheries (current MoOEMRFSO)
MoFED	Ministry of Finance and Economic Development
MoFR	Ministry of Fishery and Rodrigues
MOI	Mauritius Oceanography Institute
MoOEMRFSO	Ministry of Ocean Economy, Marine Resources, Fisheries, Shipping and Outer Island
MPA	Marine Protected Area
MPI	Ministry of Public Infrastructure, National Development Unit, Land Transport and Shipping
MPN	Most Probable Number
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
MUR	Mauritius Rupee
Na	Sodium
NCAR	National Center for Atmospheric Research
NCCAPF	National Climate Change Adaptation Policy Framework
NCEP	National Centers for Atmospheric Prediction
NCG	National Coastal Guard
NDOCC	National Disaster and Operations Coordination Centre
NDRRMC	National Disaster Risk Reduction and Management Committee
NDS	National Development Strategy
NDU	National Development Unit
NEL	National Environmental Laboratory
NGO	Non-Governmental Organization
NH_4-N	Ammonia Nitrogen
NHDC	National Housing Development Corporation
NO_2-N	Nitrite Nitrogen
NO_3-N	Nitrate Nitrogen
NPV	Net Present Value
NTU	Nephelometric Turbidity Unit
ODA	Official Development Assistance

Abbreviations	English
OJT	On the Job Training
OPS	Outline Planning Schemes
P.Fs	Planning/Designed Factor of Safety
P/R	Progress Report
PB	Public Beach
PBB	Programme-Based Budgeting
PDA	Planning and Development Act
PEFA	Public Expenditure and Financial Accountability
PER	Preliminary Environmental Report
PFM	Public Financial Management
PIANC	World Association for Waterborne Transport Infrastructure (former Permanent International Association of Navigation Congresses)
PIU	Planning and Implementation Units
PL	Pit Latrine
PM	Project Manager
PO_4-P	Phosphate-Phosphorus
PMO	Prime Minister’s Office
PMS	Performance Management System
PPG	Planning Policy Guidance
PS	Permanent Secretary
PVC	Polyvinyl Chloride
QGIS	Quantum GIS
R/D	Record of Discussion
RN-COI	Risques Naturels de la Commission de l'Océan Indien
SA	Sand
SAREC	Swedish Agency for Research Cooperation with Developing Countries
SC	Steering Committee
SC	Spot Check
SC	Soft Coral
SCOR	Scientific Committee on Oceanic Research
SIDS	Small Island Developing States
SO4	Sulphate
SS	Sewerage System
SS	Suspended Solid
SSPA	Segridad Salud Proteccion Ambiental
SST	Sea Surface Temperature
ST	Septic Tank
SWAN	Simulating Waves Nearshore
TA	Turf Algae
TAS	Treasury Accounting System
TC	Total Colifrom
TC	Technical Committee
TCPA	Town and Country Planning Act
TDS	Total Dissolved Solid
The Disasters Scheme	The Cyclone and Other Natural Disasters Scheme

Abbreviations	English
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
TICAD V	Fifth Tokyo International Conference on African Development
T-N	Total Nitrogen
TOR	Terms of Reference
T-P	Total Phosphorus
TSHD	Trailing Suction Hopper Dredger
TSS	Total Suspended Solid
UNDP	The United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization -
UoM	University of Mauritius
USD	United States Dollar
UTM	Universal Transverse Mercator
VAT	Value Added Tax
VCA	Village Council Area
VMCA	Voluntary Marine Conservation Area
WCDR	World Conference on Disaster Reduction
WGS	World Geodetic System
WMA	Wastewater Management Authority
WMO	World Meteorological Organization
WS	White Syndrome

Chapter I

Technical Guideline for Coastal Conservation

I. Technical Guideline for Coastal Conservation

1 Objective and Outline

The objective of this technical guideline for coastal conservation projects is to explain factors needing consideration when planning, designing, constructing and maintaining coastal structures and nourishing beaches in Mauritius. The basic guidelines for those activities have been developed in various countries and are openly available for reference.

One of the basic guidelines or manuals is the Coastal Engineering Manual, 2008 published by the U. S. Corps of Engineers. In the manual, the Shore Protection Project is explained in Chapter V-3 and Coastal Engineering for Environment Enhancement is in Chapter V-7. Another commonly used manual, published in Great Britain by CIRIA (Construction Industry Research and Information Association), is the Beach Management Manual, 2nd ed., 2010 and the Rock Manual, 2007, both of which are currently in use in Mauritius.

When considering whether to use such standard manuals in Mauritius one first must consider how applicable they will be to the particular situation in Mauritius. The first point to consider is does the coastal manual find a harmonious balance between the environment, conservation and coastal use by citizens. The coast in Mauritius is surrounded by coral reefs where waves are greatly attenuated. Also, the beach is an important resource for tourism. The use of the beach and lagoons needs to be considered with the conservation of the natural environment. In general, standard manuals place a strong emphasis on disaster prevention while merely trying to avoid having an adverse impact on the environment. Moreover, the manuals generally do not have an express objective of improving the environmental value of the beach nor of enhancing the utility of the beach.

The second point to consider is that standard manuals do not consider the characteristics of a coast surrounded by coral reefs. As for coastal erosion, generally sediment is supplied mainly from rivers or cliffs, and subsequently transported longshore and offshore by waves. On the other hand, in the case of coral reef coastlines, as in Mauritius, the source of beach sand is coral and shells. The coral reef both acts to dissipate wave energy and to generate currents, which then transport sediment to beaches as well as some that is lost offshore. The coral and seagrass in lagoons affect the waves and currents, thus contributing to the stability of the beach. Accordingly, the condition of these has to be considered when trying to mitigate erosion. However, sufficient studies have not been conducted on these phenomena.

The third point to consider is that the measures outlined in such manuals are not specifically developed for coasts with coral reefs, as mentioned above. Coral reefs are rich in diversity, therefore when developing coastal measures in Mauritius sufficient attention must be paid to the biological characteristics of organisms such as coral and seagrass, and not just focus on physical countermeasures. However, there is a lack of research in the field of such biodiversity-friendly countermeasures and the necessary technology is still in the trial and development stages. Nevertheless, coastal measures should fully take into account the aforementioned biological aspects.

This guideline should be periodically improved and revised based on the results of systematic evaluations.

This technical guideline for conserving Mauritius' coast will outline the following information required for the planning and designing coastal conservation measures in Mauritius:

1) Natural and design conditions

2) Planning, designing, constructing and managing coastal conservation measures

3) Case studies

1) Natural and design conditions

This section of the guideline will outline natural and design conditions that will need to be taken into consideration when planning and designing coastal protection measures in Mauritius.

2) Planning, designing, constructing and managing coastal conservation measures

This section will introduce practical steps for the planning, designing, constructing and managing measures suitable for Mauritius. This guideline will focus on two measures suitable for Mauritius, beach nourishment and flexible revetments (gravel beaches).

3) Case studies

This section will introduce three coastal conservation projects that are thought to provide the best insights when developing measures for Mauritius. Two of the projects are for tropical islands with a coral reef coast: a beach conservation project in Bali, Indonesia, and a pilot beach nourishment project in the Seychelles. The other is the project for conserving a gravel beach on the Akiya coast in Japan.

The Bali beach conservation project is one of the mitigation examples for the serious beach erosion which was occurred by the tourism development and will be a reference. Also it shows the importance of the prevention of erosion by tourism development because the measures become large scale. The pilot project of beach nourishment in Seychelles will be applied if the causes of erosion is not clear and there is a possibility of beach nourishment as measures. The gravel nourishment at Akiya will be a reference for the same kind of projects.

2 Natural and Design Conditions

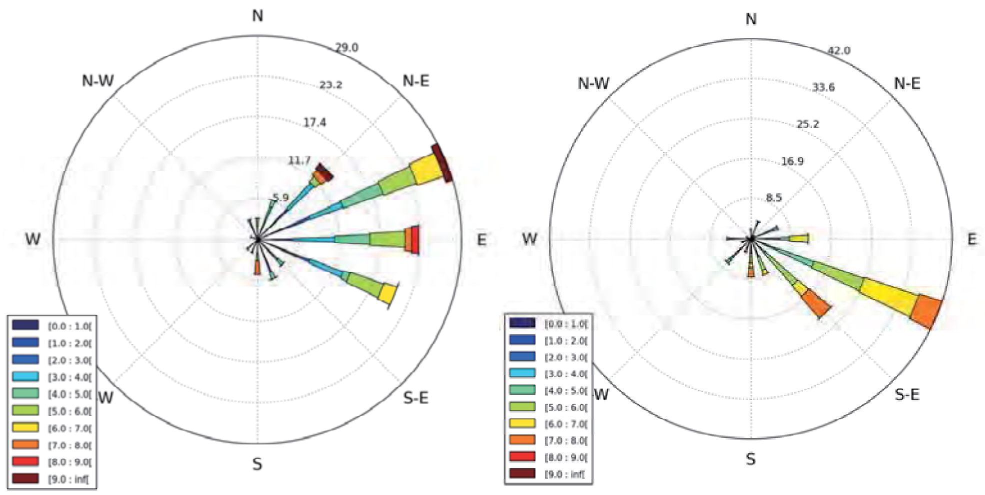
2.1 Natural Conditions in Mauritius

2.1.1 Wind Conditions

Tropical cyclones in Mauritius frequently occur in the summer season, while the south-east trade winds have a stronger influence in the winter season. Seasonal wind conditions are summarized as follows:

- Wind conditions are strongly influenced by the south-east trade winds in the winter season (i.e. May to August). Since ESE winds predominate, wind velocity is larger in the south-eastern part of Mauritius.
- South-east trade winds lose their strength the summer months (i.e. December to February) when there is a relatively lower wind velocity.
- However, tropical cyclones common in summer in Mauritius. Cyclones, depending on their route, often cause very strong winds.

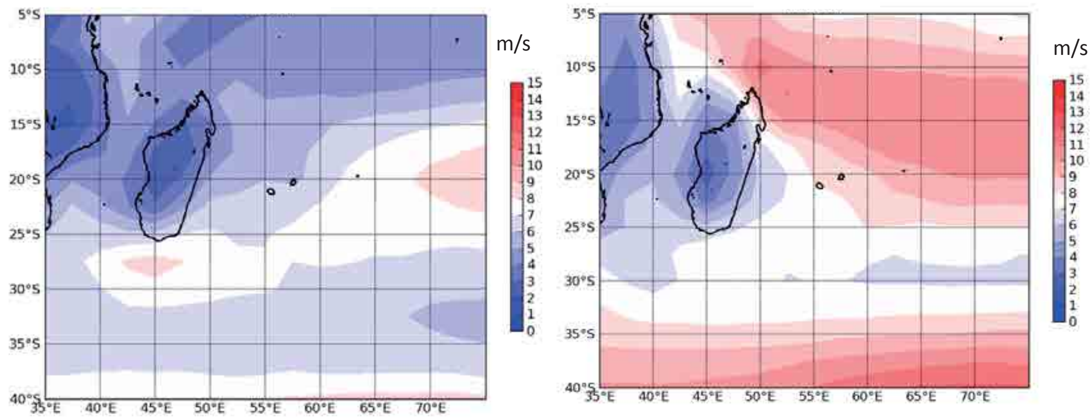
Figure 2.1.1 shows wind roses of wind velocity and direction data recorded at Plaisance observation station in 2013. These results clearly show that the difference in wind velocity and direction between the summer and winter months. Figure 2.1.2 shows the average monthly wind velocity for January and July (1980-2000), and Figure 2.1.3 shows a sample of wind direction in the same months in 2002. According to the results, wind velocity in winter is more than 10m/s on average, while that of the summer season is 5-6m/s. Moreover, wind direction is strongly influenced by the south-east trade winds in June. The influence of these trade winds in December, however, is fairly small.



11～2月　　5～8月

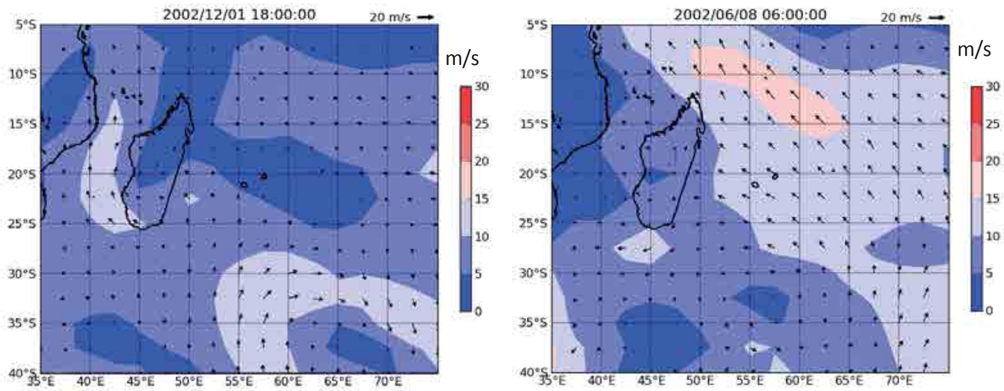
Source :Mauritius Meteorological Service

Figure 2.1.1 Wind Velocity/direction (Wind rose) (Plaisance, 2013)



Source: Arranged by JICA Expert Team based on NCEP/NCAR Re-analysis Result

Figure 2.1.2 Average Wind Velocity (1981-2010)



Source: Arranged by JICA Expert Team based on NCEP/NCAR Re-analysis Result

Figure 2.1.3 Distribution of Vector of Wind Velocity (2002)

Tropical cyclones frequently make landfall in Mauritius and commonly occur between the 30th and 60th parallel south (namely between 30 and 60 degrees latitude south) in the Southern Indian Ocean. Mauritius is located in an area where tropical cyclones pass through. And the coastal area has been damaged frequently due to this. In particular, those cyclones frequently affect Mauritius from December to March every year. Details such as the date, velocity and pressure of past major cyclones are shown in Table 2.1.1. The largest of these, such as Alix and Carol in 1960, Gervaise in 1975, Hollanda in 1994 and Dina in 2002, caused extensive damage in Mauritius.

The extreme value statistics analysis has been carried out using the minimum pressure values of the tropical cyclones. Table 2.1.2 shows the results of the extreme value statistics for each return period. From this result, it can be said that the return periods of minimum pressure for the cyclones Carol, Hollanda, and Dina are 100 years, 5 years, and 10 years, respectively.

Table 2.1.1 Major Cyclones to make Landfall/approach Mauritius

(red color is large scale cyclone)

Year	Date-Month	Name	Classification	Nearest Distance from Mauritius	Highest Gusts km/h	Lowest Pressure hPa
1892	29-Apr	-	-	-	216	947
1931	5 – 7 Mar	-	Intense Cyclone	-	180	969
1945	16-17 Jan	-	Intense Cyclone	Over Mauritius	156	953
1945	1-2 Feb	-	Intense Cyclone	South	150	969
1946	30 Jan-1 Feb	-	Intense Cyclone	Close West	129	984
1958	6-9 Apr	-	Intense Cyclone	80 km West Reunion	129	1004
1960	16-20 Jan	Alix	Intense Cyclone	30 km off Port Louis	200	970
1960	25-29 Feb	Carol	Intense Cyclone	Over Mauritius	256	943
1961	22-26 Dec	Beryl	Intense Cyclone	30 km West	171	992
1962	27-28 Feb	Jenny	Intense Cyclone	30 km North	235	995
1964	17-20 Jan	Danielle	Intense Cyclone	40 km South West	219	974
1966	5-7 Jan	Denise	Severe Depression	65 km North West	167	1003
1967	11-14 Jan	Gilberte	Severe Depression	Centre over Eastern	142	978
1970	23-25 Jan	Hermine	Severe Depression	240 km West South	125	999
1970	27-30 Mar	Louise	Intense Cyclone	140 km East	140	988
1972	11-13 Feb	Eugenie	Severe Depression	240 km North North	132	1002
1975	5-7 Feb	Gervaise	Intense Cyclone	Over Mauritius	280	951
1978	18-21 Jan	Fleur	Intense Cyclone	80 km South East	145	986
1979	21-23 Dec	Claudette	Intense Cyclone	Over Mauritius	221	965
1980	24-28 Jan	Hyacinthe	Intense Cyclone	80 km North West	129	993
1980	3-4 Feb	Jacinthe	Intense Cyclone	150 km South East	129	992
1980	12-13 Mar	Laure	Intense Cyclone	30 km North East	201	989
1981	5-7 Jan	Florine	Intense Cyclone	80 km West	135	1003
1982	5-6 Feb	Gabrielle	Mod. Depression	100 km North West	145	1001
1983	23-26 Dec	Bakoly	Intense Cyclone	55 km South West	198	992
1989	27-29 Jan	Firinga	Cyclone	80 km North West	190	994
1989	4-6 Apr	Krissy	Severe Depression	30 km South	150	976
1994	9-11 Feb	Hollanda	Intense Cyclone	20 km North West	216	984
1995	7-8 Jan	Christelle	Mod. Depression	Over Mauritius	109	994
1995	24-27 Feb	Ingrid	Cyclone	100 km North East	153	989
1995	8-13 Mar	Kylie	Severe Depression	135 km West North	114	1005
1996	24-25 Feb	Edwige	Mod. Depression	100 km North	162	1009
1996	14-16 Apr	Itelle	Intense Cyclone	275 km North	109	1011
1996	6-8 Dec	Daniella	Intense Cyclone	40 km South West	170	998
1998	10-11 Feb	Anacelle	Cyclone	50 km East	121	985
1999	8-10 Mar	Davina	Intense Cyclone	25 km South East	173	974
2000	27-29 Jan	Connie	Intense Cyclone	200 km North West	122	1003
2000	13-15 Feb	Eline	Severe Depression	130 km North	129	1006
2002	20-22 Jan	Dina	Very Intense T.C	50 km North	228	988
2003	12-13 Feb	Gerry	Tropical Cyclone	100 km North North	143	990
2003	31 Dec 03-03 Jan 04	Darius	Severe Tropical	40 km South East	113	994
2005	22-24 Mar	Hennie	Severe Tropical	60 km South East	112	990
2006	03-04 Mar	Diwa	Severe Tropical	220 km North North	126	1005.7
2007	22-25 Feb	Gamede	Tropical Cyclone	230 km North West	158	995.5

Source: Arranged by JICA Expert Team based on the data obtained from
http://mauritiusattractions.com/cyclones-in-mauritius-i-109.html

Table 2.1.2 Extreme Value Statistics of Minimum Atmospheric Pressure

Return Period	Variation	Statistic value of atmospheric pressure depth (hPa)	Standard variation	Minimum atmospheric pressure
5 year	0.7	21.1	2.8	991.9
10 year	1.2	34.1	4.0	978.9
20 year	1.7	45.2	5.4	967.8
30 year	1.9	51.2	6.2	961.8
40 year	2.2	58.4	7.2	954.6
50 year	2.5	67.5	8.4	945.5

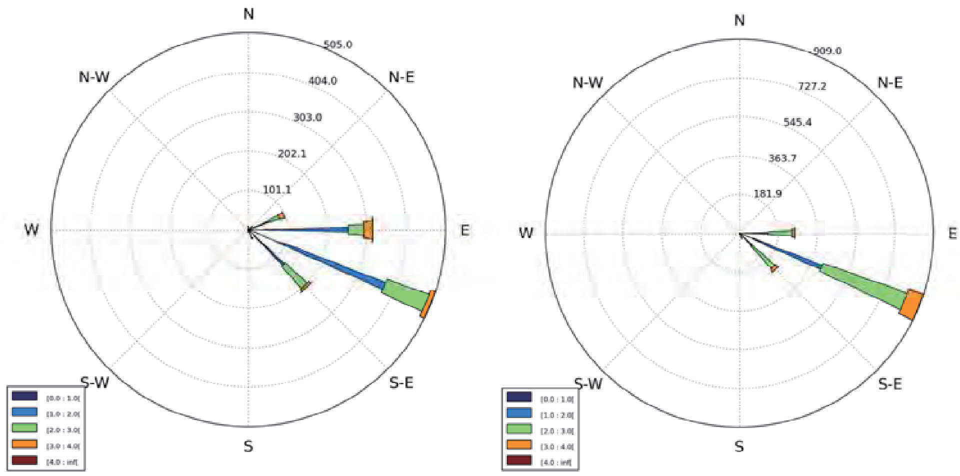
※atmospheric pressure depth = 1013 hPa – minimum pressure

Source: JICA Expert Team

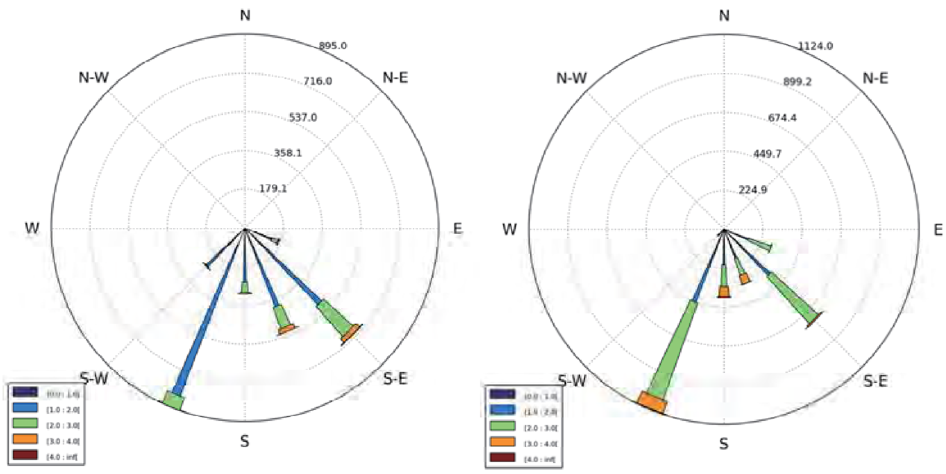
2.1.2 Wave

1) Off-shore Waves

Similar to the wind characteristics in Mauritius, the offshore wave characteristics in the summer are different from those in winter. Winter waves are influenced by south-east trade winds. In summer, the influence of south-east trade winds becomes weak and the dominant waves are generated by cyclones. The wave roses showing average wave height and direction in Blue Bay and Roches Noires are shown in Figure 2.1.4. Wave direction of ESE is dominant in both winter and summer at the observation points. It was also observed that waves 2-3m high often appeared in the winter while 1-2m high waves are common in the summer. In Blue Bay, wave height is mostly over 2.0 m and SSW is the dominant wave direction.



Roiches Noires



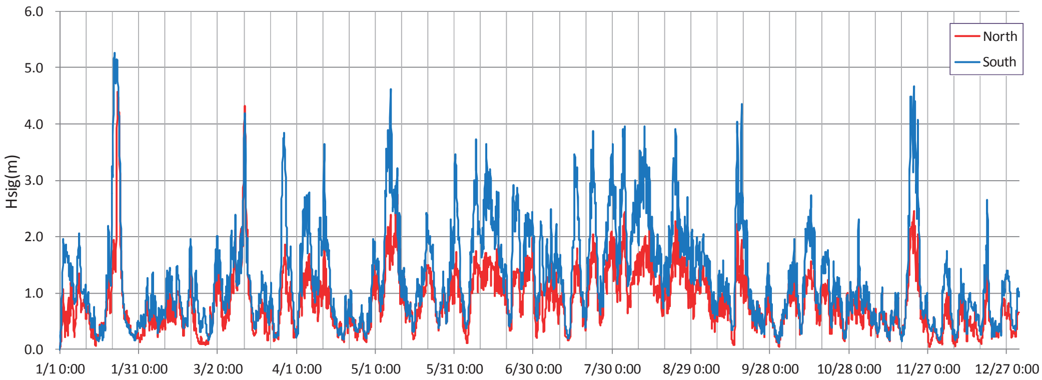
BlueBay

Source: JICA Expert Team

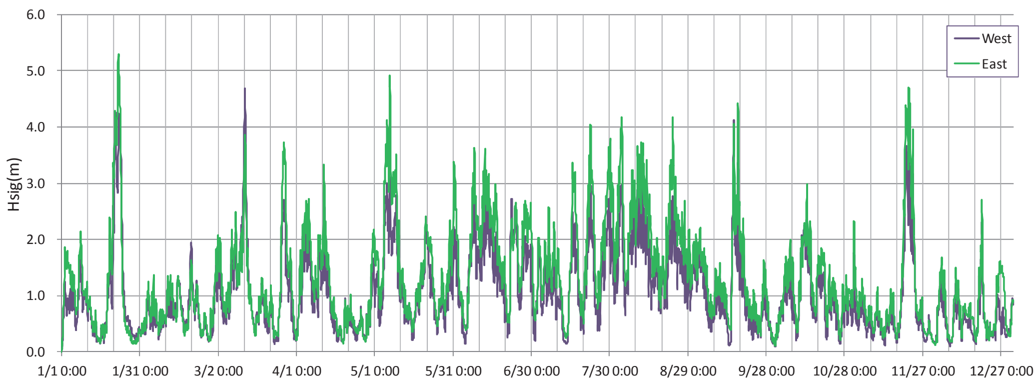
Figure 2.1.4 Wave Height/direction at Roches Noires (MOI) & Blue Bay

There are only two wave observation stations in Mauritius. Therefore, it is impossible to figure out the relation of offshore waves around Mauritius using the data from just these two observation stations. In order to estimate the wave characteristics around Mauritius, wave forecast analysis has been carried out using NCEP/NACR reanalysis wind data. As an example, the wave forecast results for 2002 are shown in Figure 2.1.5. This shows the time series of significant wave height in each direction. Figure 2.1.6 shows the significant wave distribution in cases of tropical cyclones and winter cyclones. The characteristics of waves in Mauritius are as follows:

- Significant waves from May to September in each location are mostly over 2.0m. In particular, the frequency of south and east directions is high, since these locations are situated in areas affected by waves influenced by south-east trade winds.
- Significant waves from October to April are less than 1.5m and are under quiet conditions. The wave height is higher than at other locations.
- Usually, there are many cyclones from November to March. In this forecast case, cyclone Dina was landing in Mauritius. Sometimes, waves from the cyclones are over 5.0m. However, it depends on the route of the cyclone.



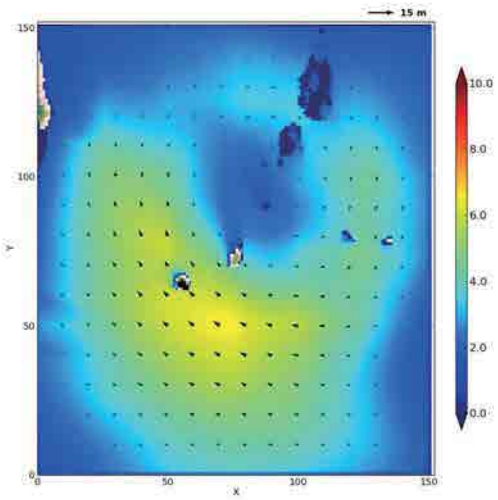
North-South Direction



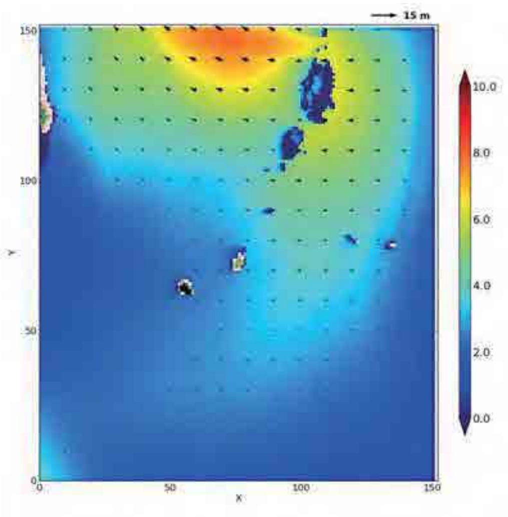
East-West Direction

Source: JICA Expert Team

Figure 2.1.5 Time Series of Predicted Wave Heights Offshore of Mauritius



Cyclone Dina(2002/1/21)



Winter Cyclone(2002/5/7）

Source: JICA Expert Team

Figure 2.1.6 Wave Forecasting to Predict Significant Wave Height Distributions (using wind of NCEP/NCAR reanalysis)

Using this model, the time series of wave height at the objective points have been calculated based on the longitudinal pressure and distribution which is assumed from the route of the representative cyclones (source: Joint Typhoon Warning Centre, JTWC).

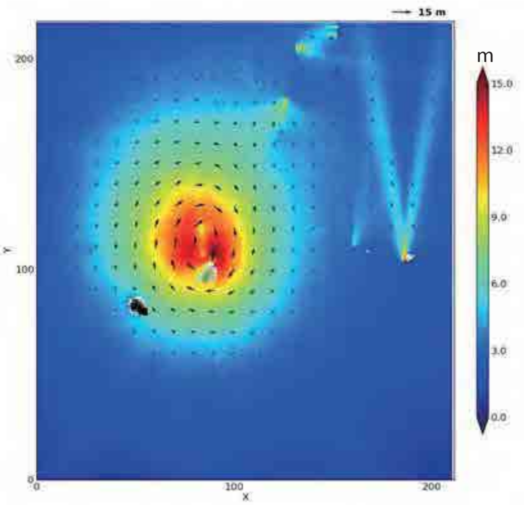
Table 2.1.3 shows the maximum significant wave height for each major cyclone in a certain time period. Wave height over 10.0m in every direction were observed during the cyclones Carol in 1960, Hollanda in 1994 and Dina in 2002. Normal waves change according to the season, however waves resulting from cyclones depend on its route and magnitude.

In 1960, Cyclone Carol caused the most serious damage to Mauritius. Tropical Cyclones and Coastal Morphology in Mauritius" (refer to Figure 2.2.23) gives a historical record of surveys conducted after Cyclone Carol such as the height of wave run-up and the situation of coastal erosion. Wave forecasting for Cyclone Carol was conducted based on records on the actual route of the cyclone from the Joint Typhoon Warning Centre (JTWC), Figure 2.1.7 shows significant wave height distribution at a discretional time. This result clearly shows that Cyclone Carol had retained similar strength after reaching the shore in Mauritius, so that the waves were quite high not only in the northern part but also the southern part. Figure 2.1.8 shows the elevation of wave run-up at that time. Although the wave height varies according to the bathymetry, reef width and so on, there were wave heights of 12 feet recorded in the southern part of Mauritius.

Table 2.1.3 Results of Wave Forecasting for Each Cyclone
(Max. Significant Wave Height)

Cyclone	Maximum significant wave height(m)			
	N	S	E	W
1960-Carol	12.51	10.94	14.00	12.61
1989-Krisy	5.07	5.76	6.26	5.44
1994-Hollanda	10.66	12.94	13.51	10.49
1995-Ingrid	6.13	8.68	8.37	6.94
1996-Bonita	5.91	4.08	5.25	4.28
1996-Daniella	7.38	6.02	7.69	10.28
1996-Flossy	3.66	5.42	5.19	4.25
1998-Anacelle	7.45	9.63	9.90	8.11
1999-Davina	7.79	9.49	10.59	11.37
2000-Connie	8.67	12.29	12.94	8.72
2002-Dina	11.78	10.12	11.49	7.41
2002-Guillaume	8.67	12.29	12.94	8.72
2003-Gerry	8.92	8.60	10.44	6.71
2005-Hennie	5.40	5.67	6.17	4.78
2007-Gamede	5.22	3.53	4.53	4.37
2008-Hondo	2.90	2.17	2.86	2.40
2009-Gael	3.12	2.21	2.86	2.95
2010-Gelane	3.32	3.17	3.65	2.15
2012-Giovanna	5.13	3.69	4.84	3.81
2013-Dumile	2.52	2.06	2.37	2.98
2013-Imelda	3.19	2.83	3.31	2.20

Source: JICA Expert Team



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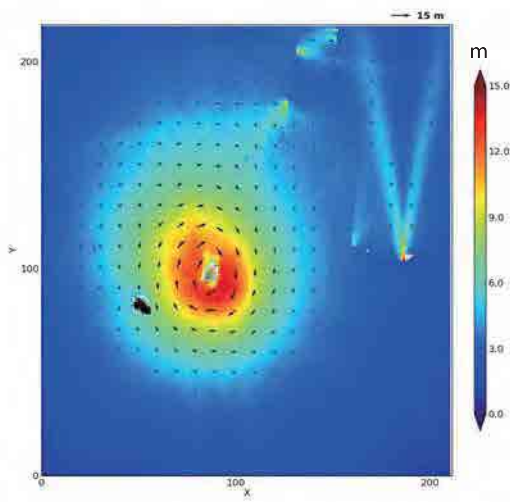

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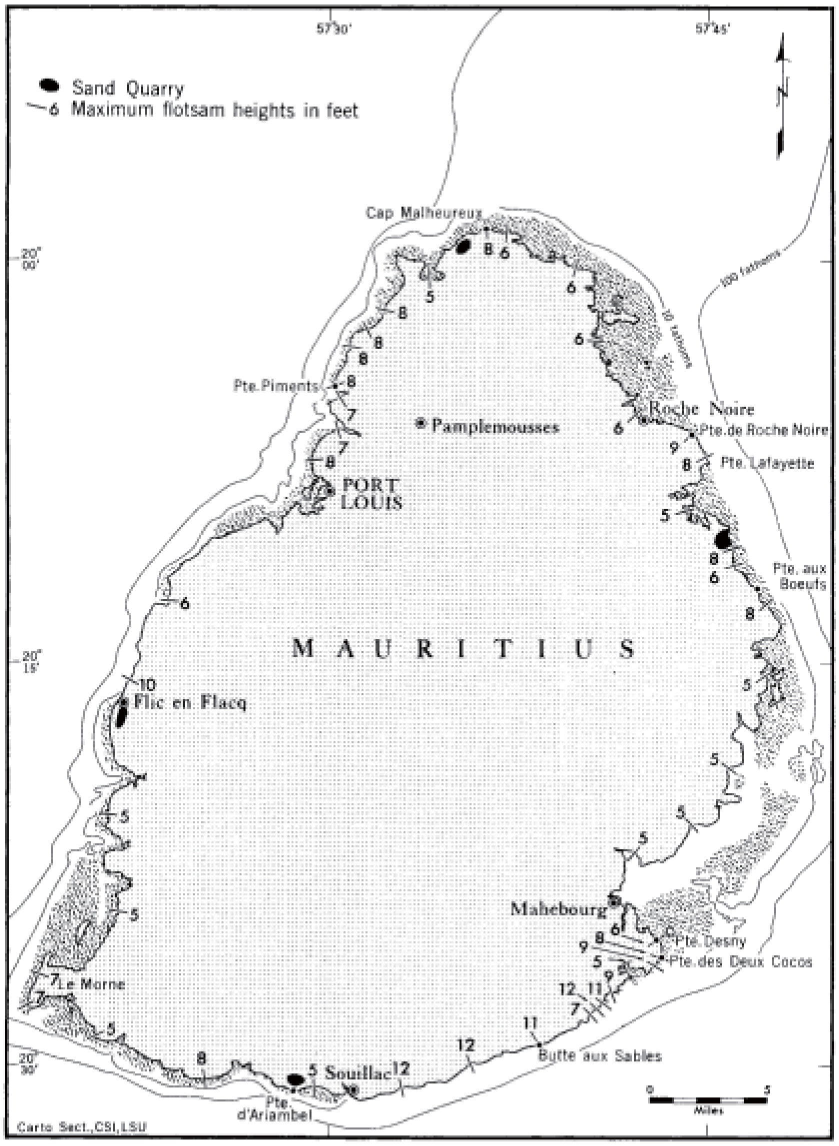
Source: JICA Expert Team

Figure 2.1.7 Wave Forecasting for Cyclone Carol



Source: Tropical Cyclones and Coastal Morphology in Mauritius

Figure 2.1.8 Wave Run-up Heights for Cyclone Carol (unit: feet)

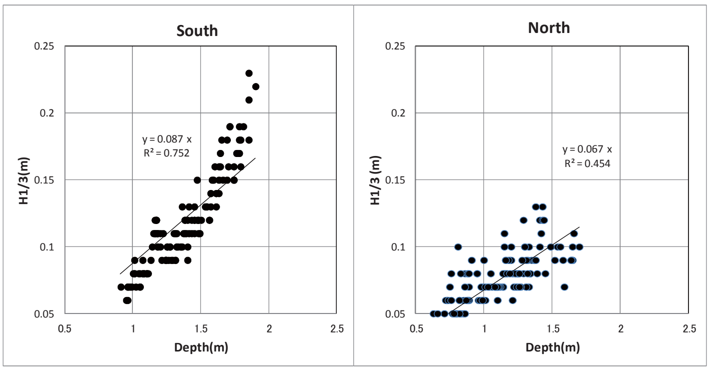
2) Relation between offshore waves and waves in lagoons

Figure 2.1.9 shows the wave and current recorder location at Pointe d'Esny in Mauritius. Figure 2.1.10 shows the relation between the water depth and the significant wave height which was obtained by the observation from February to May. From this figure, the correlation between the change of the depth and the change of wave height can be seen. The relation between the depth and the wave height is roughly H = 0.09d (H: wave height, d: depth) in the southern site (St1 in Figure 2.1.9) and H = 0.07d in the northern site (St2 in Figure 2.1.9). Figure 2.1.11 shows the results which are compared with the results in Blue Bay. The cyclone Imelda passed in the beginning of April and the relation at this time can be clearly seen.

In October 2013, the wave recorder at Pointe d'Esny was integrated to one station and an additional station was set-up at Grand Sable. The set-up conditions and location are shown in Figure 2.1.12. After that, two cyclones hit Mauritius during January and February of 2014. The wave height change in Grand Sable and Roiches Noires at that time is shown in Figure 2.1.13. When cyclone Bejisa made landfall, the significant wave height offshore was around 3.0m, while the wave height in the lagoon was only 0.3m. As for cyclone Edilson, the wave height was 4.0m offshore while 0.3m in the lagoon. Wave height increased a little but the was no significant impact observed by either cyclone. At Grand Sable, wave power attenuated since there is a 4 km long stretch from the beach to the reef edge. In this situation, wave height within the lagoon receives minimal impact from offshore waves. Furthermore, cyclone Bejisa passed through at the western part of Mauritius. Conversely, cyclone Edilson passed through at the eastern part. This might be the main reason that the wave heights of the two cyclones observed at Roiches Noires were vastly different.

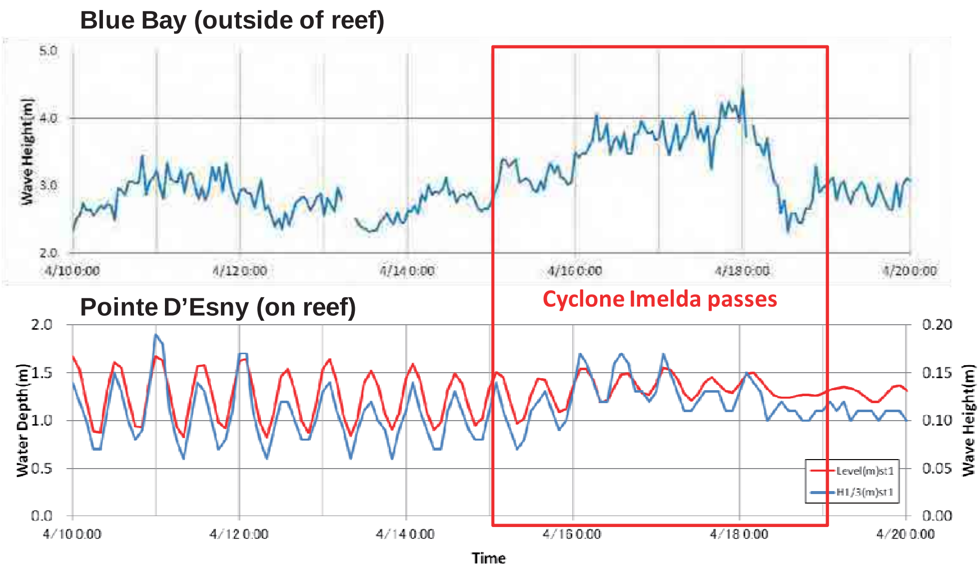
Source: JICA Expert Team

Figure 2.1.9 Wave Recorder/Current Meter location



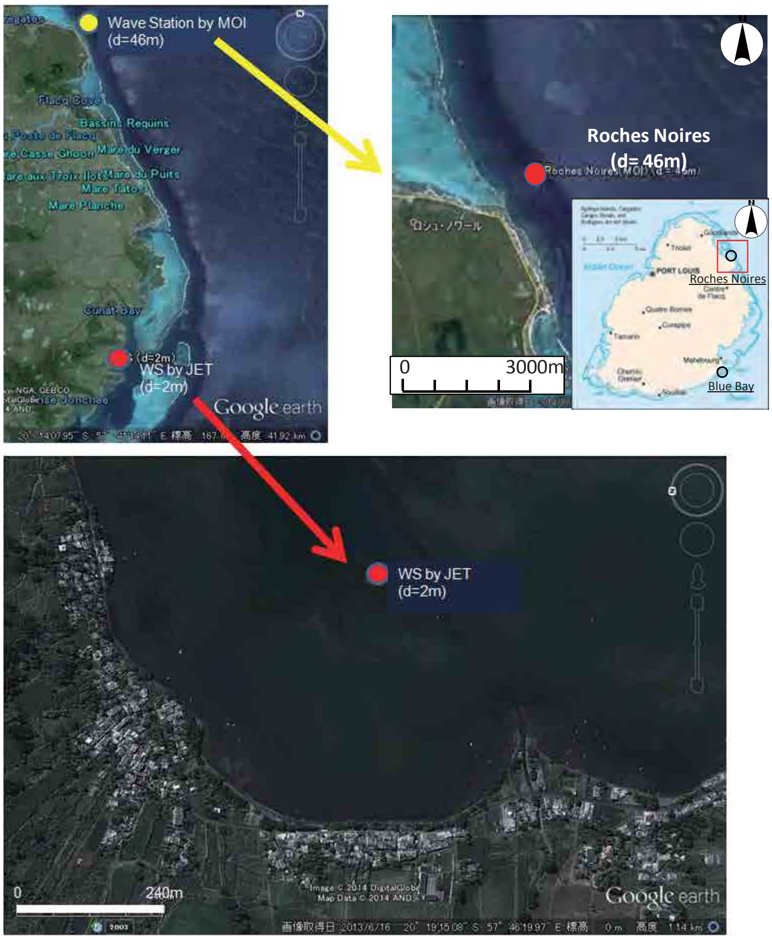
Source: JICA Expert Team

Figure 2.1.10 Relation between Depth & Wave Height



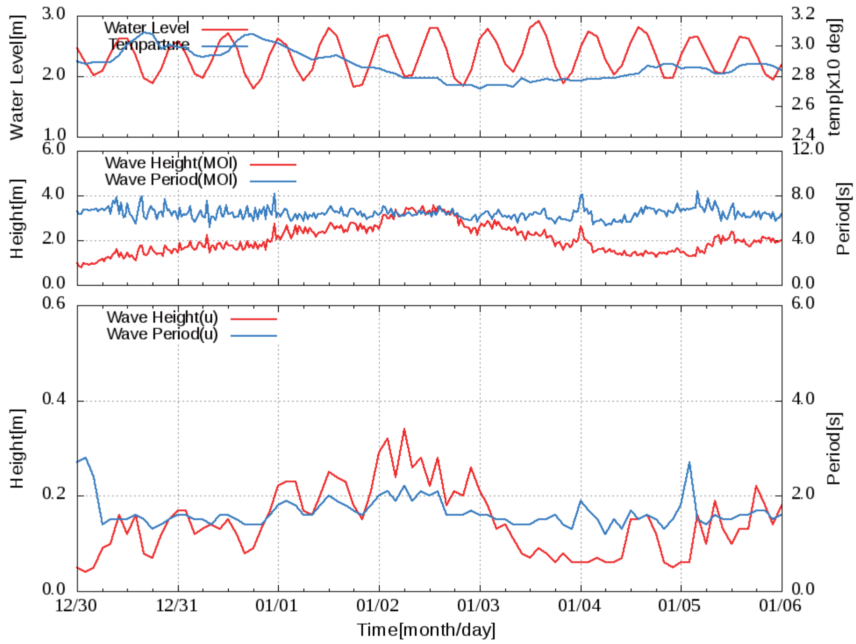
Source: JICA Expert Team

Figure 2.1.11 Comparison of Wave Forecasting between Blue Bay & Pointe d'Esny

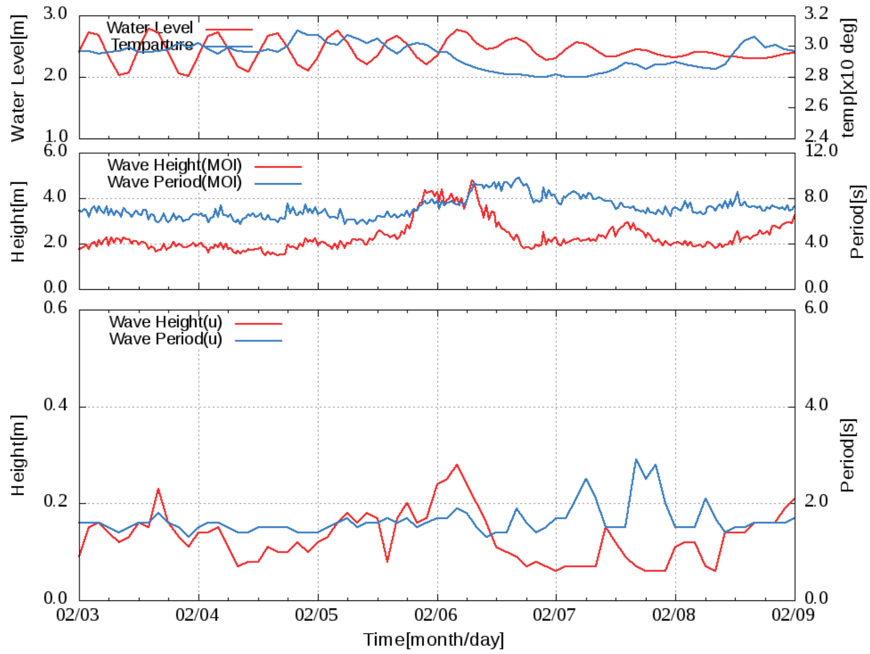


Source: Arranged by JICA Expert Team based on Google map

Figure 2.1.12 Observation Points (Roiches Noires & Grand Sable)



At the time of Cyclone Bejisa



At the time of Cyclone Edilson

Source: JICA Expert Team

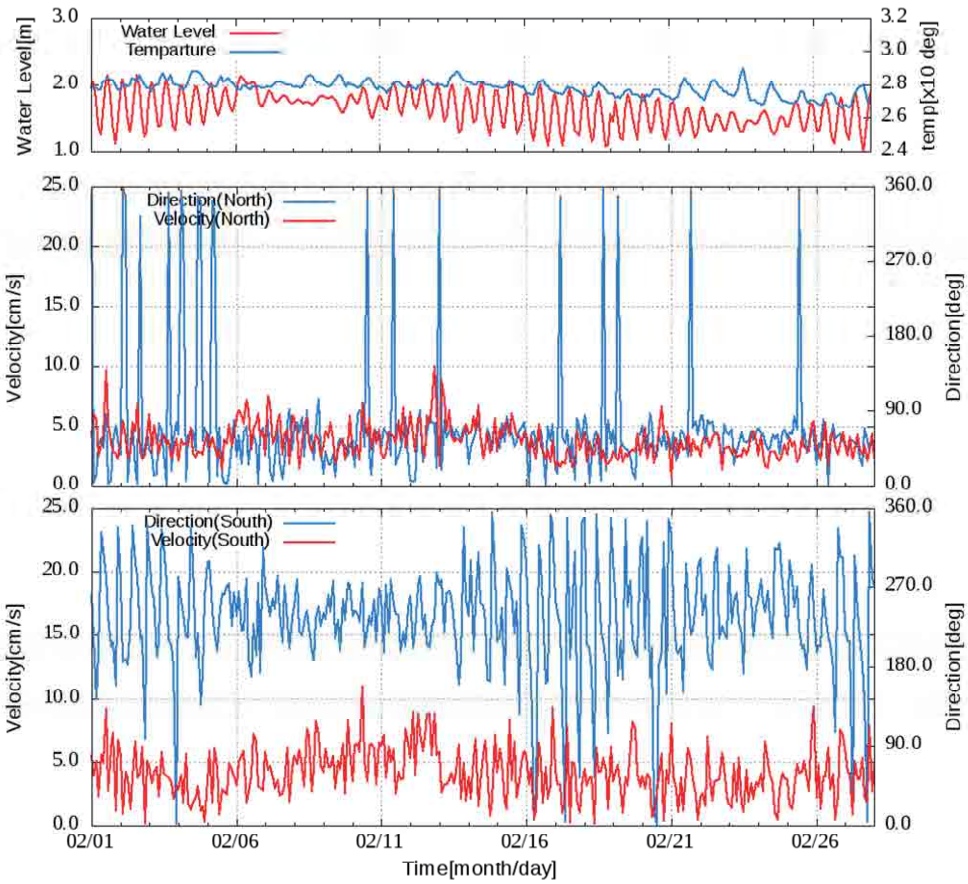
Figure 2.1.13 Changes in Wave Heights, Water Level and Temperature during Cyclones

The current at the lagoon has been continuously under observation since February 2013 by two wave recorder stations and two current meter stations at Pointe d'Esny as shown in Figure 2.1.15. Flow velocity and flow direction (at two current meter stations) at the time of cyclones is shown in Figure 2.1.15.

The result shows that no remarkable change was found on flow velocity before and after cyclones. It means that flow velocity may not change because of cyclones, but it is influenced by tide.

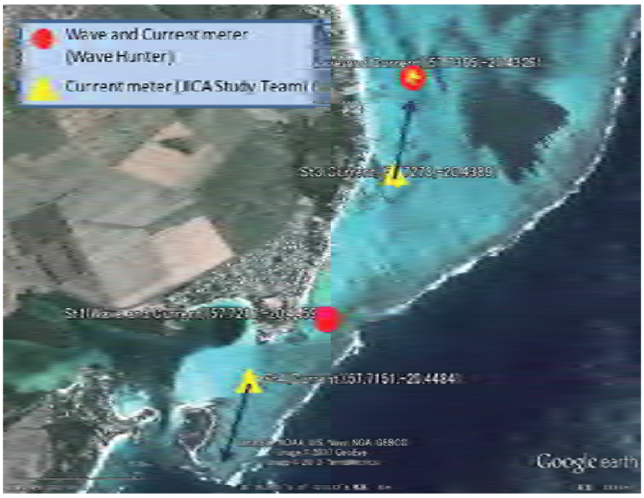
Vector of flow velocity in four observation points during cyclone Edilson is shown in Figure 2.1.15. The result shows that most of the wind velocity readings obtained were less than 10cm/s. The current meter in the northern part shows the current direction was facing north. It is thought that the shore current was developing at this point. Meanwhile, the current meter in the southern part shows the current direction was mostly facing south to west. It is thought that it is not the shore current, but rather an effect caused by the tide.

Finally, it is obvious that flow velocity at the lagoon is generally small and the shore current which is generated by offshore waves rarely occurs. The current occurs predominantly because of tide effects and/or wind disturbances.

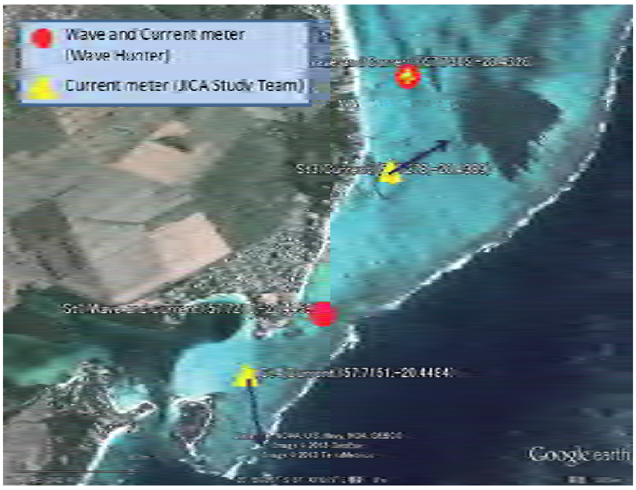


Source: JICA Expert Team

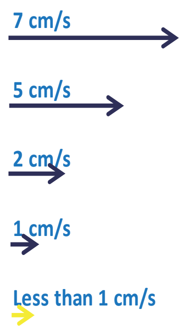
Figure 2.1.14 Time Course of Flow Velocity/Direction at Pointe d'Esny (in Feb. 2014)



2014 2/5 8:00



2014 2/6 12:00



2014 2/7 12:00

Source: JICA Expert Team

Figure 2.1.15 Distribution of Flow Velocity/Direction at the time of Cyclone Edilson

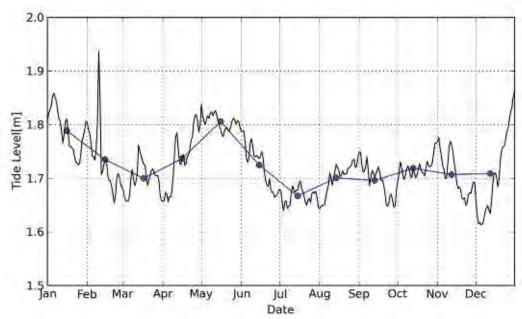
2.1.3 Water Level

1) Tide level

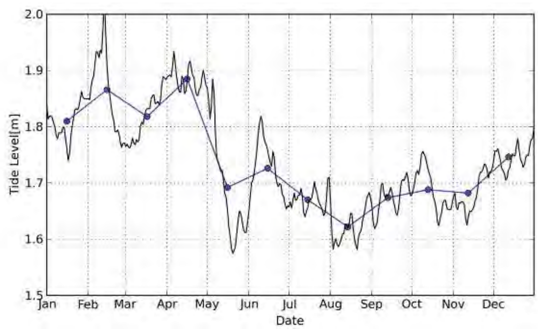
The tidal level has been observed intermittently at Port Louis. Continuous tidal observation has been undertaken since 1986. Figure 2.1.16 shows the time series of daily, monthly and annual averages in 1994 and 2003. Although the tide changes seasonally, it can be seen that the tidal level rose locally due to cyclones from January to March, while it was lower from May to October. This rise almost immediately follows the occurrence of cyclones.

In the previous study report (Tidal Analysis and Prediction in the Western Indian Ocean), harmonic decomposition was carried out in Port Louis and Port Rodrigues and the harmonic constant has been described.

Table 2.1.4 shows the harmonic constant of the main component tide. As a result, it can be seen that tide on the half-day period is dominant.



Year 1994(Hollanda)



Year 2003

Source: JICA Expert Team

Figure 2.1.16 Time Series of Annual Tidal Level (in Port Louis)

Table 2.1.4 Harmonic Constant

Symbol	Constituent name	Port Louis		Rodrigues	
		Amplitude (cm)	Phase (deg)	Amplitude (cm)	Phase (deg)
M_2	Principal lunar semidiurnal	15.16	350.49	41.34	335.53
S_2	Principal solar semidiurnal	10.17	38.13	25.19	43.78
N_2	Larger lunar elliptic semidiurnal	4.29	86.51	7.59	59.48
K_1	Luni-solar declinational diurnal	6.35	286.94	5.54	315.04
K_2	Luni-solar declinational semi diurnal	2.23	184.67	6.12	181.61
O_1	Lunar declinational diurnal	4.18	263.33	3.44	296.72
SA		12.14	228.34	13.43	252.07

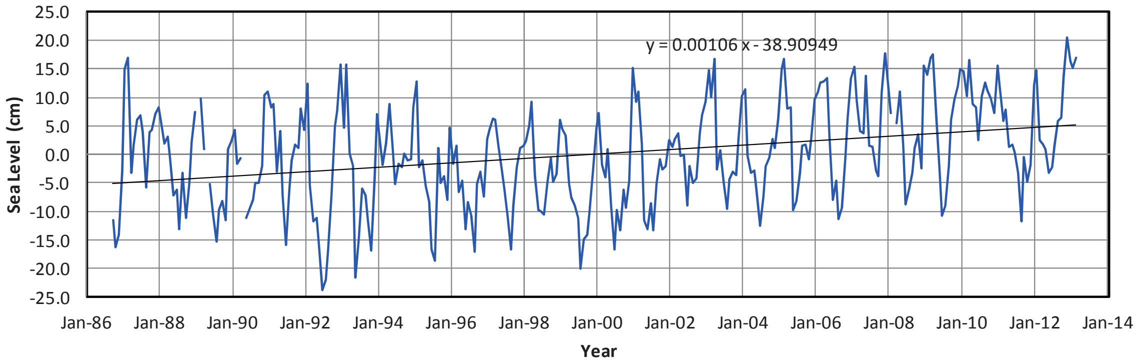
Source: Tidal Analysis and Prediction in the Western Indian Ocean Regional Report)

2) Storm Surge

In Mauritius, cyclones frequently make landfall causing the sea level to rise with the storm surge. The sea level rise from storm surges is classified into two parts: the suction effect of depression or the wind-drift effect. There are few inner bays in Mauritius. Therefore, the wind-drift effect is more dominant than the suction effect. The storm tide can be seen as the difference between the mean value and the momentary value as shown in Figure 2.1.16. The storm tide is around 30 cm and has a smaller effect than that of waves.

3) Sea Level Rise

Figure 2.1.17 shows the mean daily tide level for 30 years. From this figure, it can be seen that the tide level in Port Louis is rising 3.9mm per hour.



Source: The Global Sea Level Observing System

Figure 2.1.17 Tide Time Series in Port Louis

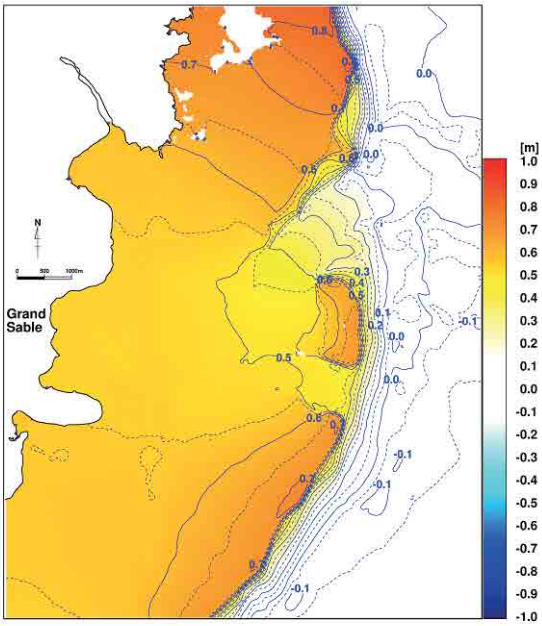
4) Sea Level Rise in Lagoon

In a wide lagoon, the water level rises from breaking waves. In order to estimate the wave set up, the wave deformation analysis has been carried out in Grand Sable which has a wide lagoon. Table 2.1.5 shows the calculation condition for wave deformation analysis using SWAN. Wave set-up is the highest for the ESE direction. Figure 2.1.18 shows the wave set-up distribution for the ESE direction. The wave-setup is about 0.55m and the wave height is about 0.4m.

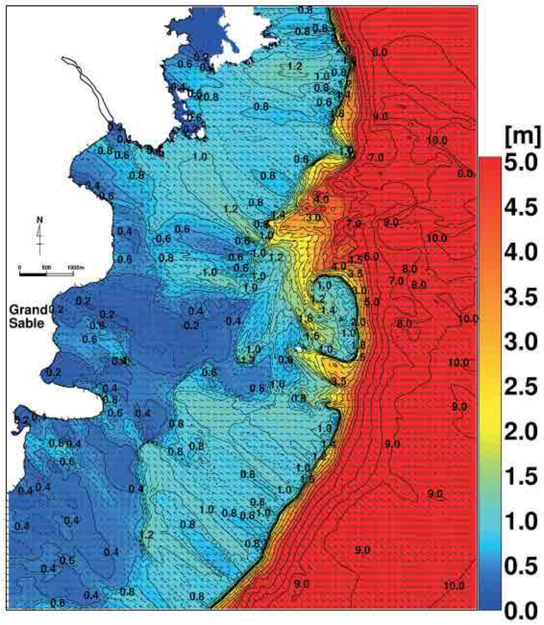
Table 2.1.5 Calculation Condition for Wave Calculation using SWAN

Design Condition	Set-up Value or Description about Consideration	Remarks
Offshore wave height, period, wave direction	16 directions in 30 probable years shown on Table 7.3.2	Determined based on 6 wave directions from NE to SSE
Tide level	CD+1.04m (MSL +0.67)	Tide level with return period of 30 years
Wave attenuation by seabed friction	Not taken into account	Designed on the safe side
Wave set-up	Taken into account	
Propagation of wind waves in the lagoon	Not taken into account	Compare additional wind wave analysis

Source: JICA Expert Team



Distribution of wave-setup
（ESE：30 years return period）



Distribution of wave height and direction
(ESE：30 years return period）

Source: JICA Expert Team

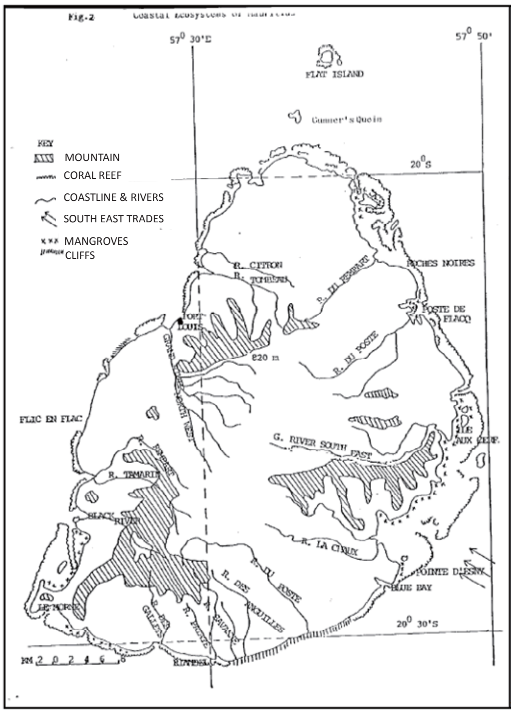
Figure 2.1.18 Calculated Wave Height and Wave Set-up

2.1.4 Geology and Geography of the coastal area

a. Geology

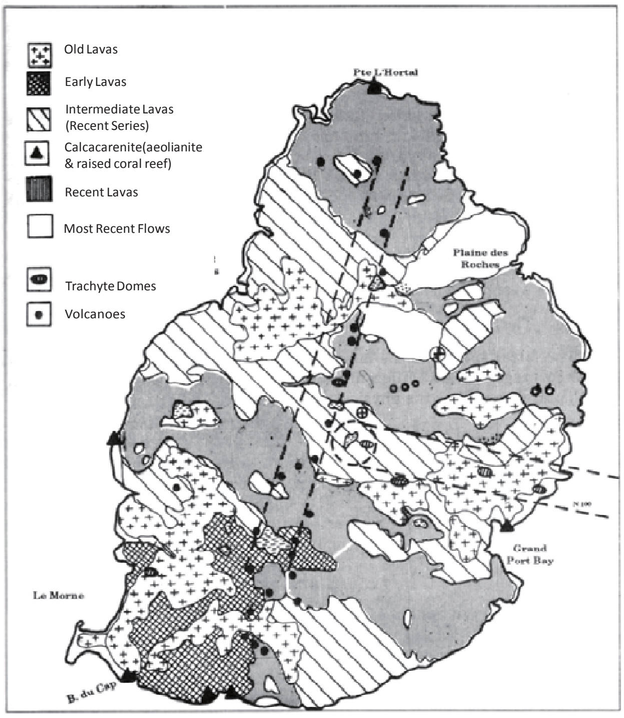
Mauritius is a volcanic island in the Indian Ocean, which is located at south latitude 20° and east longitude 57°, approximately 800 km to the east of Madagascar. The geology of the coastal area in Mauritius has several variations, such as sand, boulder, gravel, silt, limestone, etc. as shown in Figure 2.1.19.

Figure 2.1.19 shows the coastal geography and geology map of Mauritius Island. From six million to ten million-years ago, there was a period of volcanic activity on Mauritius Island. The geology at the southwest coast consists of lava which was formed over 7 million years ago. The geology at the northeast coast consists of lava which was formed over 20 thousand years ago. The geology at other areas consists of the lava from over 10 thousand years ago.



Coastal Geography

Source:IOC-UNEP-WMO-SAREC, Planning Workshop on An Integrated Approach to Coastal Erosion, Sea Level Changes and Their Impacts



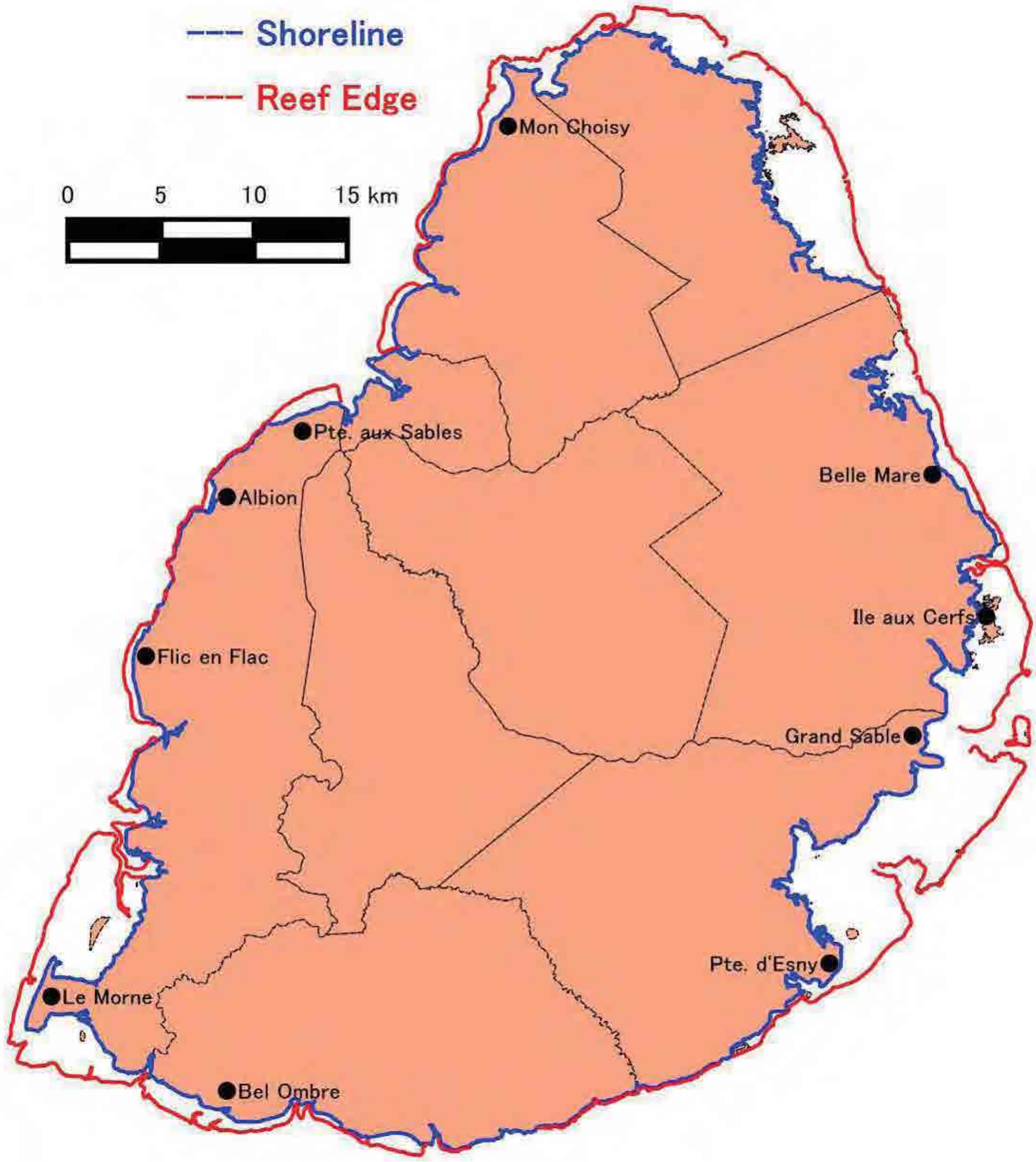
Geology

Source: Mauritius A Geomorphological Analysis

Figure 2.1.19 Coastal Geography and Geology of Mauritius Island

b. Coral Reef

The area of lagoon covered by coral reef is 243 km^2, and the distance of the reef is about 150 km around Mauritius Island. The coral reef has a width of more than 3 km in part of the east and northeast area, and it is also relatively wide in the southeast area. The front area of the major sandy beaches such as Flic en Flac and Bell Mare have reef widths of several hundred meters. On the other hand, coral reefs in parts of the south and west coastal zone are hardly formed.



Source: JICA Expert Team

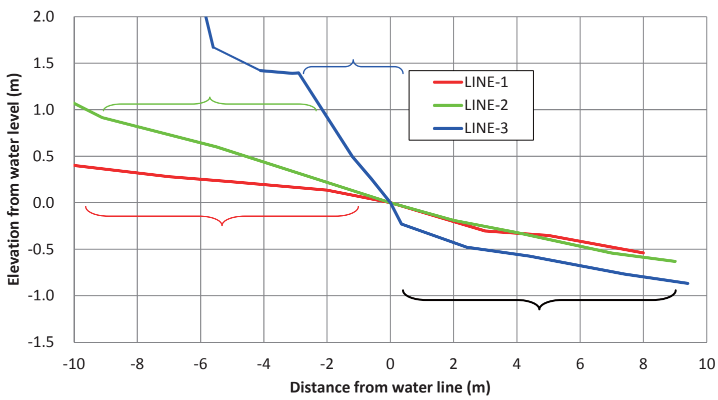
Figure 2.1.20 Coral Reed around Mauritius Island

c. Coastal topography

Figure 2.1.22 shows the result of a beach profile survey in Pte. d'Esny as a representative coast in Mauritius, shown in Figure 2.1.21. It tends to accumulate sediment in the south side of the jetty and erode in the north side because of littoral drift from south to north. LINE-1 is the accumulation zone and has a wide beach. On the other hand, LINE-3 is eroded and has a narrow beach. Sand packs are used to try to mitigate this erosion. LINE-2 is in between LINE-1 and LINE-3. The offshore shoreline at each line has approximately the same slope at 1/15. On the other hand, the foreshore has a different slope. The foreshore slope of LINE-1, which has a wide beach, is gentle at about 1/25. Intermediate LINE-2 has about 1/10 beach slope. The slope of eroded LINE-3 is sharp at about 1/2. In this way, the foreshore of the beach has a different slope in the same series of coast. It has a gentle slope in the accumulated zone, and a sharp slope in the eroded zone.

Source : Arranged by JICA Expert Team based on data(2008) of Ministry of Housing and Lands in Mauritius

Figure 2.1.21 Survey Lines of Beach Profile in Pte. d'Esny



Source: JICA Expert Team

Figure 2.1.22 Result of Beach Profile Survey in Pte. d'Esny (17/10/2014)

d. Coastal Sediment

Figure 2.1.23 and Figure 2.1.24 show results of sediment surveys at several representative beaches in Mauritius.

- Particular Features on Grain Size (Figure 2.1.23) :

① The grain size of sand at Mon Choisy, Flic en Flac and Pte. d'Esny is distributed from 0.2 to 0.34mm. These results indicate that the grain size at these coasts is smaller than other coasts in Mauritius.

② The grain size at the inner reef area of Le Morne is 0.5 to 0.8 mm. The grain size at the outer reef area is 0.75 mm.

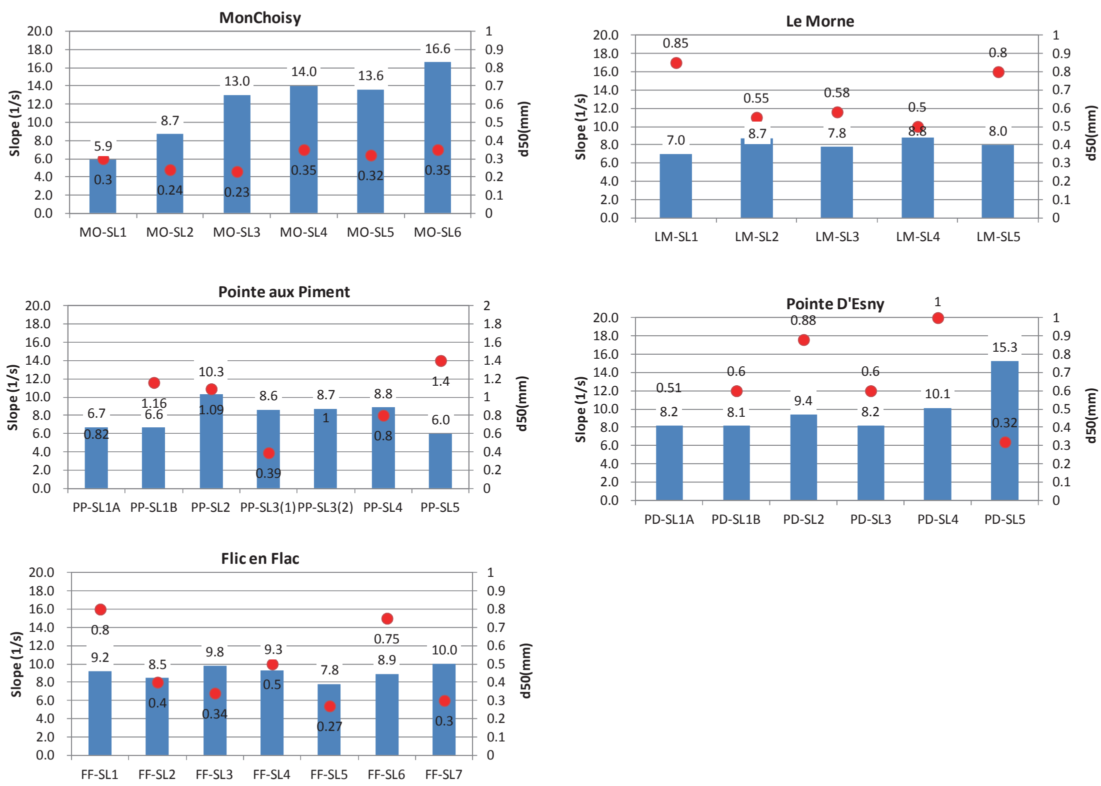
③ The grain size at Pte. aux Piment is distributed from 0.4 to 1.4 mm. Littoral drift was not observed as a cause for the difference of grain sizes.

- Relation between Distance from Reef Edge and Grain Size (Figure 2.1.24):

① The width of the coral reef at Grand Sable is about 5km. The grain size becomes smaller in accordance with the distance from the reef edge at both of the north and south points. This trend indicates that the coarse sand is transported from onshore to offshore after breaking off from the reef edge. The grain size becomes large at a point of approximately 4km from the reef edge. The existence of a natural channel might influence such changes in grain size.

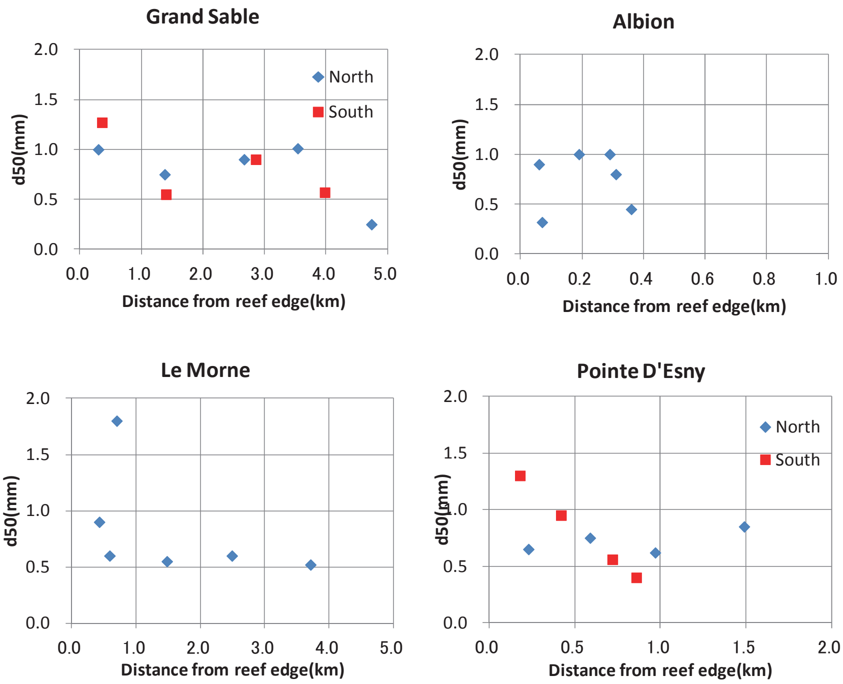
② The width of the coral reef at Pte. d'Esny drastically changes from 0.5km at the south part to 2km at the north. The grain size at the south area changes from 1.3 mm at the nearby reef edge to almost half this size at the middle point. On the other hand, there is no significant on-offshore difference of grain size at the north part. The tendency for distributed differences in grain size between the south and the north parts of Pte. d'Esny might be caused by the difference of the width of the coral reefs.

③ No pattern for differences of grain size at on-offshore directions was observed at Le Morne and Albion.



Source: JICA Expert Team

Figure 2.1.23 Distribution of Beach Slope and Grain Size

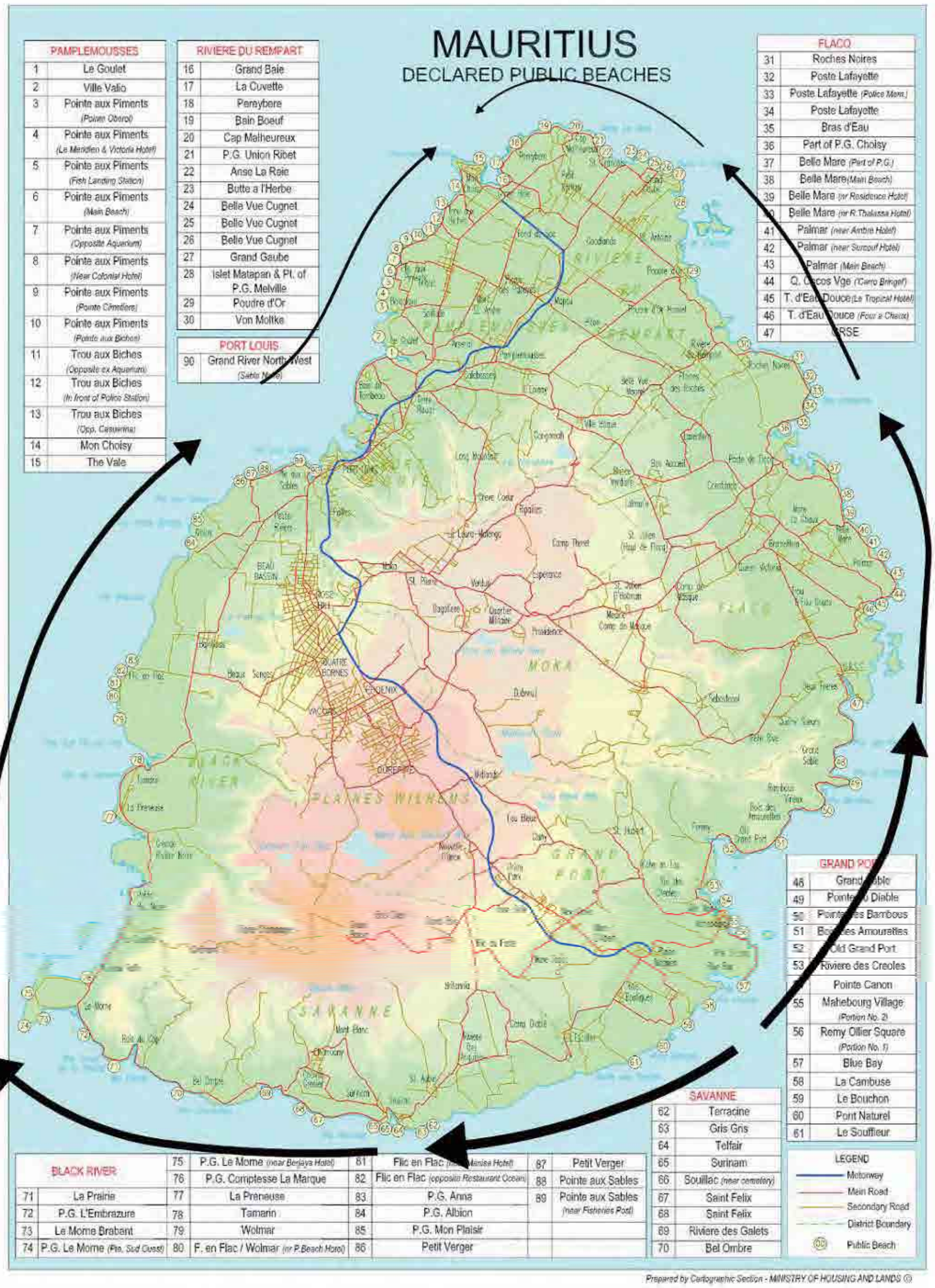


Source: JICA Expert Team

Figure 2.1.24 Relation between Distance of Reef Edge and Grain Size

e. Characteristics of Littoral Drift

Macroscopically, the dominant direction of littoral drift around Mauritius Island is shown in Figure 2.1.25. Characteristics shown include wind and wave, differences of beach width around capes or jetties, and so on. It has a counterclockwise direction in the north area from Blue Bay, in the southeast of the island. Conversely, it has a clockwise direction in the west area from there.



Source: JICA Expert Team

Figure 2.1.25 Macroscopic Dominant Direction of Littoral Drift around Mauritius Island

2.2 Design Condition

2.2.1 Design Offshore Wave

In the wave forecasting, the maximum significant wave height in the four directions (East, West, North and South) of Mauritius was estimated by SWAN (wave forecasting model). In order to simulate and adjust the wave forecasting model, the estimated value was evaluated in comparison to the real data of Cyclone Giovanna in 2012. Figure 2.2.1 shows the above evaluation results. These results clearly confirm that the wave height and period at peak times are sufficiently corresponding, although this is underestimated before cyclones hit.

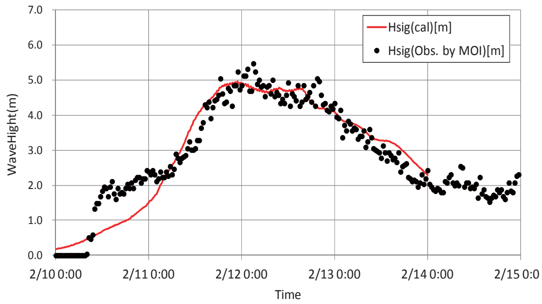
Using this model, the time series of wave height at the objective points has been calculated based on the longitudinal pressure and distribution which is estimated from the route of the representative cyclone (JTWC). Table 2.2.1 shows the maximum significant wave height for each major cyclone in certain time periods. Wave height with over 10.0m at every direction can be seen in Cyclone Carol in 1960, Hollanda in 1994 and Dina in 2002.

Table 2.2.1 Result of Wave Forecasting for Each Cyclone

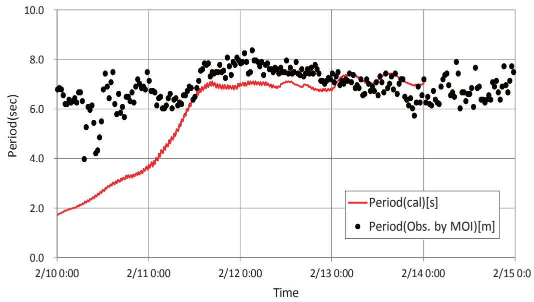
Cyclone	Maximum significant wave height(m)			
	N	S	E	W
1960-Carol	12.51	10.94	14.00	12.61
1989-Krisy	5.07	5.76	6.26	5.44
1994-Hollanda	10.66	12.94	13.51	10.49
1995-Ingrid	6.13	8.68	8.37	6.94
1996-Bonita	5.91	4.08	5.25	4.28
1996-Daniella	7.38	6.02	7.69	10.28
1996-Flossy	3.66	5.42	5.19	4.25
1998-Anacelle	7.45	9.63	9.90	8.11
1999-Davina	7.79	9.49	10.59	11.37
2000-Connie	8.67	12.29	12.94	8.72
2002-Dina	11.78	10.12	11.49	7.41
2002-Guillaume	8.67	12.29	12.94	8.72
2003-Gerry	8.92	8.60	10.44	6.71
2005-Hennie	5.40	5.67	6.17	4.78
2007-Gamede	5.22	3.53	4.53	4.37
2008-Hondo	2.90	2.17	2.86	2.40
2009-Gael	3.12	2.21	2.86	2.95
2010-Gelane	3.32	3.17	3.65	2.15
2012-Giovanna	5.13	3.69	4.84	3.81
2013-Dumile	2.52	2.06	2.37	2.98
2013-Imelda	3.19	2.83	3.31	2.20

Source: JICA Expert Team

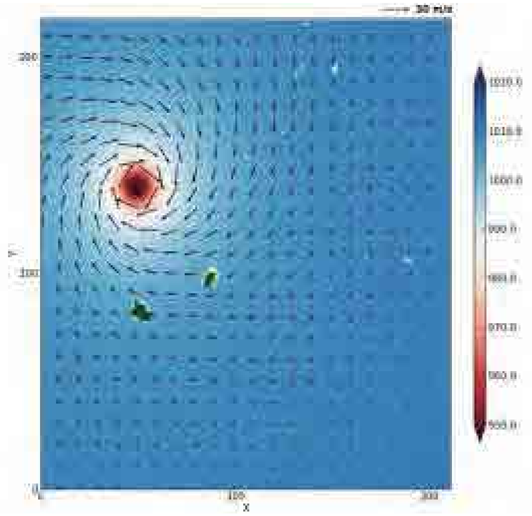
This study shows that the cyclones are stronger in the northern part, however wave forecasting shows the opposite results in some cases. This was caused by the strong waves that occurred in the southern part of Mauritius when the clock-wise wind of the cyclones passed through the coastal area in Mauritius. In addition, the result of wave forecasting made by Era-40 includes waves in all situations, not only cyclones. We can see that wave distribution relies on seasonal conditions, and that may be dependent on the route and scale of the cyclones occurring in Mauritius.



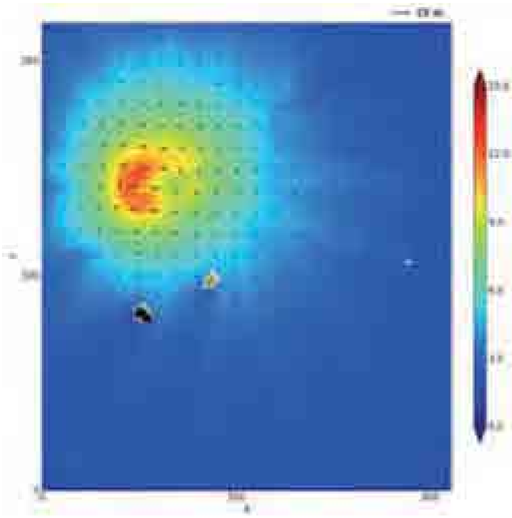
Wave height



Period



Wind velocity/pressure distribution



Significant wave height distribution

Source: JICA Expert Team

Figure 2.2.1 Verification Result of Cyclone, Giovanna

The extreme value statistics analysis has been carried out using the results of the wave forecast as shown in Table 2.2.2. Table 2.2.3 shows the results for each return period. In order to estimate the design wave condition in the physical countermeasure area at Grand Sable, the return period of the waves have been calculated by splitting the directional spectrum. Table 2.2.3 shows the result of the extreme value statistics analysis in each direction. The wave period was calculated using the relation between the wave height and the period observed by MOI.

Table 2.2.2 Extreme Value Statistics

	N		S		E		W	
Return Period	H(m)	T(s)	H(m)	T(s)	H(m)	T(s)	H(m)	T(s)
5 years	6.0	9.6	6.2	9.7	7.0	10.2	5.7	9.5
10 years	8.3	11.0	9.0	11.4	10.0	12.0	8.2	11.0
20 years	10.0	12.0	11.1	12.7	12.3	13.4	10.1	12.1
30 years	10.9	12.6	12.2	13.4	13.4	14.1	11.1	12.7
50 years	11.9	13.2	13.5	14.1	14.7	14.8	12.2	13.3
100 years	13.2	13.9	15.0	15.0	16.4	15.8	13.6	14.1

Source: JICA Expert Team

Table 2.2.3 Estimated Offshore Wave Height with Each Return Period for Each Offshore Wave Direction

Offshore Wave Direction	**S**		**SSE**		**SE**		**ESE**		**E**	
Return Period	**H_0(m)**	**T_0(s)**	**H_0(m)**	**T_0(s)**	**H_0(m)**	**T_0(s)**	**H_0(m)**	**T_0(s)**	**H_0(m)**	**T_0(s)**
5years	4.3	8.6	4.8	8.9	4.9	9.0	4.8	8.9	4.2	8.5
10years	7.2	10.4	7.3	10.5	7.3	10.5	7.3	10.4	6.9	10.1
20years	9.3	11.6	9.4	11.6	9.2	11.5	9.2	11.5	9.1	11.5
30years	10.3	12.2	10.3	12.2	10.1	12.1	10.1	12.1	**10.3**	**12.2**
50years	11.4	12.9	11.4	12.9	11.2	12.7	11.2	12.7	11.7	13.0
100years	12.8	13.8	12.7	13.7	12.5	13.5	12.5	13.5	13.5	14.1

Offshore Wave Direction	**ENE**		**NE**		**NNE**		**N**	
Return Period	**H_0(m)**	**T_0(s)**	**H_0(m)**	**T_0(s)**	**H_0(m)**	**T_0(s)**	**H_0(m)**	**T_0(s)**
5years	3.3	8.0	2.8	7.7	2.9	7.8	2.3	7.3
10years	5.9	9.6	5.4	9.2	4.8	8.9	4.7	8.9
20years	8.5	11.1	8.0	10.8	7.1	10.3	7.2	10.3
30years	10.1	12.1	9.5	11.7	8.6	11.2	8.7	11.2
50years	12.0	13.2	11.5	12.9	10.7	12.4	10.5	12.3
100years	14.7	14.8	14.1	14.4	13.7	14.3	12.9	13.8

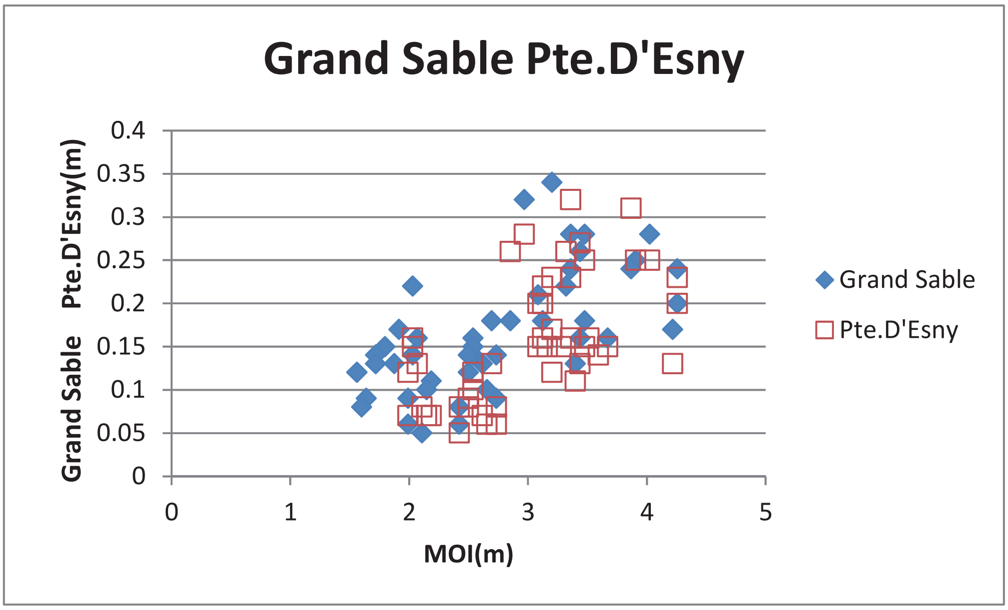
Source: JICA Expert Team

2.2.2 Design Wave Heights within Reef

In Mauritius, the design wave acting on the coast has to be estimated taking into account the deformation of waves in a coral reef located in front of the coast. Incident waves break on the reef, dissipate by bottom friction and reach the coast. If the attenuation of the incident wave is large, the wind waves generated in a lagoon have to be considered. The impact of incident waves is more dominant than wind waves if the probability of incident waves is higher.

The waves, after breaking on the reef, decrease in height and period according to the tidal level at the edge of the reef. The dissipation of waves by bottom friction is controlled by the water depth and the distance from the edge to the coast in a lagoon. The estimation of those conditions is difficult because the observation and the understanding of the phenomenon are limited.

The relation of the wave height observed at Pte d'Esny and Grand Sable by JET and at Blue Bay by MOI is shown in Figure 2.2.2. The wave height in the reef is about 10% of the incident wave height at its maximum. The results can be used as a rough estimation of the design wave height within a reef. Improvement of accuracy is required by accumulation of observation data.



Source: JICA Expert Team

Figure 2.2.2 Wave Height Relation between Offshore and within Reef

The period in the reef seems to decrease in comparison to the offshore design wave periods but the degree is not clear. One of the proposals is to take an average of the period between the offshore wave and the wave in a lagoon. In this regard, further study is necessary.

2.2.3 Design Water Level within a Reef

Several factors have to be considered with regard to the design water level within a reef. Those include astronomical tide, storm surge, wave setup and sea level rise in the future. The highest astronomical tide is estimated from the MHWS (Mean High Water Springs).

- Port Louis: +0.25m (above MSL)
- Southeast coast: +0.43m (above MSL)

Storm surges are caused by a depression of atmospheric pressure and cyclonic wind forces. Potentially, there is a 1cm rise in sea level for every 1hPa of depression. The abnormal level observed by Cyclone Carol (1960) at Port Louis was 2ft (0.6m) and the lowest depression was 70=1013-943 hPa. The surge height was almost comparable to the depression. That depression was the lowest observed in Mauritius for over 50 years.

The wave setup is caused by breaking waves at the edge of the reef and its level decreases according to the generation of reef currents, which is affected by the topography. The setup is high if the waves are high and the outflow channel is narrow. The observation at Pte d'Esny shows that the setup is 3% of the incident wave height. The results can be used as a rough estimation of the setup in a reef if the topography is similar.

The sea level rise also has to be considered. At present, the rate is 3.9mm/year. However the rate is increasing. The estimated value becomes 0.2m within 50 years and 0.4m within 100 years if the trend is the same as at present.

The design water level is the total of those values explained above. As an example, if the wave height is 10m and the probability is 50 years, the water level is as follows:

- Design Water Level = Astronomical Tide + Storm Surge + Setup + Sea level Rise = 0.25+ 0.6+0.03*10+0.2 m =+1.35m (above MSL) at the west coast

- Design Water Level = Astronomical Tide + Storm Surge + Setup + Sea level Rise = 0.43+ 0.6+0.03*10+0.2 m =+1.53m (above MSL) at the southeast coast

There are many uncertainties for the determination of design conditions. Observation at the site and the accumulation of data is necessary. Then the observation of waves and tides has to be continued and revisions are necessary based on the results.

3 Coastal Conservation Measures

3.1 Introduction

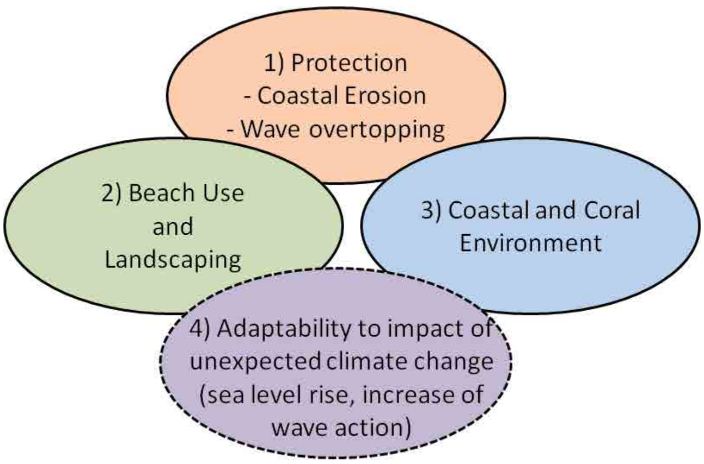
a. Policy of Coastal Conservation in Mauritius

1) Proposed coastal conservation measures shall mainly take in account the following three factors; ***1) protection***, ***2) beach use and landscaping and 3) coastal and coral environment***. Most of the coastal area in Mauritius is formed by coral reefs and is highly utilized by tourists, so these considerations must be paid greater attention compared to other countries.

2) Furthermore, the risk of coastal disasters due to future climate change is becoming more apparent, especially for island countries. Thus, ***4) applicability of measures to the impact of unexpected climate change*** is also an important factor when planning countermeasures in Mauritius (Figure 3.1.1).

3) The costal conservation in Mauritius can be achieved not only for undertaking a ***"Project"***, but also for conducting **"Relevant *sustainable coastal and coral reef management*"** by taking advantage of resources and the scale of Mauritius (not a big country but a small island country).

4) Effective ***re-use of sand*** based on ***"Integrated management of the sand budget"*** will be required to maintain sustainable coral sandy beaches.



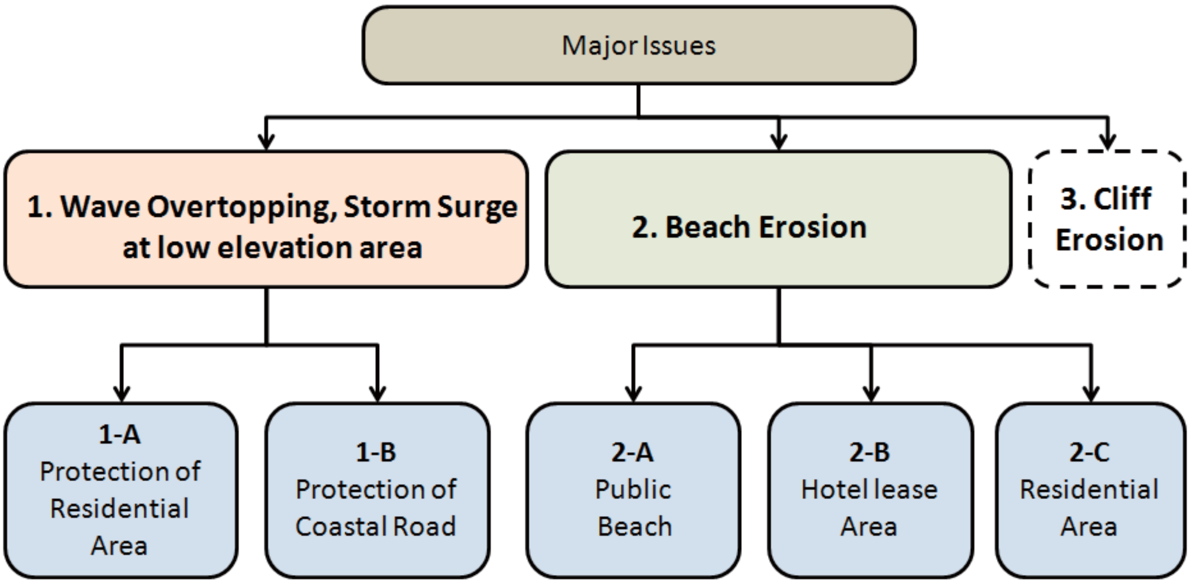
Source: JICA Expert Team

Figure 3.1.1 Consideration on Coastal Conservation Measures in Mauritius

b. Categorizing of Coastal Issues and Principle of Coastal Protection Measures

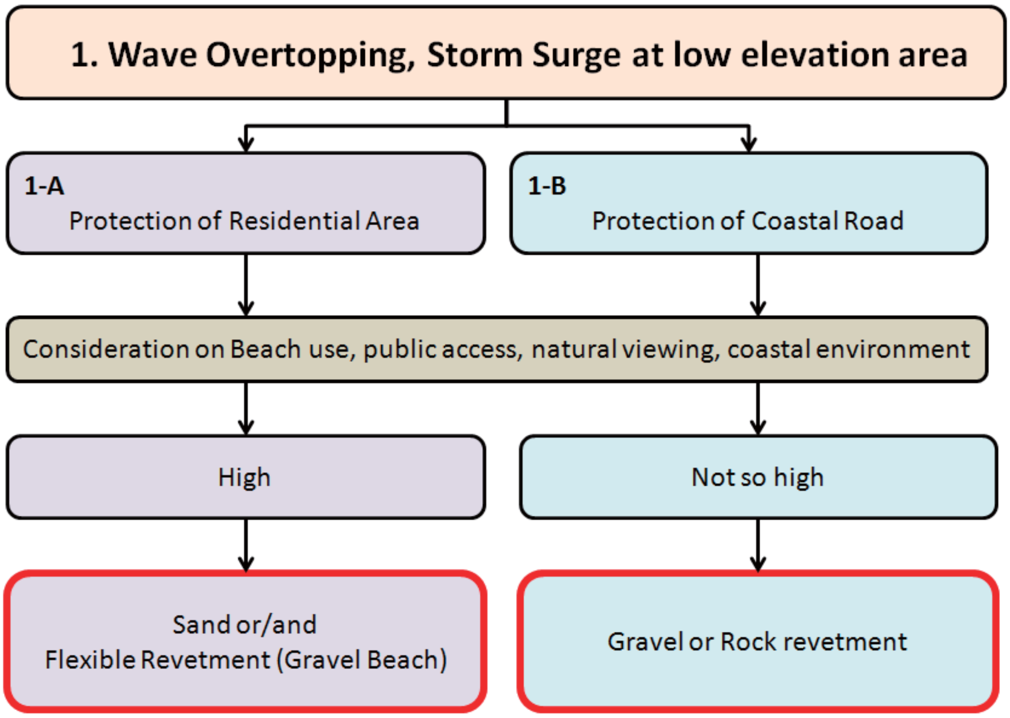
Figure 3.1.2 shows the major coastal issues and categories for coastal areas in Mauritius. There are two main coastal issues in Mauritius, that is 1) Wave overtopping and storm surge at low elevation coastal areas, and 2) Beach erosion. The coastal protection measures in Mauritius shall mainly consider the aforementioned two coastal issues.

Proposed coastal protection measures must take into consideration the condition of land use in the surrounding hinterland. The basic concepts of the proposed coastal measures for each coastal issue at each area are shown in Figure 3.1.3 and Figure 3.1.4.



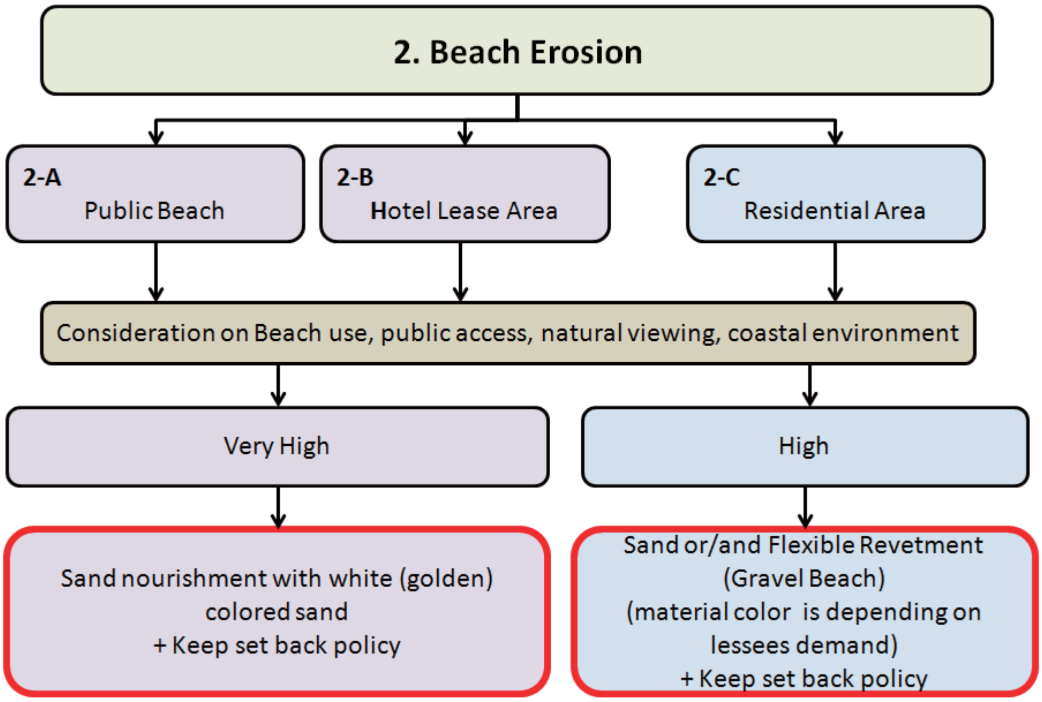
Source: JICA Expert Team

Figure 3.1.2 Categorizing of Coastal Issue



Source: JICA Expert Team

Figure 3.1.3 Principle of Coastal Protection Measures for Wave Overtopping



Source: JICA Expert Team

Figure 3.1.4 Principle of Coastal Protection Measures for Beach Erosion

3.2 Nourishment

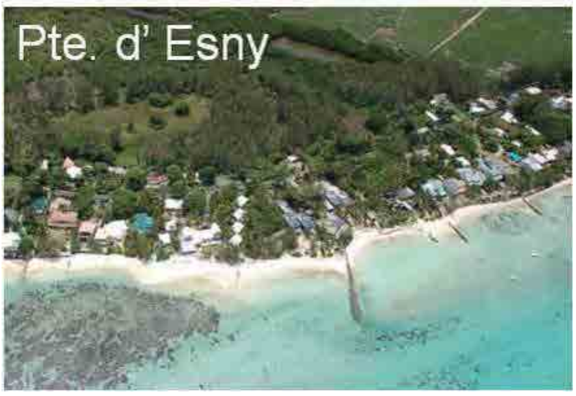
3.2.1 Categorizing of Existing Coasts and Principle Method of Nourishment

1) In case of maintaining natural sandy beaches without artificial coastal structures (Category-A) as shown in Figure 3.2.1, ***only sand nourishment (including gravel nourishment) with appropriate management (beach re-profiling)*** will be applied as environmentally friendly measures. Artificial structural measures shall be limited as much as possible.

2) Even in cases whereby artificial coastal structures such as groynes and revetments already exist to protect properties (Category-B), ***sand nourishment (including gravel nourishment) with appropriate management (beach re-profiling)*** will be basically applied. However, re-assessment of structures shall be required by factoring in the impact of the structures on the integrated littoral movement of the beach, and re-arrangement of the structures (including modification and partial removal of structures) shall be investigated.

3) ***Hard structure measures only*** are strongly discouraged taking into account the beach use and the advantage of maintaining sandy beaches in Mauritius as well as based on the failure of past experiences carried out in other countries. However, there is an exception for cases solely intended for "protection of land or hinter facilities" without the need for taking into consideration other factors.

Example of Category A (Natural coasts are maintained)



Example of Category B (Sandy beach was disappeared and foreshore area is covered by coastal structures)

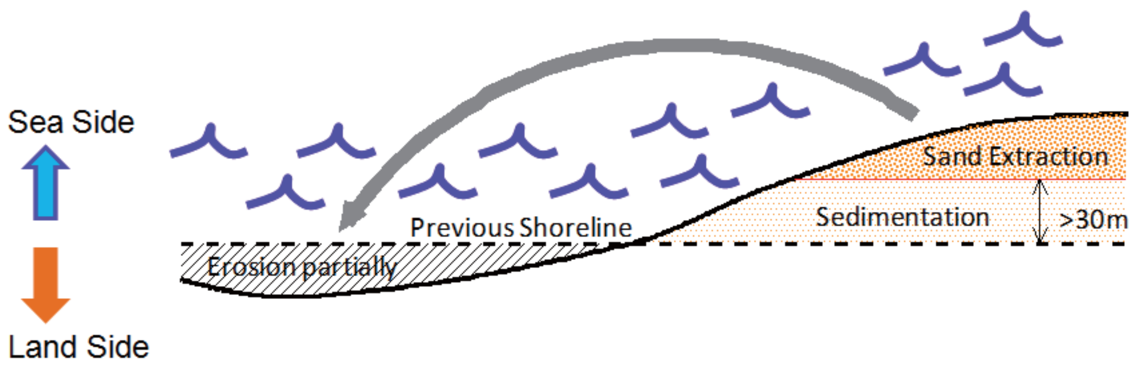
Source: JICA Expert Team

Figure 3.2.1 Natural Coast (Category A) and Structure Coast (Category B)

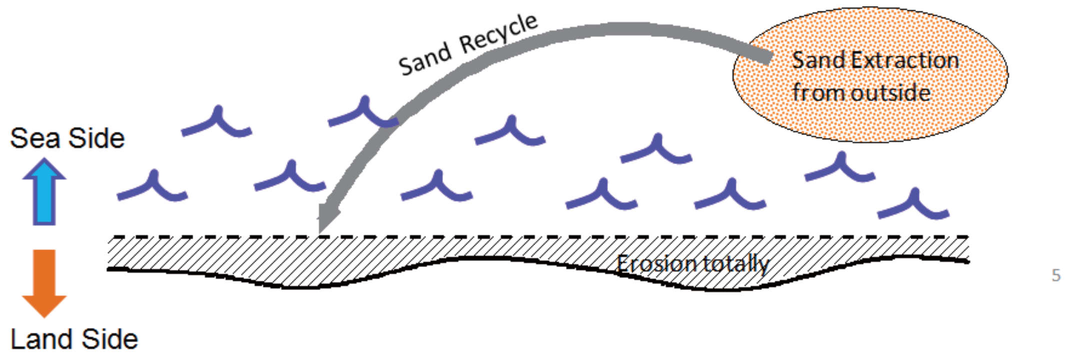
4) In case the sediment budget of the beach balances or increases in total (Category I,II) as shown in Figure 3.2.2, sand for maintenance inside of this beach (e.g. by sand recycling) is only recommended for cases of sufficient buffer zones (30m setback rule) exists. If the sediment budget of the beach decreases in total (Category III), the sand for maintenance has to be procured outside of this beach. However, appropriate sand sources shall be found taking into account cost efficiency, easy methods and environmental impact based on comprehensive sediment management in Mauritius.

5) Sand sources on the beach are mainly from corals and coral reefs. It is strongly required to preserve and rehabilitate coral and coral reef conditions to maintain sand sources for long term measures.

6) The reclamation of beach is different from the nourishment which is applied for the restoration of eroded beach. The beach is formed by the characteristics of geological and wave conditions. The reclaimed beach has a characteristic that return to the original form. Then the reclamation should be avoided as coastal conservation measures.



"Category I,II" (Sediment budget totally balanced or increase, and beach is eroded partially)



"Category III" (sediment budget totally decrease and beach is eroded totally)

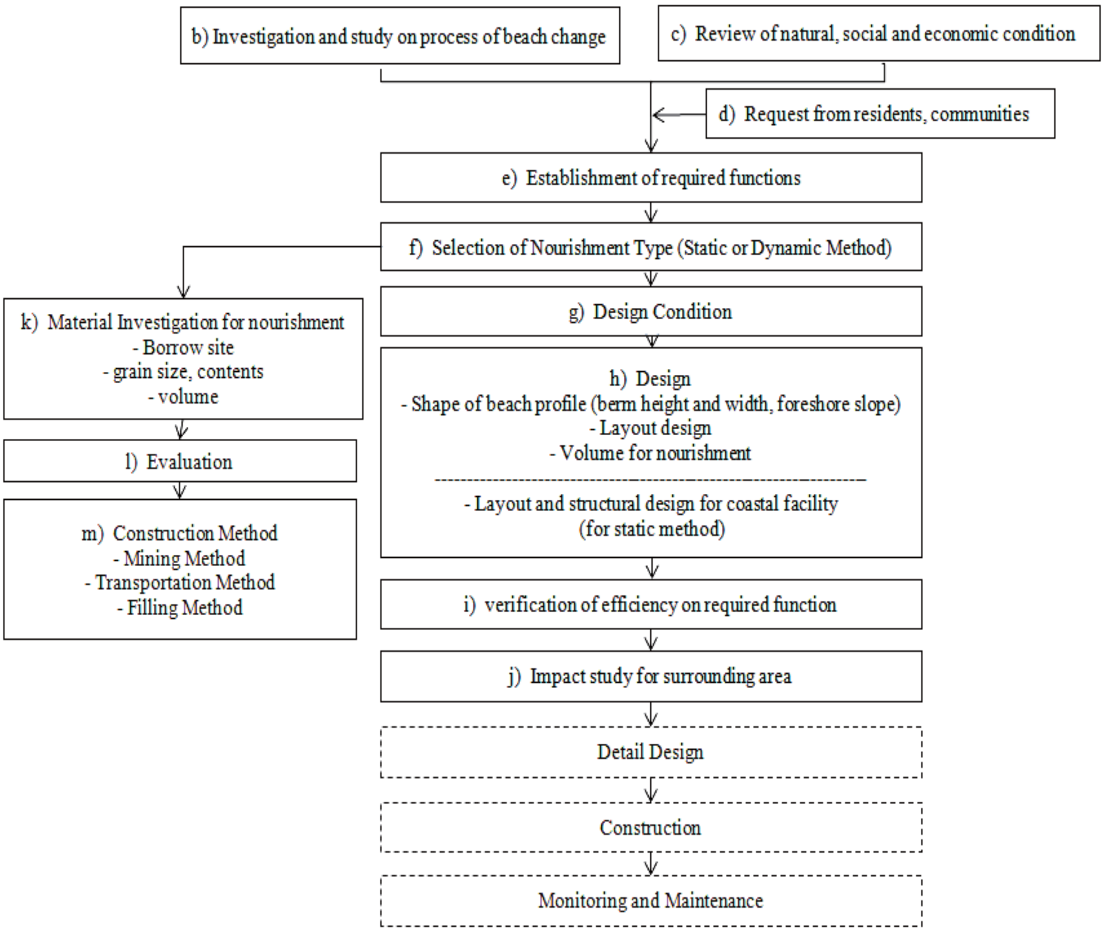
Source: JICA Expert Team

Figure 3.2.2 Category on Sediment Budget and Principle of Coastal Measures

3.2.2 Planning and Design

a. Flow Chart of Planning and Design for Nourishment

Figure 3.2.3 shows the flow chart of planning and design procedure for nourishment.



Source : Manual for Beach Nourishment (Public Works Research Center (2005) arranged by JICA Expert Team

Figure 3.2.3 Flow Chart for Procedure of Planning and Design for Nourishment

b. Investigation and Study for Coastal Change Processes

It is very important to obtain sufficient understanding of both the short and long term beach processes. After obtaining sufficient understanding of both terms of coastal change processes the study on planning and design for nourishment can start. Otherwise, there is a possibility to provide inaccurate planning and designs for coastal conservation measures.

For the study of coastal change processes, the following issues shall be clarified:

- Costal change over the short and long term (shoreline change, profile change, change in hinterland, change in coastal environment, etc.)
- Sand sources and littoral drift

- Cause of coastal erosion

The representative approaching methods for the study of coastal change processes are as follows:

- Site investigation (checking of beach shape, slope, sand characteristics, response of the coastline to the facilities, taking photos, simple survey, interview survey for residents, etc.)
- Mapping analysis using past aerial and satellite photos
- Analysis of past monitoring data (using survey data, land view photo, etc.)
- Conducting wave current observation, additional survey, etc., if required

c. Review of Natural, Social and Economic Conditions

It is needless to say that the proposed coastal protection measures shall take into account natural, social and economic conditions. Also as presented in Figure 3.1.2 to Figure 3.1.4, it is important to take into account the characteristics of land use and conditions in hinterland areas.

d. Request from Residents and Communities

The residents who are living in the targeted coastal areas for measures are the most affected stakeholders due to the executing of coastal protection measures. As they have their own requests for undertaking coastal protection measures, it shall be taken into account in the proposed measures. However, sometimes their requests are just based on their individual demands, and such requests are sometimes inconsistent with the proposed integrated coastal measures. Thus, consensus building is very important for planning and design of coastal protection measures that are in line with people’s requests.

They are used to staying in the target coastal area for a long time. So, they have a lot of knowledge for the change of coastal processes based on their experience. Such local knowledge is useful to enhance the understanding of coastal change processes at the project coast.

e. Establishment of Required Functions

As presented in Figure 3.1.1, it is necessary to make the required functions clear from four essential points of view, including 1) protection, 2) beach use and landscaping, 3) coastal and coral environment, and 4) adaptability to future climate change. It is necessary to establish concrete targets for each point in the planning of coastal protection measures.

f. Selection of Nourishment Type (Static or Dynamic Method)

There are mainly two types for nourishment, which are called *static method* and *dynamic method*.

The *static method* forms an artificial static condition, by obstructing the littoral drift where necessary, to minimize the sand discharge after the nourishment, and it is common to use some coastal facilities together, such as groynes, headlands, offshore breakwaters, etc. as shown in Figure 3.2.4.

On the other hand, the *dynamic method* recovers the natural littoral process as much as possible by artificial means. It is common not to use the artificial coastal facilities, just to fill the sand (Figure 3.2.5). Sand recycling or sand bypassing from areas of sand accumulation to eroded areas are measures used in the *dynamic method*.

Which types of method will be suitable and applied, depends on the results for items b) to d) as mentioned before.

Source : Nippon Koei co. Ltd.

Figure 3.2.4 Static Method (e.g. Bali Beach Conservation Project in Indoensia)

Source : Nippon Koei co. Ltd.

Figure 3.2.5 Dynamic Method (e.g. Bali Beach Conservation Project in Indoensia)

g. Design Condition

For the design of other types of physical marine measures such as breakwaters, revetments, wharves for port facilities, it is required to set the design condition strictly in accordance with the targeted durability period. Thus, the mathematical approach is applied. On the other hand, the same approach is required for the nourishment design. However, a physical approach based on field data is more important. The actual current coastal conditions are the result of external forces such as waves, change of sea level, currents, etc. to the coasts which have their own characteristics of geology, topography, littoral drift, etc. Thus, the detailed analysis only for the mathematical approach without the physical approach is meaningless and sometimes such an approach may cause serious mistakes on the nourishment design.

As factors of design conditions, the following design conditions shall be established:

1) Incident wave condition

Especially it is important to identify the wave direction both seasonally and long term for identification of littoral drift.

2) Wind

Incident waves at coral reef coasts are affected by not only the propagated waves from offshore but also wind generated waves on the reef.

3) Sea level (tide and wave set-up)

Due to the shallowness of depth on the reef, the incident waves on the reef are mainly affected by the change of depth. The change of depth on the reef is mainly caused by tidal change and wave set-up which will be significant when a big storm hits.

4) Grain size of sand

The grain size of sand significantly influences the setting of the shore slope, height and width of the beach.

h. Design

The following design studies are required for nourishment.

1) Shape of beach profile

Berm (backshore) height

Berm height is basically set to keep the same height as that in existing beach conditions. However, it is necessary to check the sufficiency of berm height by a mathematical approach to calculate the wave run-up in the given design conditions for incident waves.

If it is difficult to identify the existing berm height on site, for example, due to loss of sandy berm, it is required to estimate the traces or evidence of past berm height from the collected data and field investigation at surrounding coasts as well as using a mathematical approach.

Berm (backshore) width

Berm width shall be set taking into account both of the existing conditions and requirements. However, if the width is set too wide compared to that in existing (or past) conditions, this will lead to an unstable condition, and significant sand discharge may occur.

Foreshore slope

Foreshore slope is also set to keep the same slope as that in the existing beach condition. Here, the important thing is to employ the sand with appropriate grain size since the foreshore slope is basically defined by the grain size of sand. Thus, it is not allowed to employ the finer sand in place of existing sand.

2) Layout design of nourishment

In the layout design for nourishment, it is necessary to set as stable an alignment as possible for the shoreline in order to minimize the sand discharge after the nourishment. The expected stable alignment will be determined by checking the angle between incident wave direction and the shoreline based on the field observation and numerical approach, if required.

3) Volume for nourishment

For Initial nourishment

The required sand volume for initial nourishment will be set based on the difference between the existing beach profile and the planned one determined as mentioned above. For the volume estimate, it is necessary to consider an increase in volume between that in the activity of sand mining and of filling on site.

For maintenance nourishment

With regard to the planning and design of maintenance nourishment (additional sand fill after the initial nourishment), it is neceesary to determine, a) volume of sand for maintenance, b) frequency for maintenance and c) position for sand fill. An example of a concrete approach to planning and design of maintenance work can be refered to the coastal conservation plan at Point aux Sables, Ile aux Cerfs, Point d'Esny which is presented in Volume 2, Coastal Conservation Plan.

4) Layout and structural design for coastal facility(s) (for static method)

When the *static method* for nourishment is employed as a proposed coastal protection measure, the layout and structural design for supplementary coastal structures, such as groynes, headlands, offshore (submerged) breakwaters, etc. are required. The concrete design method can be refered to in several published technical guidelines, including *Shore Protection Manual* (1984), *CEM* (Coastal Engineering Manual, 2008), and *Rock Manual* (2007).

The important points for planning and design of supplementary coastal structures are as follows:

- The proposed strucure shall take into account not only function but also beach use, landscaping and the coastal environment.
- The number and dimension for proposed structures shall be minimized as much as possible in order to fufill the functional requirements.

Source : Nippon Koei co. Ltd.

Figure 3.2.6 Example of Well-Environmental Harmonized Groyne
(Bali Beach Conservation Project in Indonesia)

i. Verification of Efficiency of the Required Functionality of Measures

The efficiency of the required functionality of the measures will actually be verified after obtaining the results based on monitoring after the execution of the measures. In order to verify the efficiency of proposed measures during the planning and design stage, it is common to apply the mathematical approach, including numerical modeling.

j. Impact study for surrounding area

It is important to verify all possible impacts the execution of coastal protection measures may have on surrounding areas. In the planning and design stage, it is common to verify the impact on surrounding areas using mathematical approaches, including numerical modeling. There are two types of numerical modeling to predict the impact on the surrounding coastal areas; the “shoreline (1-line or multi-line) predictive model” and the “2-dimentional wave, current and topography change model”. The most important consideration is that even if the high forefront numerical modeling is applied for the impact study, it is hard to obtain realistic results without actual verification data such as history of coastal change based on the past monitoring survey data, aerial photos, satellite images, etc. Also even if the future impact can be predicted using the numerical modeling with sufficient verification data, the actual phenomena (coastal change) may be different from the predicted one. Thus, the actual impact to the surrounding area shall be clarified by monitoring the results of proposed coastal conservation measures.

k. Material Investigation for Nourishment

l. Evaluation

m. Construction Method

For the above items which are related to sand source, please refer to sections 3.2.3 and 3.2.4.

3.2.3 Sand procurement Site for Beach Nourishment

As described above, the main measures in target coasts can be roughly divided into (1) soft measures such as beach nourishment, sand recycling and setback, etc. and (2) hard measures such as relocating groynes and training jetties, repairing gentle type seawalls, etc. But, in most target coasts, soft measures such as beach nourishment and sand recycling, etc. are effective. Accordingly, continuous procurement or extraction of sand and appropriate movement of accumulated sand to the erosion area becomes very important. When taking these soft measures, continual monitoring and maintenance are necessary in addition to securing of a stable supply of sand in order to maintain the coast in the long term from the point of view of adaptive management.

Regarding securing beach nourishment materials, if there is an area of accumulated sand in the target coasts, sand bypass and sand recycling, which transfers the accumulated sand to the erosion area, is possible, and if there is no accumulated area, external procurement or extraction (quarry and seabed) of sand from land or sea is possible. Based on existing materials and site reconnaissance, the possibility of beach nourishment by sand bypass, sand recycling and external procurement in target coasts is shown below.

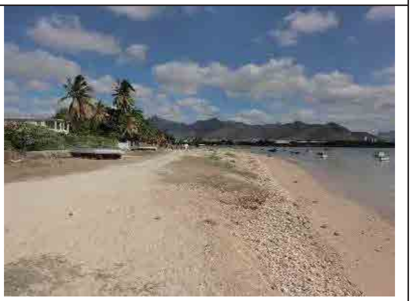
a. Diversion from neighboring coast (sand bypass, sand recycling)

To maintain the coast for a long time, dynamic beach nourishment can be said to be a preservation method which covers the entire series of sediment transport systems. The dynamic beach nourishment in target coasts includes (1) sand bypass to secure continuity of alongshore sediment by artificially transporting drift sand from areas of coast where continuity of alongshore drift has been prevented by structures and (2) sand recycling to collect the sediment which flowed out to the downstream in the sediment transport system and to recycle it to the upstream.

Table 3.2.1 Applicable Coasts of Sand Bypass and Sand Recycling

No.	Target coasts	Overview of coastal maintenance plan	Photos of accumulated area
1	T. d'Eau Douce	<u>Sand recycling</u> Sand spit develops in the downstream of this coast and a large amount of sand accumulates in the bay`s inner part. Since there is a tendency to erode at the upstream, it is conceivable to make use of accumulated sand from this bay`s inner part. In addition, since the downstream on the northern pocket beach has a tendency to accumulate, it is an effective measure to replenish the erosion area in the upstream with this sand. <u>Annual accumulated amount: 869m^3/year</u>	 Accumulated area in the bay back  North accumulated area

No.	Target coasts	Overview of coastal maintenance plan	Photos of accumulated area
2	Ile aux Cerfs	Sand recycling Sand accumulates between two islands and dredging has been carried out to secure the waterway. Because there is an erosion trend in the upstream of this coast, it is an effective measure to replenish the dredged sand in the erosion area. Annual accumulated amount: 1,506m^3	
3	Pte. d'Esny	Sand recycling A groyne exists in the downstream of this coast and a great deal of sand accumulates there. Because measures against erosion are taken by an upright seawall in the erosion area, to replenish the sediment in the erosion area is an effective countermeasure. But it is necessary to coordinate with the tenants behind the coast with respect to sand extraction. Furthermore, it is necessary to sufficiently discuss the cost burden of construction. Annual accumulated amount: 982m^3/year	
4	Bel Ombre	Sand recycling Since an area of accumulated sand exists in the east side of this coast, it is possible to keep the beach in good condition for a long time by replenishing the sand in the west side of the erosion area. Annual accumulated amount: 559m^3/year	
5	Le Morne	Sand bypass A training jetty is installed in the northern channel of this coast and a great deal of sand accumulates in the upstream. On the other hand, as the downstream has a tendency to erode, the continuity of the one way direction of the littoral drift is prevented. It is able to maintain the coast by replenishing the downstream with accumulated sand periodically. Annual accumulated amount: 358m^3/year	
6	Flic en Flac	Sand recycling A great deal of sand accumulates in the northernmost tip of this coast. The public beach park on the upstream of this coast has a trend towards erosion and beach scarp is formed. It is able to maintain the coast by replenishing the downstream with the sand accumulated periodically. The sand recycling was already carried out since June 2014. Annual accumulated amount: 593m^3/year	

No.	Target coasts	Overview of coastal maintenance plan	Photos of accumulated area
7	Pte. aux Sables	Sand recycling A sand accumulated area exists in the downstream of the north side of this coast. The upstream of this area has a trend towards erosion, so it is possible to maintain the coast by replenishing the accumulated sediment in the erosion area of the upstream. Annual accumulated amount: 636m^3/year	
8	Bras d'Eau	Sand recycling An accumulated area of sand exists in the downstream of the west side of this coast. The upstream of this area has a trend towards erosion and beach scarp has formed in front of a public toilet. It is possible to maintain the coast by replenishing the accumulated sediment in the erosion area of the upstream. Annual accumulated amount: 128m^3/year	
9	Baie du Tombeau	Sand recycling An accumulated area of sand exists in the downstream of the south side of this coast. The upstream of this area has a trend towards erosion, so it is possible to maintain the coast by replenishing the accumulated sediment in the erosion area of the upstream. In addition, an accumulated area of sand exists in the offshore of this coast. There is a possibility that part of this sand can also be used as the beach nourishment material. Annual accumulated amount: 178m^3/year	

Source: JICA Expert Team

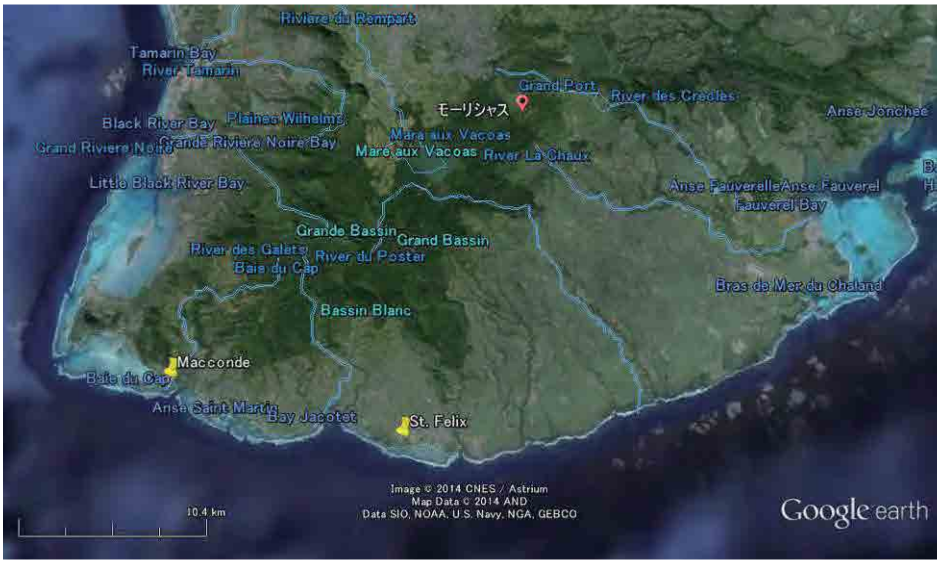
The accumulated area and an image of the replenishment of sand in erosion areas at target coasts are shown in Figure 3.2.7 as a sample.

Source: JICA Expert Team

Figure 3.2.7 Sand Recycling Image at Baie du Tombeau

b. Procurement from quarry

If a sand accumulated area does not exist at the target coasts, or if sand extraction is impossible due to regulations or because local residents don’t agree to sand extraction, (even though an accumulated point has been verified), it will be necessary to procure nourishment materials from outside. Currently, the possibility of external procurement is limited to (1) extraction from a land quarry, and (2) sea that is outside the lagoon and sand extraction does not have an effect on the environment. Extraction from land (1) is limited to two points; St. Felix and Macconde of Nanbu of Mauritius. For sand collection from the sea (2), MoI is currently investigating the potential. The location of the land quarries is shown below.



Source: JICA Expert Team

Figure 3.2.8 Sand Procurement on Land in Mauritius

Table 3.2.2 Overview of Land Quarry

Item	St. Felix	Macconde
Daily possible extraction amount	290 ton（about 160m^3）	200 ton（about 110m^3） Proportion: gravel: 22%, sand: 30%、lime: 48%
Annual possible extraction amount	72,250 ton（about 40,000m^3）	52,500 ton（about 29,000m^3）
Maximum extraction amount	820,000 ton（about 450,000m^3）	157,000 ton（87,000m^3）
Extraction period	Year 2025	Year 2017（during the extended procedure of 30 years, at present）
Grain size	0.6-5mm	4-10mm and below 2mm
Unit price	MUR 1,000/ton MUR 1,500/ton (transporting included)	～2mm: MUR 790/ton (Inc. Tax Rp. 908.5) 4-10mm: MUR 1,300/ton (Inc. Tax Rp. 1,495)

Item	St. Felix	Macconde
Photos of site situation		

Source: JICA Expert Team

Regarding the annual extraction capacity of the two sand quarries on the land, St. Felix and Macconde are 40,000m^3 and 29,000m^3 respectively. However, regarding the materials of Macconde, the proportion of sand is about 30%, Therefore, the volume that can be used for beach nourishment sand is about 9,000m^3 per year. Also, because extraction sand is limited, a shortage of sand is an issue when considering continuous maintenance of beach nourishment in the future. In addition, since land sand includes a lot of silt, it is also necessary to consider the effects of pollution after beach nourishment. In particular, it is necessary to thoroughly consider the possibility of silt settling on the reef and causing deterioration in water quality at the coral coast.

c. Extraction from seabed

The investigation of sand was conducted by MOI in the offshore in the outside of the lagoons of three coasts; Flic en Flac, Trou aux Biches and Mon Choisy. It will be difficult to procure sufficient amounts of sand from the land in the future. Therefore, this investigation has been carried out for the purpose of procuring sufficient amounts of sand as well as sand of good quality in order to maintain sandy beaches in the long and medium terms. Overview of the sand investigation outside the lagoon at this time is shown in Table 3.2.3. Concerning the sand investigation, the following three points are mentioned:

・Specification of the possible quantity of sand extraction as well as the quality of sand (e.g. composition) in the accumulated area of the seas around Mauritius.

・Impact on the surrounding environment when sand is extracted and review of impact mitigation.

・Way to collect sand in the accumulated area of sand (extraction method), extraction costs and consideration of environment impact assessment.

Table 3.2.3 Overview of Sand Investigation in the Outside of the Lagoon by MOI

Investigation area	Estimated extraction amount	Sand quality	Depth
Flic en Flac ● Pearle Beach front	2,760 m^3	Mixing of coarse-fine sand	3m
● La Piogue front	12,240 m^3	Fine sand	14-17.5m
● Sofitel front	5,000 m^3	Mixing of coarse-fine sand	
Trou aux Biches		Mixing of	

Investigation area	Estimated extraction amount	Sand quality	Depth
● Public beach front	1,164m^3	coarse-fine sand	11-13m
● Trou aux Biches Hotel front	5,320m^3	Mixing of coarse-fine sand	9-11m
Mon Choisy	8,770m^3	Mixing of coarse-fine sand	10m
Total	35,254m^3		-

Source: JICA Expert Team

At this time, various problems have been revealed by sand surveys at the investigated sea areas. These include a small amount than can be extracted (only about 35,000m^3), detailed information about sand quality (grain size, composition, etc.) is not clear, water depth varies widely between 3m and 17.5m, and that water depth shallower than 15m is critical for coral and sand and so on. Therefore, in order to ensure a stable sand supply of good-quality sand in the future, it is thought that implementation of a broader and more detailed investigation is necessary.

The content and flow of the sand survey at investigation sea areas which will be needed in the future are proposed in Figure 3.2.9. This survey consists of (1) preparation work, (2) preliminary survey, (3) field survey, (4) analysis and evaluation, (5) study for construction method and plan, and (6) study for operation and maintenance plan. Also, in consideration of the environment, sand extraction should be carried out in the ocean in areas more than 15m deep. However, since there is a limit to the capacity the dredger MoI possesses and operations to extract sand in areas of ocean deeper than15m is difficult, the dredgers are expected to be procured from a third country. Therefore, taking into account the fact that the cost of transporting the dredger to Mauritius takes up a high percentage of the total cost of nourishment and that medium- and long-term sand maintenance (replenishment) will be needed, it is desirable to extract as much sand as possible in one operation and stock it on land. Possible candidate sites to stock pile the sand are available land in one of the sand mining areas or an existing borrow pit close to the coast (St.Felix or Macconde). However, due consideration of the treatment of wastewater, which flows out when dredged sand is discharged, is necessary when planning an environmentally- (e.g. coral-) friendly system

One possible area as a place for sand extraction outside the lagoon is the place where the reef gap (break) has developed in the range of water between 15m and 30m deep or the depth that exists between wide reefs. However, as for the latter, because it is adjacent to the reef, it is necessary to make rules about extraction selection methods and equipment, adequate environmental research, and sand extraction. With the above conditions in mind, possible sea areas, including those MoI has investigated, are shown in Table 3.2.4.

Preparation work

↓

Preliminary survey

・Data collection of bathymetric map and sea chart every 1 m contour (target areas with 15 m-30m depth considering environmental impact and capacity of dredger).
・Data collection of hydrographic conditions such as currents and waves
・Confirmation of several information from GIS system
・Identification of candidate sites for sand bank considering above several information

↓

Field survey

・Wide-range investigation for sand bank by using Side Scan Sonar and sampling of sand at candidate sites in order to grasp area and thickness of sand deposit
・Evaluation of result of the above investigation
・Detailed investigation by diving to collect samples and to check environmental impact on coral, water quality and so on
・Diving survey of thickness of sand deposit

↓

Analysis and evaluation

・Sieve analysis of collected sand sample
・Chemical composition analysis
・Calculation of potential volume of sand at each sand bank
・Overall evaluation considering quality, quantity and environmental impact

↓

Study for construction method and plan

・Study of site condition such as depth, current, waves, and bathymetric feature, etc. at target sites
・Selection of type of dredger considering above conditions
・Study for construction methods including mobilization, dreading, pumping, stocking, transporting, leveling, demobilization
・Study for environmental impact during above activities
・Cost estimation for above activities

↓

Study for operation and maintenance plan

・Study for periodic monitoring and analysis based on concept for adaptive management
・Study for maintenance and management plan

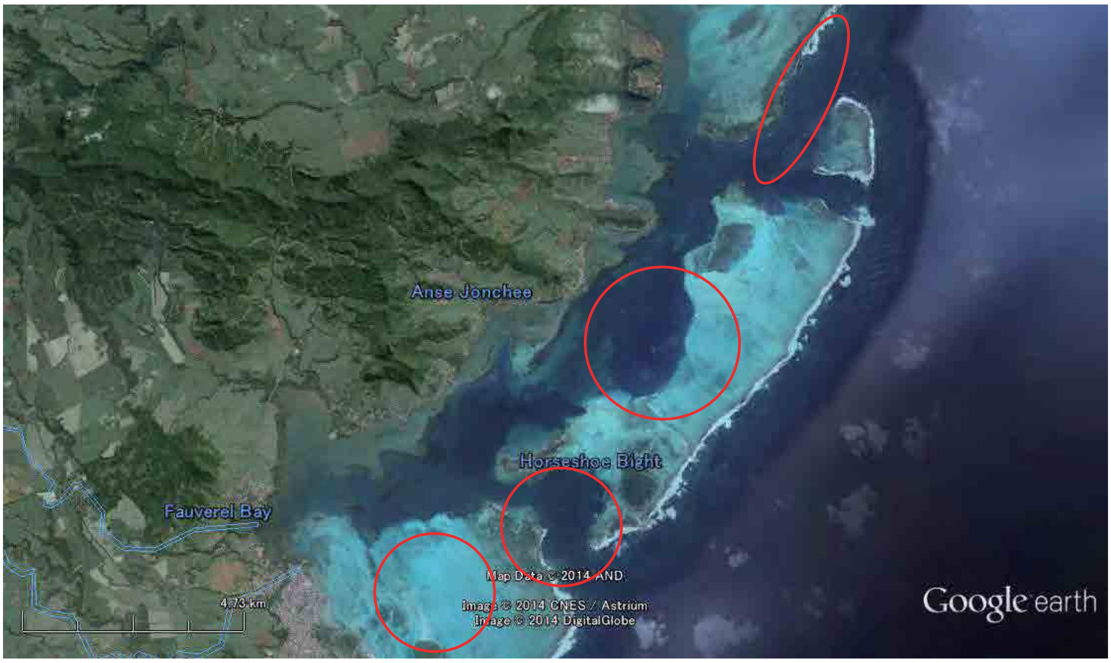
Source: JICA Expert Team

Figure 3.2.9 Research and Study Flow on Sand Procurement of Outside Lagoon (Plan)

Table 3.2.4 List of Area with the Possibility of Sand Accumulation (As Reference)

Place/location	Potential area
Mon Choisy / Pte. aux Cannoniers	● In the reef gap at Mon Choisy ● In the bay at Pte. aux Cannoniers
Grand Gaube	● In the reef gap
Trou d' Eau Douce	● In the reef gap
Bambous Virieux	● In the lagoon and deep area within channel ● In the reef gap Refer to Figure
Pte. d'Esny	● In the lagoon
Baie du Cap & Anse Saint Martin	● In the reef gap
Le Morne	● In the reef gap

Source: JICA Expert Team



Source: JICA Expert Team

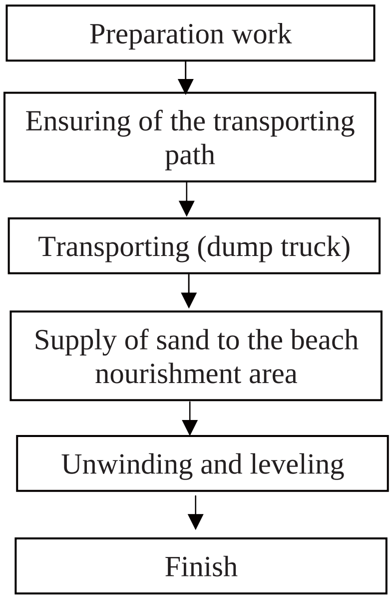
Figure 3.2.10 Areas Likely to have Sufficient Accumulations of Sand: Bambous Virieux & Pte. d'Esny (as reference)

3.2.4 Construction Stage

a. Sand extraction and transporting on land

When accumulated sand is supplied to an erosion area in continuous coast through sand bypass, sand recycling and so on, construction is carried out in the following order: ensuring the transporting path, transporting sediment, supplying sand to the beach nourishment area, and spreading and leveling. Because many target coasts are located in resort areas, it is necessary to pay attention to the selection of transporting paths, work time and ensuring the safety of beach users. Also, prior to sand extraction, after confirming the public-private boundary with tenants who lease the land at the back of the accumulated area, it is important to explain extraction range and volume to them and obtain their consensus.

Unloading, spreading and leveling of dredged sand is carried out by backhoes, and then sand is bulldozed to a given ground elevation. As it is difficult to level sand underwater, the work will be carried out roughly, namely the accuracy of the leveling will not need to be perfect, and then final leveling will be left to natural forces such as waves and currents.



Source: JICA Expert Team

Figure 3.2.11 Construction Flow of Beach Nourishment on Land

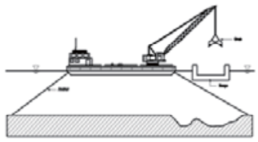
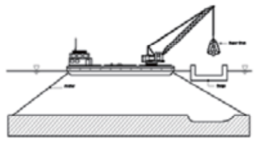
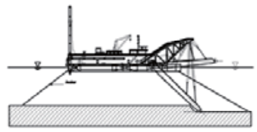
b. Sand extraction and transporting on land

Beach nourishment by external procurement is carried out in the following order: extracting from the seabed, transporting, spreading and leveling. When sand is extracted from the seabed, it is necessary to consider the environmental issues. Therefore, in order to minimize the impact on water turbidity and existing coral, a comparative review of three proposals regarding the dredging method were made, which are shown in Table 3.2.5.

As a realistic method which can be used for sand extraction from the outside of the lagoon for beach nourishment, construction using one of the following two types of dredger is considered to be the best. The first type is called grab bucket dredger and another is trailer suction hopper dredger (TSHD). In case of grab bucket dredger, the work period generally takes a long time because the dredging ability of this dredger is inferior to TSHD, but it is possible to reduce the influence on the turbidity of the water.

Furthermore, it is effective to use a special grab type of bucket that was designed to minimize environmental impacts such as on turbidity and coral. It is assumed that it will only be able to source such a grab type dredger from Japan. However, when deciding whether to use this type of dredger, it will be necessary to analyse the impact on turbidity during the detailed design.

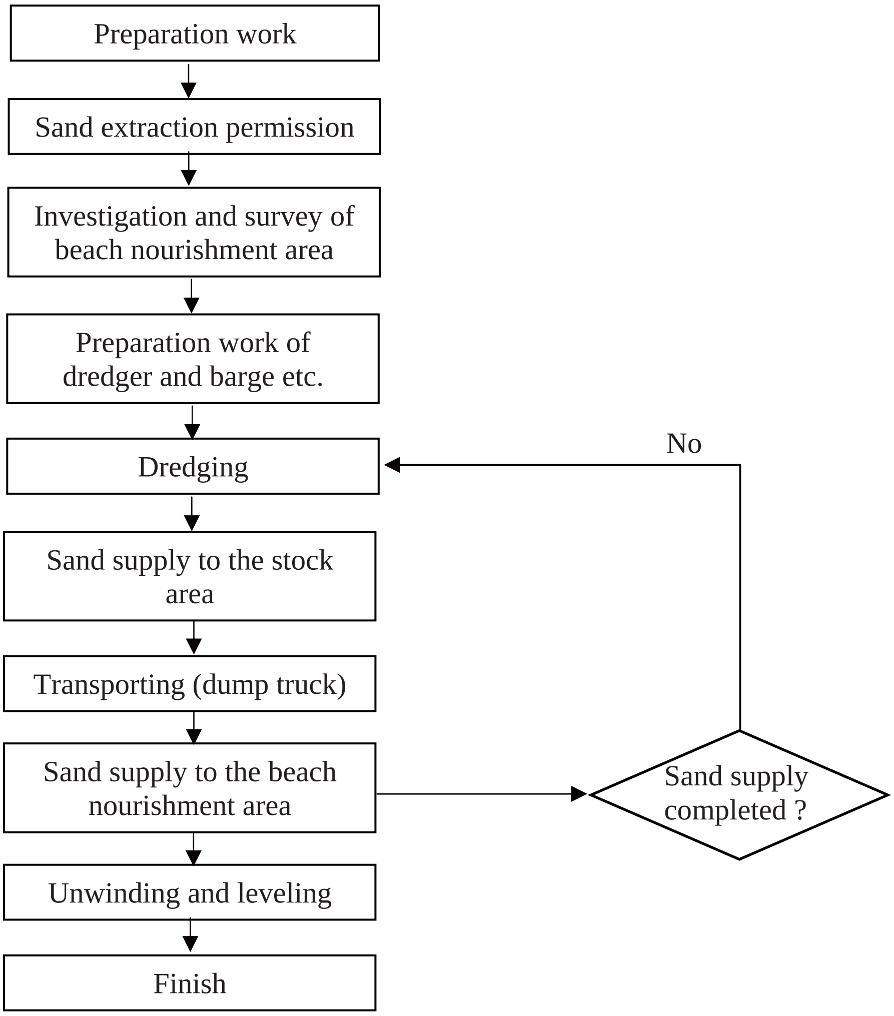
Table 3.2.5 The Method Comparison of Seabed Sand Extraction

Description	Dredger Type	Case-A	Case-B	Case-C
		Grub Bucket +Barge	Super Grub Bucket+Barge	Trailer Suction Hopper Dredger
Construction Method				
Condition				
Water Depth	～25 m	Good	Good	Good
Dredger Capacity		SD 5m3	SD 5m3	SD 6000PS
Layer Thickness	0.8 ～1.0 m	○	Good	Good
Soil Property	Sand	○	Good	Good
Obstruction	Coral	○	Good	Bad
Surplus water	Light→Good○	Fair	Good	Bad
Turbidity	Light→Good○	Bad	Good	Fair
Capacity	m3/Hour	120	82.8	2,000
Cost*	m3/IDR	95,800	101,400	685,715
Work Periods (340,000m3, 1Party)		10 months	14 months	1 months
Judgment		Bad	Good	Bad

*) The cost Include dredging works and transportation to stock yard

Source: JICA Expert Team

Beach nourishment construction flow is shown in Figure 3.2.12.



Source: JICA Expert Team

Figure 3.2.12 Construction Flow of Beach Nourishment by External Procurement

3.2.5 After Construction

a. Periodic monitoring after beach nourishment

Basically the coast sectional survey and photography, at the fixed point shown in the beach topographic monitoring guidelines in the next section, provides periodic monitoring after beach nourishment. Monitoring shall be carried out about once every three months for one year after beach nourishment and about once every six months from the second year on. However, monitoring shall be carried out at any time such as in case of high waves or heavy rain. Moreover, in typical coasts it is desirable to observe wave and currents on the reef and also to grasp beach transformation (geomorphological change) mechanisms and the relation between sand outflow and external force of waves.

And, when beach nourishment is conducted by external procurement, in order to evaluate the behavior and yield of sand after beach nourishment, it is desirable to sample the sediment and analyze the grain size in the three positions of the foreshore (HWL, MSL and LWL) after beach nourishment. A relation between grain size distribution of bottom materials and the foreshore shape just after the beach nourishment, after six months and after about one year is grasped respectively and the result is kept as the basic data for future maintenance and beach nourishment plans of other coasts.

In order to understand coral, change of water quality and so on after beach nourishment, it is necessary to make a survey of coral and water quality at fixed points. The monitoring content is explained in detail by reef environmental monitoring in the implementation of continual monitoring in the next section. MOF and MOI are assumed to be the implementing agencies for monitoring.

b. Adaptive management based on the monitoring result

Sandy beaches formed by beach nourishment vary continuously because of the long-term variations of littoral drift and continuous pounding of waves. Therefore, after sand is charged, it is required to implement the monitoring continuously as described above, and if maintenance is considered necessary, it is important to review the point of sand replenishment, foreshore slope, amount of sand to be replenished and frequency of replenishment as the need arises. When the outflow rate of the beach nourishment material changes suddenly by littoral drift, the above items are reviewed accordingly based on adaptive management, and then replenishment frequency and maintenance improving and maintaining amount are established again. Also, when the effect of the replenished sand is poor, in some cases, review of beach nourishment material should be considered in addition to the possible reasons loss of the replenished sand.

3.3 Flexible Revetment

3.3.1 Introduction

Flexible revetments are covered by a layer of material movable by wave action, are flexible to the external force, and take into consideration conservation of environment and beach use. For covering material, gravel or blocks are used. Here gravel is selected for use because it is easy to obtain in Mauritius.

Such a gravel-based flexible revetment will be able to easily correspond to changing requirements including disaster prevention, beach use, natural environment as well as sea level rise by climate change.

The guideline for flexible revetments is explained taking into consideration environmental conditions in Mauritius for designing, construction and management.

The flexible revetment is applicable to the following coasts:

(1) Coasts with wide reefs over 500m of wave dissipation and the bed material is mixed silt, sand and gravel.

Because the flexible revetment allows movement of the cover material, other type is advantageous to the coast facing open seas with severe wave conditions. In the sandy beach, it is more appropriate to maintain the beach than the construction of revetment.

(2) Coast with incoming waves perpendicular to the shoreline

It is not applicable to the coasts where the incoming waves are not perpendicular on average because the cover material is easy to move alongshore. If the rate of transport is small it can be applied with groynes.

(3) The beach is used for recreation and fishing

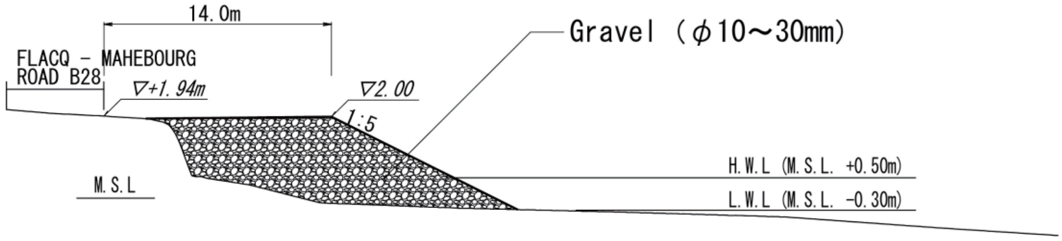
The vertical revetment is advantageous economically if the function is only to prevent waves from overtopping or collapsing of slopes. The flexible revetment is not suitable. However it is applicable if the scouring in front of the vertical structure becomes a problem.

Please refer to the following guidelines if the revetment is applied to the other types of coasts explained above.

PIANC(1992): Guidelines for the Design and Construction of Flexible Revetments Incorporating Geotextiles in Marine Environment

Here the type of flexible revetment is shown in Figure 3.3.1. The ground is covered with gravel and sometimes sand is placed in front if there is a need to aid beach use. If the cover volume becomes large, soil is used instead. Also the crest is covered by soil with turf considering the beach use.

The application of this chapter is under the condition that the flexible revetment is planned based on the comparison of alternatives for coastal conservation measures upon considering the necessity, type, arrangement and scale of the structures.



Source: JICA Expert Team

Figure 3.3.1 Section of Flexible Revetment

3.3.2 Planning

In the design of the revetment, a series of steps is taken such as understanding the present conditions, analyzing problems, setting design conditions, detailing designs, and selecting materials.

a. Understanding of present conditions

Necessary items to be investigated for the target coast are topography, geology, coastal climate, related structures, beach use, natural environment and construction conditions.

b. Analysis of problems

The revetment is required to function as protection for the slope and prevention of wave overtopping and has to take into consideration improvement of coastal use and the natural environment. The requirements for the revetment are summarized from the analysis of the present state and problems. The design method and conditions are analyzed to realize these requirements. Since individual requirements may be contradictory to each other, the design has to solve those conflicts while clarifying them.

For the protection of the slope, damage conditions, the range, and protection requirements are investigated. For wave overtopping and run-up, the coastal climate, topography and past damage from high waves are investigated. For the coastal use, the present coastal use and requirements of local people are summarized. For the environment, the ecosystem, the condition and changes of mangroves, seagrass and coral are summarized. Based on these results, the required specifications are set for the flexible revetment.

c. Setting design conditions

The following items are considered design conditions.

(1) Sea conditions of tides, waves, and currents
(2) Coastal topography, geology and bottom material
(3) Sediment transport
(4) Beach and coastal use
(5) Reef environment
(6) Construction conditions

The sea condition is set from Chapter 2 of the guideline.

The topography of the sea bed and land form is surveyed in detail in the planning area. The bottom material is studied by the site reconnaissance.

The sediment transport is studied from the aerial photos and satellite images though the change is not predominant. Also information from local people can be obtained.

For the beach and lagoon use, the information can be obtained from site reconnaissance and local people. The beach uses considered are walking, fishing, bathing, playing, and boat landing. The lagoon uses are boat mooring, fishing and water sports.

For the environment, the information on water quality, marine organisms including bottom dwelling organisms and fish is collected and studied by site reconnaissance.

For revetment construction matters it is necessary to investigate matters such as how best to procure materials and sediment, and climatic conditions.

The objectives for the revetment are set based on the required specifications. Then the crown height with the slope has enough function to prevent wave overtopping. Criteria for the slope include prevention of wave overtopping, stability of cover material and use as a fishing boat landing. The cover material has to be stable and good for beach use and the ecological environment.

d. Detailed design

The alignment of the revetment is to be parallel to the existing shoreline. The cover material moves on-off shore and alongshore. The offshore movement can be controlled by the selection of material because the slope reaches equilibrium according to the size of material and the incoming wave height. On the other hand, the material will move alongshore if waves are inclined to the beach. The beach will reach equilibrium if the existing bed material is easily moveable. Then the alignment is set parallel to the existing shoreline.

If the bed material is difficult to move by wave action the cover material tends to be transported alongshore. This especially happens on the coast where the incoming waves are inclined to the shoreline. In this case, if a flexible revetment is planned, groynes are necessary to prevent alongshore movement

The crown height is high enough to prevent wave run-up. The wave run-up can be estimated by the following equation if the tidal level, incoming wave height and period, and the slope are given.

$$R/H = \alpha * S/(H/L_0)^{\wedge}0.5$$

Here, R is the wave run-up height in m, H is the wave height in front of the revetment in m, α is a parameter=0.9, and S is the slope.

A reasonable slope for the revetment is 1:5 for considering the wave run-up, beach use, and the stability of cover material from past experiments. If sand is placed in front of the revetment, the slope will be from 1:7 to 1:10 according to the diameter of the sand.

e. Selection of materials

The cover material of 2cm in diameter is appropriate for considering the beach use. The turf at the crown is also good for use and has resistance to the waves. Vegetation at the crown is also possible with soil because wave action is not severe.

Placing sand in front of the revetment is also possible. In this case the movement offshore and alongshore has to be investigated. High waves transport sediment offshore and low waves onshore. The beach will reach equilibrium and be different from the initial slope. For the alongshore movement, the beach material will sometimes be lost.

Mineral crushed stone as cover material is reasonable. It is easy to obtain and intended to be similar to the material at the site. If the bed material is coral it is better to use coral sand. If it is difficult to obtain enough volume, a mixture of mineral and coral sand can be used to decrease the volume of coral. The cover layer should be 50cm thick because the beach changes by waves.

The soil is also used when considering the construction cost if the volume of the embankment is large under the cover. It is necessary to deal with the workability and the contamination of water during construction when soil is used. Two alternatives will be compared. One is soil and the other is gravel as the embankment material.

Coral sand is also used as one of the alternatives. White sand provides for a pleasant landscape. However it is not adaptable to the environment if the existing material is silt, mineral, sand, or gravel. Also it is not desirable for harmony with the surrounding landscape.

3.3.3 Construction

a. Construction plan

The main items for construction are preparation, safety and construction management, environmental monitoring and mitigation measures, construction of revetment, survey and other works such as drainage works. The schedule will be made for those items.

b. Supervision

The construction will be supervised for the management and the monitoring of the field work. The items are as follows:

- Sharing information with the contractor, such as the contents, schedule, construction methods and procedures, etc.
- Managing safety and monitoring the environment to prevent accidents during construction
- Checking the quantity and quality of construction material used such as gravel, sand, concrete and drainage pipes
- Directing the revetment position and checking the finishing profile of the revetment by survey
- Managing and reporting the progress and time table of the work

3.3.4 Others

a. Environmental impact assessment (EIA)

The environment impact will be accessed by the EIA guideline. The followings should be noted for a flexible revetment:

The biological habitat may change if the cover material is different from the existing bed material after construction. It is necessary to use the same material as the current one.

There is a possibility to improve the water quality because the sea water exchanges between gravel. However the effect will not last for a long term.

For the environment regarding beach use, the example at Grand Sable shows that garbage dumping is reduced and the beach becomes cleaner as a result of revetment designs that encourage resident activities.

The impact expected during construction includes air contamination and vibration by heavy machines, accidents, turbidity of sea water by the gravel placing, and tree logging. Those are temporary and measures have been selected to prevent and mitigate such impacts.

b. Maintenance

The following are maintenance items for the flexible revetment.

- Deformation of the revetment by waves: The beach profile is monitored at least once a year and the stability is inspected. If necessary gravel will be added.
- Beach cleaning: Garbage dumping will be prevented and the beach will be cleaned with the participation of residents.
- Beach use: Maintain a good environment and promote activities such as having picnics, fishing and walking.
- Theft of gravel: There is a possibility that the gravel will be stolen for construction use. It has to be monitored and education is necessary for preventing theft.

4 Examples

4.1 Bali Beach Conservation Project in Indonesia

Bali Island in Indonesia is a world-famous resort area, and beaches with golden colored coral sands are one of the most important resources for tourism. However, serious beach erosion has occurred since the 1970s in proportion to the tourism development along the coastal areas.

To recover the previous natural coral sandy beaches, the Indonesian government decided to conduct the beach conservation project financed by JBIC (now JICA). Three seriously eroded beaches (Sanur, Nusa Dua and Kuta) with a total 18-km length of coastline and one sea cliff erosion area (Tanah Lot Temple) were selected taking into consideration their tourism importance. At Sanur, Nusa Dua and Kuta, beach nourishment of approximately 1.3 million m3 volume of sand was conducted, together with the construction of supplementary coastal structures such as groynes, headlands and offshore breakwaters to minimize the outflow of nourished sand due to waves. For the planning and design of the artificial coastal structures, not only the functional point of view to minimize sand outflow after nourishment was well-considered, but also the natural landscaping and beach utilization as a resort and Balinese religious place. At the Tanah Lot area, the artificial reefs (submerged breakwater) to reduce high wave actions and artificial rocks to protect the eroded sea cliff were adopted to recover its natural landscape as a tourism and religious area. Furthermore, coral transplantation was carried out at Kuta beach with a 1.0-ha area to rehabilitate coral reefs damaged due to coral mining.

As described above, the Bali Beach Conservation Project has several similar issues, studies, and activities to those in Mauritius. Thus, introducing this Project may provide a lot of useful information to the implementation of nourishment in Mauritius.

The following points are mainly presented in this section:

1) Outline of the Project

2) Planning and design considerations

3) Beach change after the nourishment based on 3-years beach profile survey

4) Implementation of large-scale coral transplantation

Case Study 1

- Bali Beach Conservation Project in Bali Island, Indonesia -

BEACH NOURISHMENT ON CORAL REEF COAST AND THE RESULTING BEACH CHANGE

(Source: Nippon Koei Co., Ltd.)

Background and Objective

Background

◆Bali Island in Indonesia is a world-famous resort area, and the coral sandy beaches are one of the most important resources for tourism.

◆Serious beach erosion has occurred since 1970s owing to the tourism development along the coastal areas.

◆To recover the previous coral sandy beaches, Indonesian government decided to execute the *beach conservation project at Sanur, Nusa Dua and Kuta Beaches* financed by Japanese government as ODA (Official Development Assistance) project.

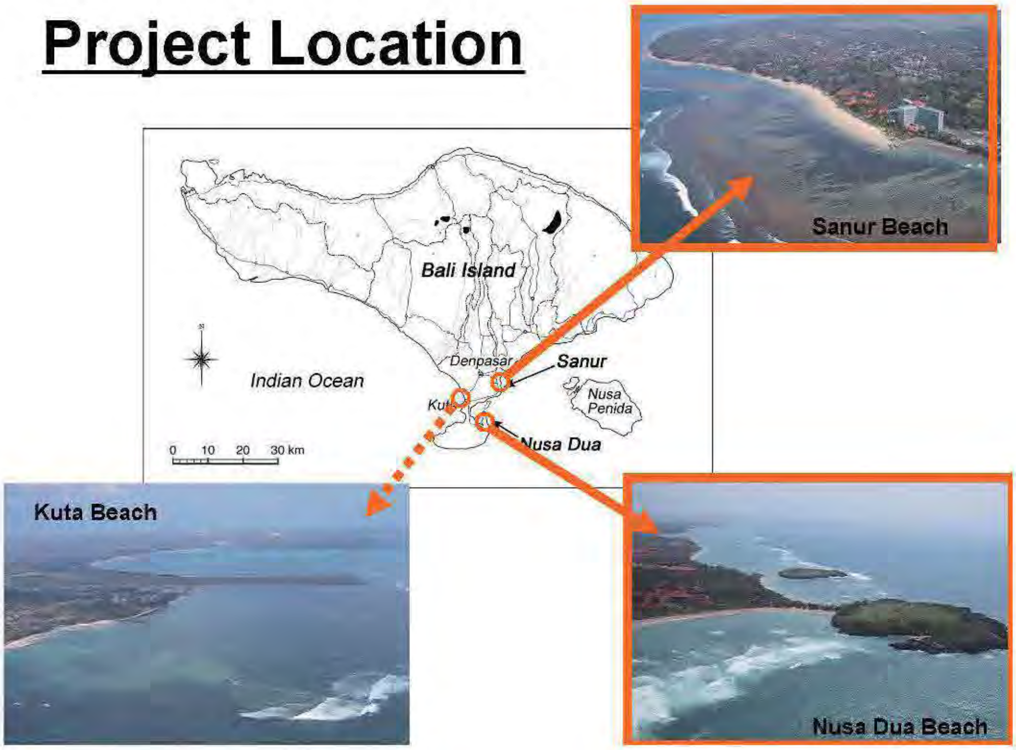
Objective

◆To introduce Beach Nourishment Project conducted at Sanur & Nusa Dua Beaches and its design considerations

◆To show the beach change after the nourishment based on the monitoring survey result for 3-years at Sanur Beach

Natural Condition & Cause of Erosion

Project Location

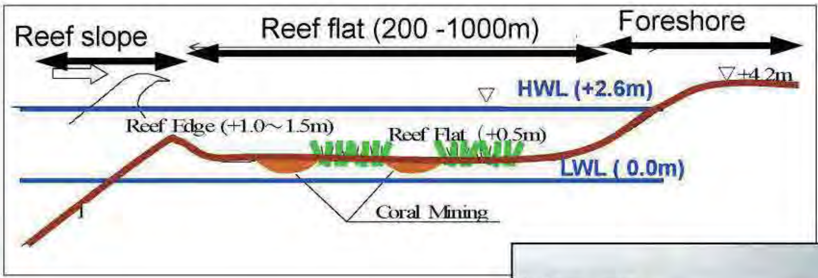


Configuration of Coastal Line and Coral Reef at Sanur

H1/3 : more or less than 1 m
T1/3 : 9～11s

Configuration of Coastal Line and Coral Reef at Nusa Dua

Image of Coral Reef Flat



- ◆Seabed elevation on reef flat : +0.5m
- ◆Tide Level: HWL +2.6m LWL 0.0m
  - → Reef flat is dry-up during low tide
- ◆Most of reef flat area is covered by seaglass.

Why beach erosion became serious since 1970's?

- ➢Coral mining which was carried out on the reef actively in 1970's to obtain building materials (Photo 1)
- ➢Large scale construction on the reef such as runway construction, digging of coral reef for resort development (Photo 2)
- ➢Individual construction of coastal structures on beach front such as seawall, groins (Photo 3)
- ➢Increase of storm attacking due to global warming


Photo 1 Coral Mining

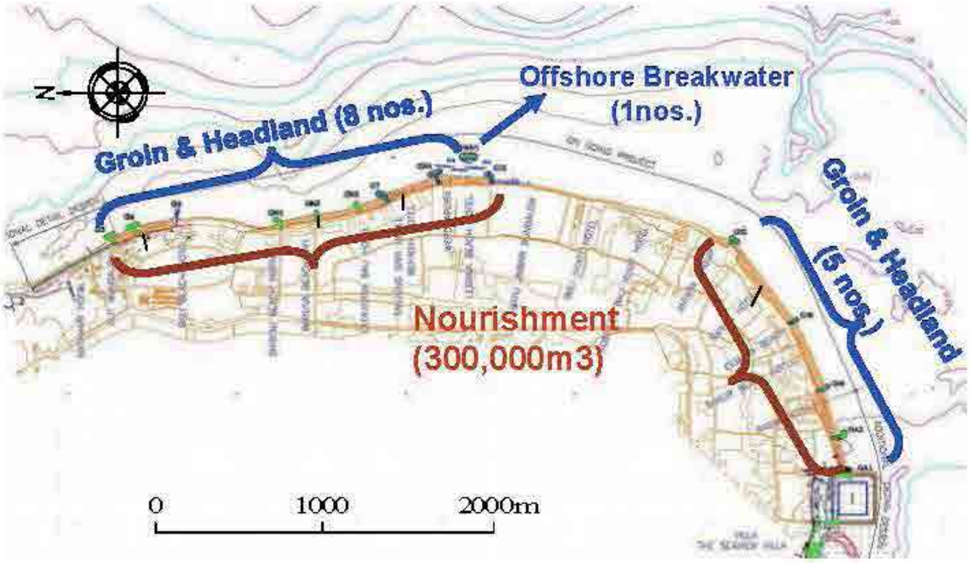

Photo 2
Large Scale Coral Digging


Photo 3 Individual Construction of Coastal Structures

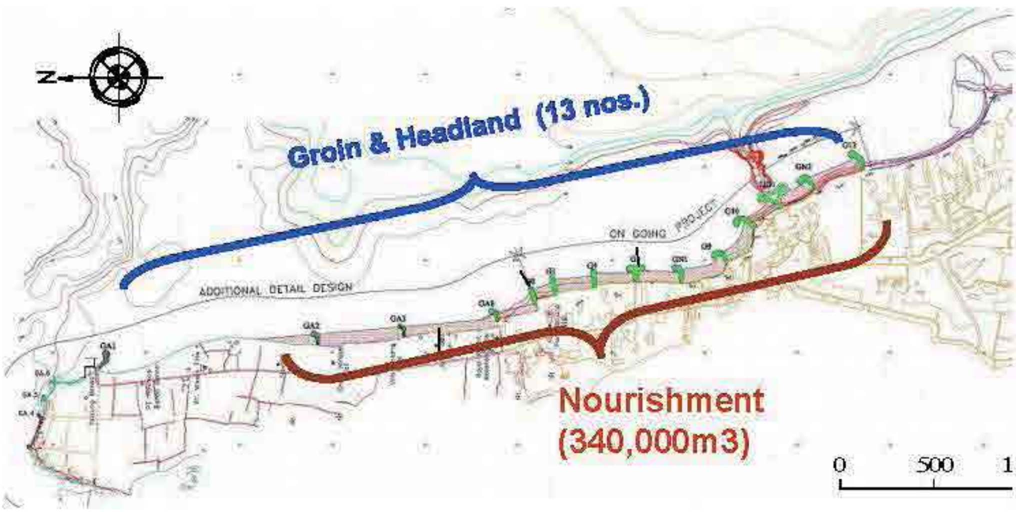
Condition of Beach Erosion

Project Outline

Sanur Project



Nusa Dua Project



Method of Sand Filling

- Sand for beach nourishment was obtained from the offshore outer reef area with depth of 20 - 30 m
- Sand was collected and transported by using a trailer suction hopper dredger (Photo 1)
- Sand was filled on the beach by using sand discharge pipe (Photo 2,3)


Photo 1 Suction Hopper Dredger


Photo 2 Pipe Arrangement


Photo 3 Discharge on the Beach

Design Principle

Requirement on Planning & Design

- Beach is utilized not only for tourists, but also for Balinese residents as recreation and religious ceremony area.
- Thus, highly consideration for both tourists and residents should be required on beach utilization
- The natural viewing as resort area shall be maintained as much as possible.
- It is necessary to preserve the coastal environment (Especially, not to damage lived corals and coral reef)

Design of Groins, Headlands and Offshore Breakwaters

- The dimensions of coastal structures (crown height, width, length) were minimized as far as maintaining the required function.
- The color of materials was well selected to harmonize as beach resort. (light-colored lime stones were adopted as armor material.)

Design of Headlands, Groins

Design of Beach Nourishment

Layout Design

Layout shape of nourishment was designed based on combined the result of field investigation, numerical analysis and experimental formula.

Section Design

Beach Slope and berm elevation were determined by the result of field survey to keep as the same as natural state condition (Beach Slope: 1/8 - 1/10, Berm Elevation: DL+4.0 - +4.2m)

Sand Specification

Sands with almost same specification in color and composition as existing beaches were selected

Before & After Project

Comparison before and after Project

- Nusa Dua Beach -

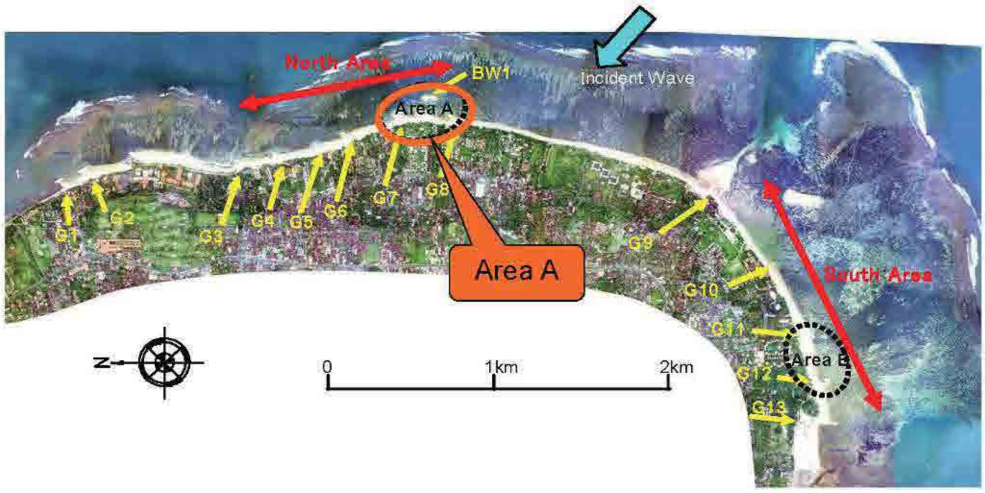
Comparison before and after Project

- Sanur Beach -

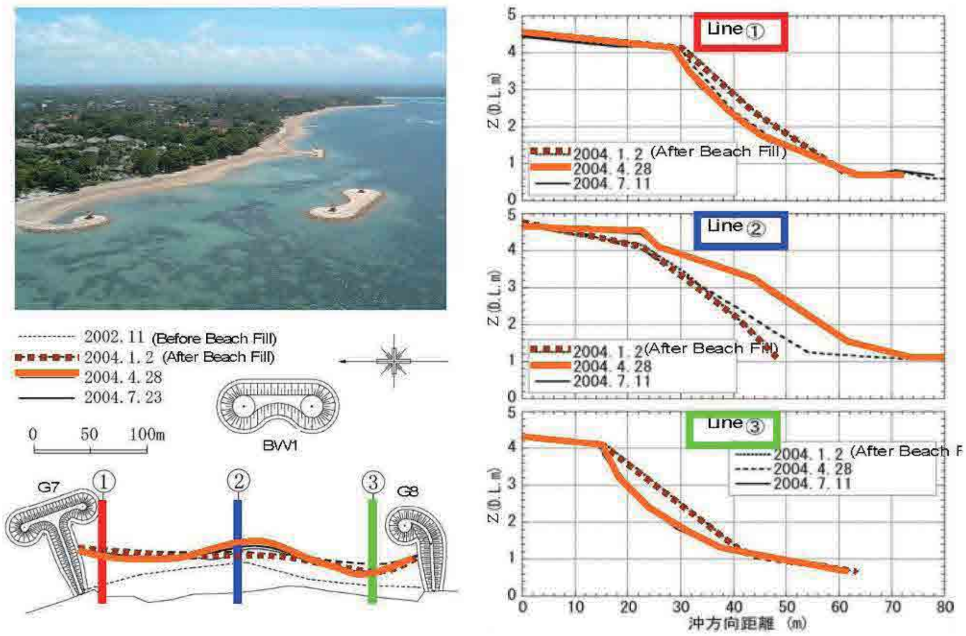
Beach Change After Nourishment

(Analysis of Shoreline Monitoring)

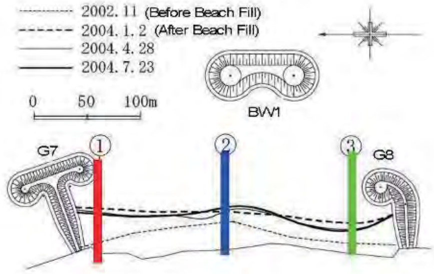
Area A in Sanur (as Example)

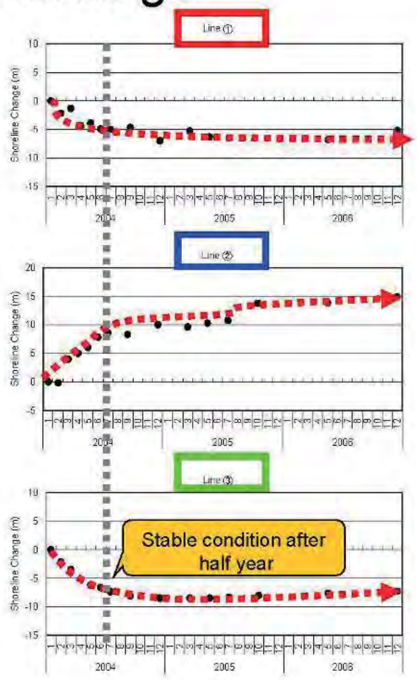


Profile Change after Nourishment at Area A



Time series of Shoreline Change for 3 years





Summary

◆Beach conservation project implemented in Bali Island, Indonesia was introduced.

◆Design considerations were presented to fulfil not only the functional point of view, but also beach utilization and landscaping.

◆From the shoreline monitoring results at Sanur, stable beach condition could be obtained mostly in half year after the nourishment.

Implementation of Large- Scale Coral Transplantation at Kuta Shallow Lagoon in Bali Island, Indonesia


(Source: Nippon Koei Co., Ltd.)

Background (1/4)

◆The Kuta lagoon which is located at south-west of Bali Island in Indonesia has been damaged by

1) large-scale coral mining carried out in 1960s to 1970s to obtain the building material
2) construction of the runway in 1960s on the lagoon.

Bali Island, indonesia

Background (2/4)

◆The damage of coral and change in condition of waves and current induced the serious beach erosion on the beaches in Bali Island.

Serious Beach Erosion in Bali

Background (3/4)

◆To rehabilitate and recover the sandy beach as before, ***Bali Beach Conservation Project*** has been conducted by Indonesian Government financed by Japanese government as ODA (Official Development Assistant) project

Recovered Sandy Beach in Kuta

Background (4/4)

◆The coral transplantation using coral fragments has been also conducted to rehabilitate the damaged corals in Kuta lagoon as a part of this project.

◆The total area of coral transplantation was 1 ha and high survival rate were required as the part of project.

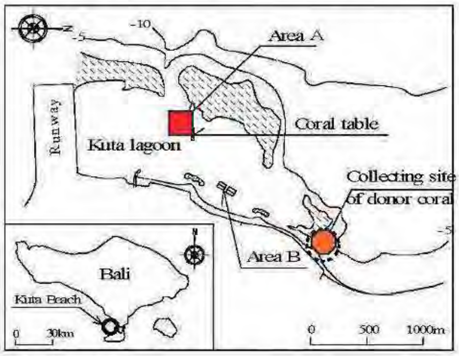
Executed Coral Transplantation on Kuta Shallow Lagoon

Objective of Presentation

◆To introduce the method of coral transplantation implemented in Kuta shallow lagoon

◆To show the coral growth and habitant condition based on the monitoring result for 1.5 years after the transplantation

Outline of the Project



Kuta Lagoon:

2.5km longshore distance and

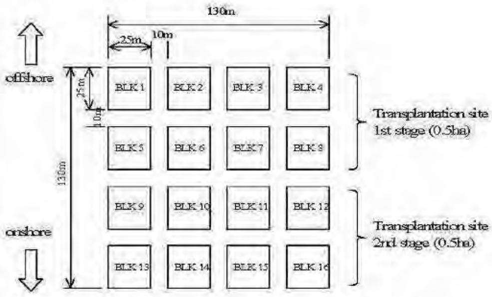
0.5 -1.3km width

Transplantation Area :

700m far from the shore (Area A)

Implementation:

1st stage: Sep. to Nov. in 2007 (0.5ha) 2nd stage: Jun. to Aug. in 2008 (0.5ha)



- Area A was divided into 16 blocks with squire 25m on a side for each block
- Substrate : natural Limestone (1t, 0.6m in height)
- Total num. of substrate: 5,000 unit fragments: 120,000 pieces

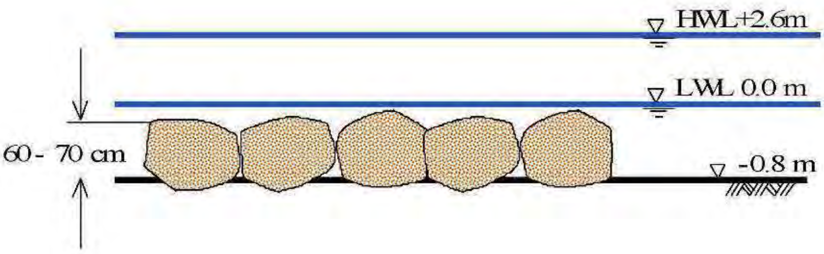
Natural Condition

Tide: HWL: +2.6m, LWL: 0.0m
Wave Height: 1 m (at outer reef)
0.3 – 0.5m (inside of lagoon)
Wave Period : 10 - 16s (at outer reef)
7 - 8s (inside of lagoon)
Current : 0.1m/s (in Av.)
0.4m/s (in Maximum)

Relation of seabed, tide & top level of substrates

Substrate

(limestone)



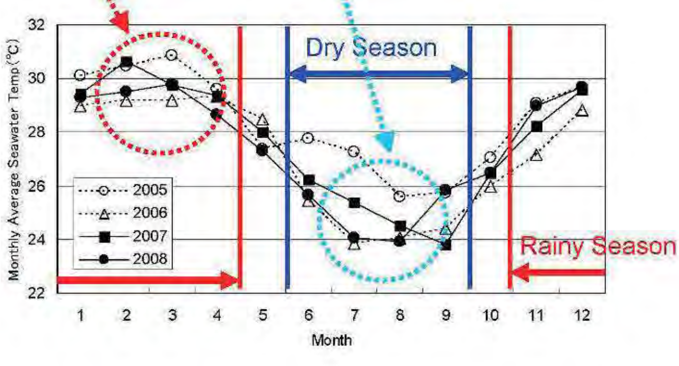
Monthly Change of Seawater Temperature

Rainy season: increased up to nearly 29 ° C

(sometimes more than 30 ° C)

Dry season: decreased to 24 to 26 ° C

Difference between daytime and nighttime : 1.5 to 2° C,



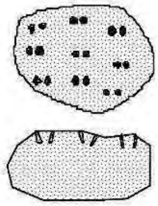
Species and Number of Coral Transplanted

Type	Species	Nos.	%
Branching	*Acropora* sp.	107,987	95.8
Leaf	*Turbinaria* sp.	1,993	1.7
	Montipora sp.	1,500	1.3
Massive	*Favia, Favites* sp. *Porites* sp. *Goniopora* sp.	504	0.5
Others		718	0.6
	Total	111,802	100

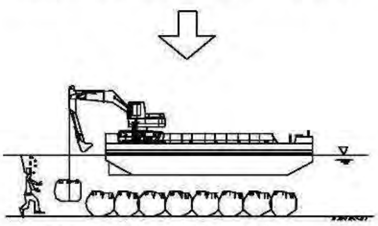
◆ *Acropora nobilis* was main species of donor coral with 95% occupation.

◆ Leafy corals such as *Montipora* sp., *Turbinaria* sp., and massive corals have been also used even though the total amount was a few.

Procedure of Transplantation
1. Making holes and installation of substrates

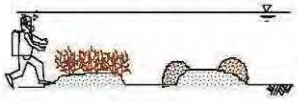


9 pairs of holes on upper surface of substrates was drilled on the land

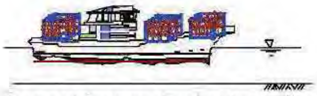


After drilling, substrates were transported from land to the site by barge and installed

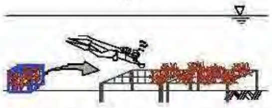
Procedure of Transplantation
2. Collection of donor corals and transport them to coral table



Collection of donor corals using a chiesel

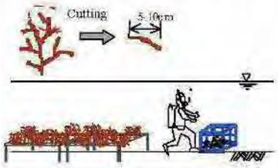


Transport donor corals using styrene form boxes

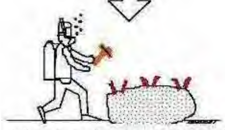


Setting donor corals on the coral table for acclimation at least 1 day or longer

Procedure of Transplantation
3. Fragmentation and transplantation



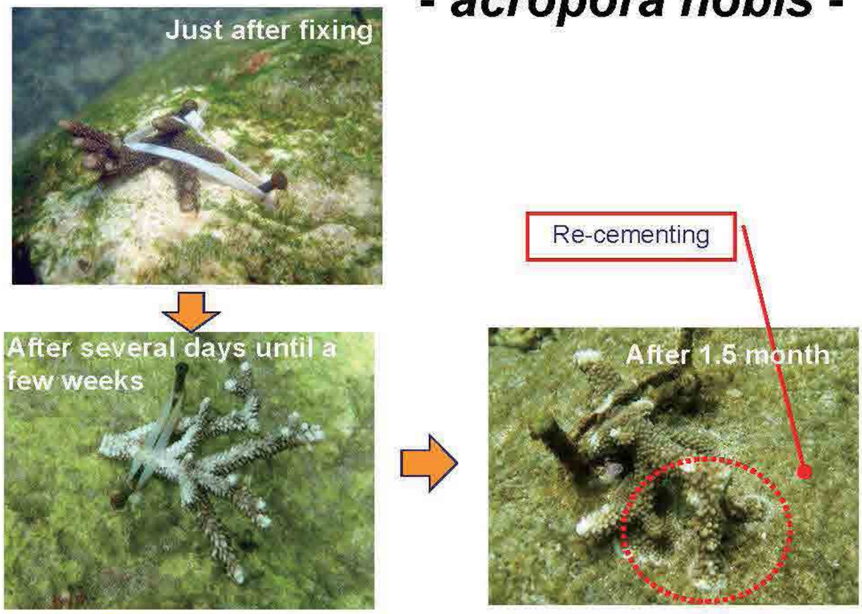
Fragmentation and acclimation



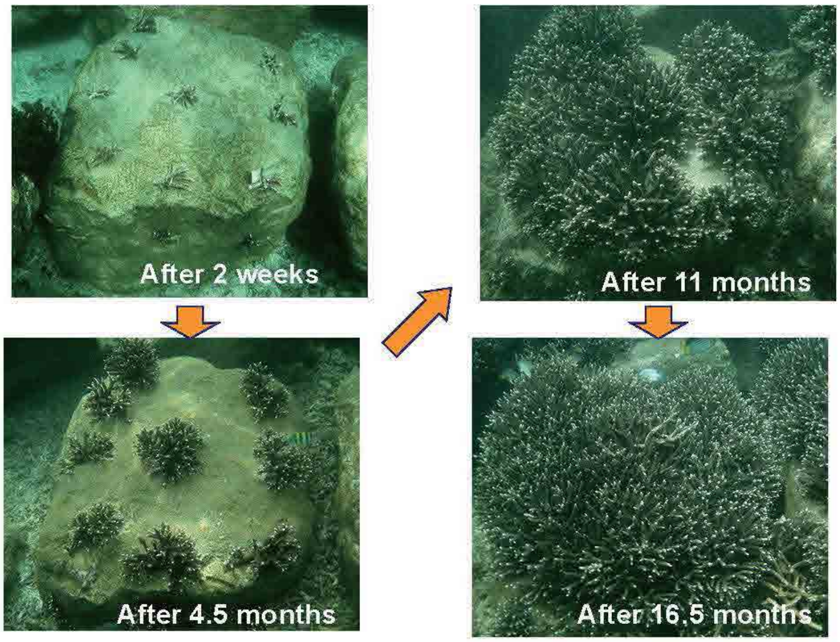
Cleaning substrate surface, driving nail in the holes

Transplantation using plastic cable-tie

Condition after transplantation
- *acropora nobis* -



Growth of *Acropora nobilis*

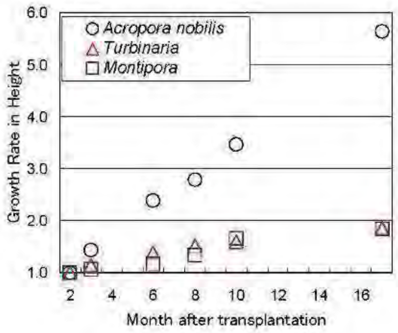


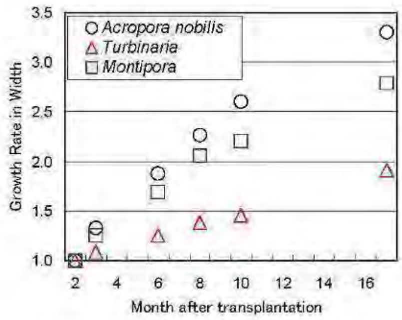
Growth of Leafy Corals
- *Montipora* sp. and *Turbinaria* sp. -

Growth of Coral Colonies

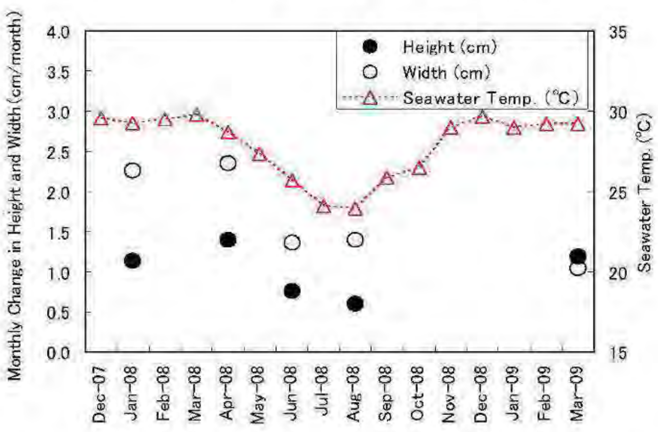
Growth Rate in Height and Width
(until 17 months after transplantation)

	Height	Width
Acropora nobilis :	5.6 times (13.1cm/year),	3.3 times (17.2cm/year)
Montipora sp. :	1.9 times (1.9cm/year),	2.8 times (9.3cm/year)
Turbinaria sp. :	1.8 times (1.9cm/year),	1.8 times (5.3cm/year)





Relation between Monthly Growth Rate and Change in Seawater Temperature
- *Acropora nobilis* -



Similar trend (High growth rate was observed during high seawater period)

Possible Mortality Factors

1) Bleaching and death due to rapid growth of seaweeds on the surface of substrates

Possible Mortality Factors

2) Sedimentation and brush up of coral fragments on the substrate caused by significant sand movement during the storm

Possible Mortality Factors

3) Detachment of corals due to high wave action, especially for well gown-up corals.

4) Human activity (e.g. treading and anchor throwing)

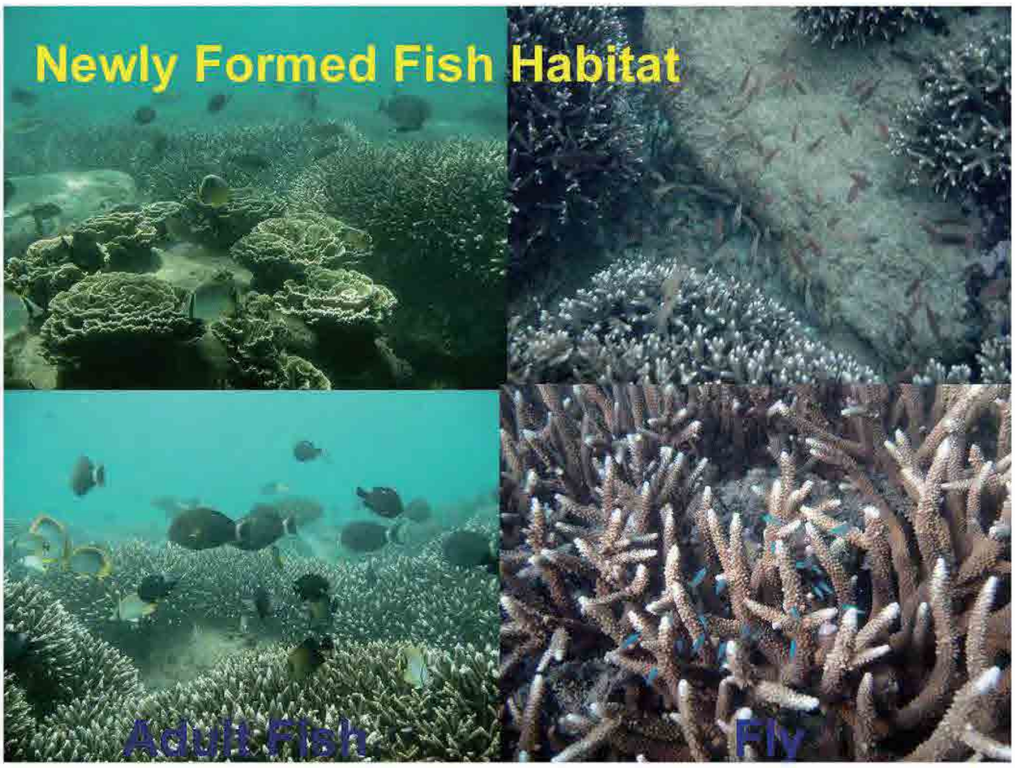
5) Natural causes (e.g. bleaching due to high seawater temperature, emersion during lowest low tide, etc.)

6) Unknown coral death, probably due to biological causes

Survival Rate

Species	Taken from	Sample Num	5month	9month	1.5 year
Branching and Leaf Type	Same Lagoon (Kuta lagoon)	196	97.4%	96.9%	**95.0%**
Massive Coral (except *Goiopora* sp.)		54			**96.0%**
Massive Coral (*Goiopora* sp.)		27			**28.0%**
Branching Type	other lagoon (Candy Dasa lagoon)	157			**57.0%**

High survival rate for branching, leafy corals and massive coral (except *Goiopora* sp.) was obtained for 1.5 years after coral transplantation



Current Condition

April 2010

June 2010

4.2 Sand Nourishment in Seychelles

4.2.1 Introduction

The pilot project of beach nourishment was implemented in Seychelles where the island is surrounded by coral reef as Mauritius. The example will be applied if the causes of erosion is not clear and there is a possibility of beach nourishment as measures. The outline of the project is explained as follows.

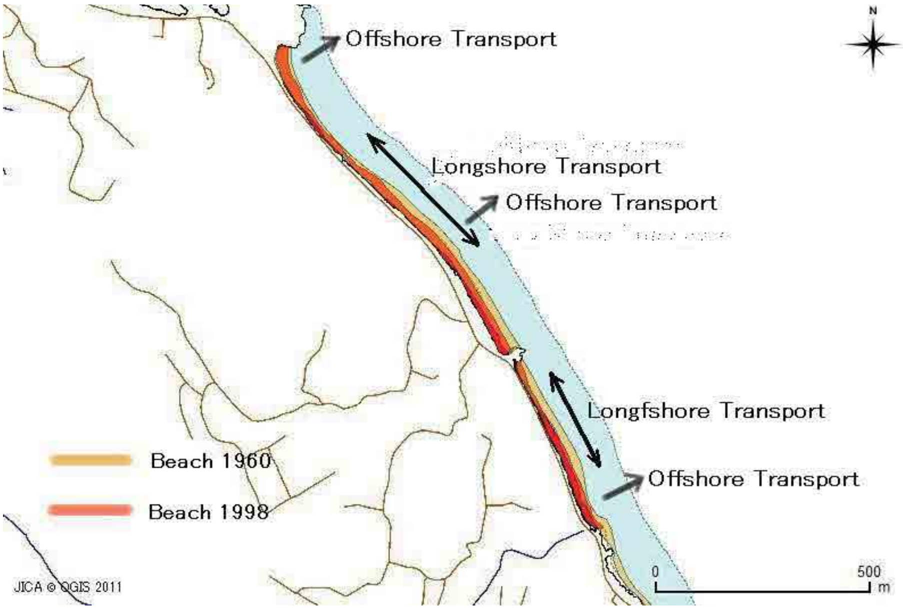
In the Republic of Seychelles, studies for coastal erosion and flood control management were conducted with the technical cooperation of JICA. Sand was nourished at the North East Point, located northwest of Mahe, as one of the pilot projects. The coast was eroded from the 1960s and the conservation plan was formulated as shown in Table 4.2.1.

Table 4.2.1 North East Point Conservation Plan

Item	Explanation
Coastal conditions	The 2km-long coast is located in the northeast part of Mahe and is protected by a narrow coral reef 100m wide and beach rock. Waves come from the northwest in winter and from the southeast in summer. A coastal road and houses are located along the coast and the beach is used by local residents for recreation.
Problems	Erosion and wave run-up at high tide on the coastal road affect traffic. The beach was eroded by a width of 30m from 1960 to 2011 and the seasonal variation was about 20 m. A possible cause of the long-term erosion is offshore transport.
Evaluation of alternatives	Sand or gravel nourishment has been selected to compensate for the loss of sand and to make beach use even maintenance nourishment because revetments cause loss of sand in front of the revetment.
Contents of the plan	Sand nourishment for 20m in width for a 2 km stretch of the beach is proposed with maintenance nourishment.

Source: JICA Expert Team

At the coast, about 30 m of erosion occurred from the 1960s to 2011 or 0.5 m/year on average and the seasonal variation in the coastline is about 20 m. Wave and sand run-up at high tide on the coastal road is also one of the problems. A possible cause of the long-term erosion is offshore transport. The seasonal variation is caused by the north-west monsoons and the south-east trade winds. The conditions of erosion and sediment movements are shown in Figure 4.2.1



Source: JICA Expert Team

Figure 4.2.1 Estimated Sediment Movement at North East Point

The pilot project was conducted to confirm the effectiveness of sand nourishment as a coastal conservation measure and to investigate the conditions and causes of the erosion. Quartz sand of 6,600t was nourished along the 400m long coast. After the work, the characteristics of sediment movement were studied by beach monitoring.

4.2.2 Design of Nourishment

The design conditions of the sea were based on the materials. The design wave and tide were decided based on the observation as the probability of 25 years.

- Design significant wave height: 4m, significant wave period: 8s
- Tidal level: High water level: +1.44m (above MSL), the maximum astronomical tide:+1.00m, the minimum astronomical tide: -0.9m

The wave height on the reef was estimated and the wave runup height reached 3.6m in 2010 and 4.0m in 2050 if future sea level rises are considered. The height was estimated on the beach slope of 1:7. If the beach is eroded and the vertical scarp is formed above 1.5m the runup height reaches 4.3m. At that point, waves would overtop the coastal road of 3m in height if the present conditions remain.

a. Design

The profile, volume and material of nourishment was designed taking into account the present conditions, design conditions, and the effects of wave overtopping.

- Length of nourishment: 400m
- Material: mineral sand
- Section of nourishment: crown height of 2m (above MSL), width: 10m, slope 1:3
- Volume of sand: 4.400 m^3, weight: 6,600t

The beach area which needs nourishment is divided by a rocky beach into two parts namely 950m and 400m long for a total of 1,350m. For the pilot project, the effect of nourishment was tested at the shorter beach.
There are two alternatives for sand material; mineral or coral sand. Mineral sand was selected because the amount is plentiful and it can be used cautiously in the future. Mineral sand is a little bit different from the existing sand. It is unavoidable because the coral sand is limited, expensive and expected to be difficult to obtain in future.

The volume and section of nourishment were decided from factors including eroded volume, wave runup and budget.

There are several methods for the estimation of the volume of nourishment. Here the method proposed by Thieler et al (2000) was applied. The method is at first to nourish the volume of past beach erosion from 5 to 10 years ago. Then the beach changes are monitored and the volume for future nourishment is estimated based on the results (Thieler, E. R., O. H. Pilkey, R. S. Young, D. M. Bush, and F. Chai: The Use of Mathematical Models to Predict Beach Behavior for U. S. Coastal Engineering: A Critical Review, J. Coastal Research, Vol.16, No.1, pp.48-70, 2000).

At the North East Point, the long term shoreline erosion was 0.5m/year and the estimated erosion was 1.5m^3/m/year. For the wave runup, problems arise if the beach has eroded because at present the coastal road is from MSL+2.5m to +3.0m high, the runup height is MSL+2.4m at the mean profile, and the runup height is MSL+2.5m on the eroded beach of seasonal variation. The difference of the mean sectional area and the eroded one is 11m^3/m as the standard deviation. If the nourishment is 11m^3/m, it is expected to last about seven years from the calculation of 11 m^3/m /1.5 m^3/m /year=7years.

The section of nourishment is MSL+2m high at the crown comparable to wave runup height and 1:3 of the slope for the construction works and safety. The crown becomes 10m from the present beach profile if the volume is 11m^3/m. The sectional profile changes according to the waves to a shape corresponding to the particle size of the sediment. Then the section is set from workability. The section and plan is shown in Figure 4.2.2.

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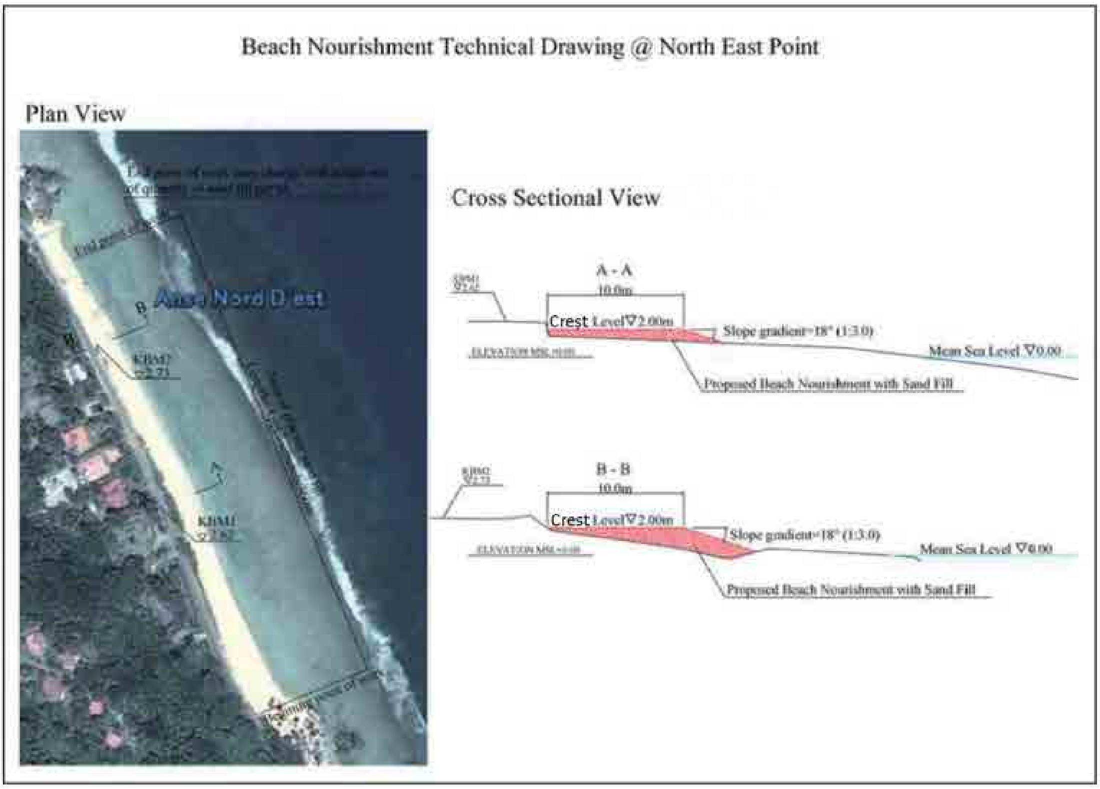
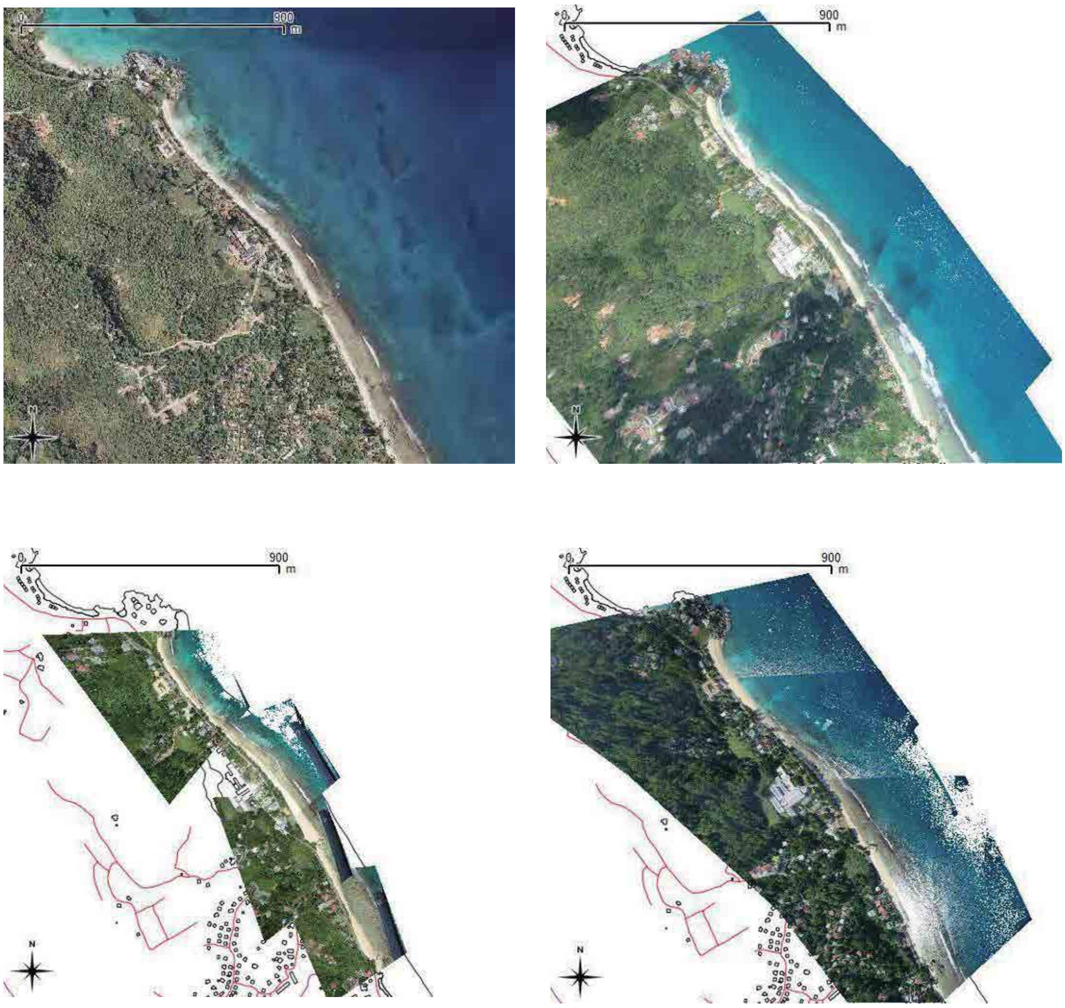


Source: JICA Expert Team

Figure 4.2.2 Plan of Nourishment at North East Point

4.2.3 Evaluation of Project

The purposes of the pilot project at North East Point is to introduce sand nourishment in Seychelles for mitigation of coastal erosion, to evaluate the effects of the nourishment and to estimate the causes and volume of coastal erosion. Sand was nourished 4000m along south beach with a volume of 6,600t(4,000m^3) sand in March 2012 as a pilot project. The coastline changes of the past and recent past taken by satellite and helicopter are shown in Figure 4.2.3. The sand was nourished between March 2013 to November 2013, as shown in the Figure.



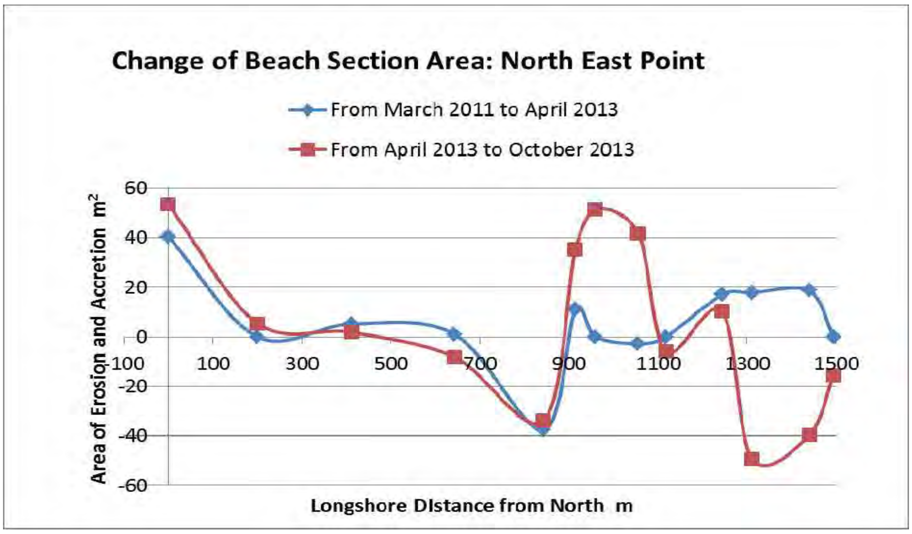
Source: JICA Expert Team

Figure 4.2.3 Temporal Coastline Changes at North East Point

After the nourishment in November 2013, the beach eroded and rock appeared at the south as shown in Figure 4.2.4. On the contrary, accretion occurred at the northern part of the beach. The changes in the beach section area before the nourishment, from March 2011 to April 2013, and after the nourishment, from April 2013 to October 2013, are shown in Figure 4.2.5. The nourishment is 400m long from 1,100m to 1,500m in the figure and the interval of the section is 100m. The changes within two years of the nourishment are accretion in the vicinity of the very northern start point of the nourished area and erosion north of the rock reef at a longshore distance of 900m from the start point. South of the rock reef, the beach has accreted and the volume corresponds to that of the nourishment. The sediment moved north in this period due to the southeast waves and the volume is estimated at about 7,000 m^3. The sediment budget for the whole beach showed no change of erosion during the four months from March 2011 to April 2013. From these results, the beach changes seasonally and the budget changes yearly.

Source: JICA Expert Team

Figure 4.2.4 Photos after 7 Months of Nourishment



Source: JICA Expert Team

Figure 4.2.5 Change of Beach Section Area at North East Point

The long-term volume of erosion is difficult to estimate from the monitoring results for one year because of seasonal changes. It is necessary to continue the beach monitoring. The effect of the nourishment is clear as of January 2014. Accretion occurred due to the nourishment in the northern part where the risk is high.

The direction of the measures is (1) continuous sand nourishment as planned, (2) control of longshore sediment movement by a groyne with nourishment in the south and setback in the north, and (3) construction of rock armouring if the loss of sediment is too great. The continuous monitoring will indicate the best solution from the alternatives by enabling proper understanding the situation.

4.2.4 Summary

Sand was nourished on the coral reef beach as a pilot project for the measures against coastal erosion, wave overtopping and for understanding the conditions of coastal erosion. The monitoring results after the project shows that the sediment transport and related beach changes are largely due to the change of wave directions. The loss of sediment matches the estimated volume from the past shoreline changes. However, the long term monitoring is necessary to understand and to find measures for the coastal erosion because the yearly change is large.

The example of Seychelles can be applied in Mauritius at the beach with narrow coral reef and active sediment movement. The analysis of shoreline changes used in the project will be applied to the beach change analysis of the same kind of problems though the accumulation of beach profile data is necessary for long term.

4.3 Akiya beach

The gravel nourishment at Akiya in Japan is explained and will be a reference for the same kind of projects in Mauritius.

4.3.1 Background of Beach Nourishment with Gravel

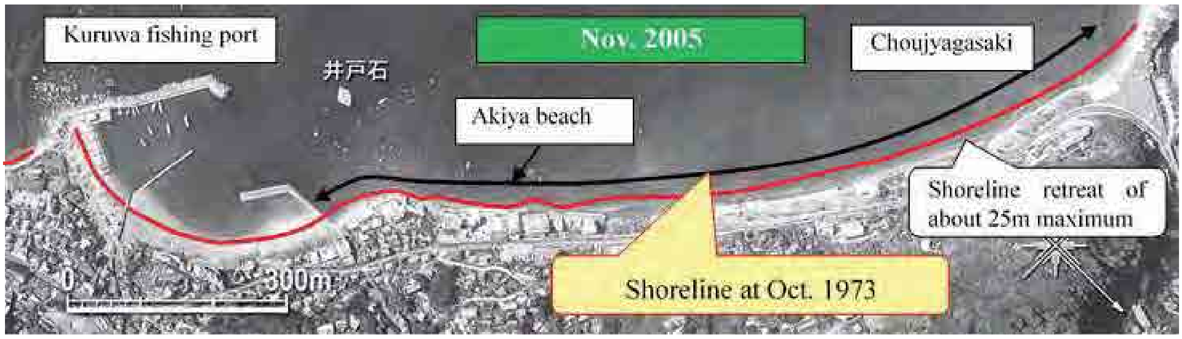
Akiya beach is a pocket beach located on the west side of Miura Peninsula (see Figure 4.3.1) and extends for about 1.3km. There are rock reefs in front of the beach and they are good fisheries for octopus, turban shell and abalone, etc. Moreover, it is a scenic beach from where Mt. Fuji can be seen on a clear day. The beach is often used for walking and surfing, etc. In recent years, since coastal erosion caused overtopping into the hinterland by high waves, there is concern about damage to houses and national route No.134. Under these circumstances, in October 2003, Kanagawa prefecture established the *Working group for developing a plan to protect Akiya Beach (Kuruwa District)* consisting of residents, beach users, government personnel and academic experts. This working group was set up to investigate countermeasures against coastal erosion. As a result, the gravel beach nourishment method was adopted as a construction method without any structural countermeasures. In 2013, the beach nourishment of about 80,000m^3 was completed according to plan.

Source: JICA Expert Team

Figure 4.3.1 Location of Akiya Beach

4.3.2 Study

The erosion situation of Akiya Beach is shown in the change of the shoreline by aerial photographs. Figure 4.3.2 shows the shoreline position in 1973 which was entered on the aerial photograph in 2005 with a red line. This proves that about a maximum 25m of shoreline retreat has occurred.



Source: Kobayashi, et. al., Journal of Japan Society of Civil Engineers, Ser. B3 (Ocean Engineering) Vol.67(2011) No.2

Figure 4.3.2 Erosion Situation of Akiya Beach

Moreover, since sedimentation is seen behind the breakwater of the Kuruwa fishing port while the erosion of Akiya Beach is seen from the superposition of aerial photographs, it is estimated that a main factor of erosion is that sand from Akiya Beach was drawn in the shielding region of the breakwater of the Kuruwa fishing port. In order to plan the countermeasures, studies shown in the following table were conducted.

Table 4.3.1 Studies for Planning the Countermeasures

Study item	Study content
Shoreline analysis by aerial photographs	To grasp the situation of erosion and to decipher the changes in shoreline position from aerial photographs
Wave data arrangement	To grasp the wave characteristic to act on Akiya Beach by wave data arrangement and wave transformation calculation
Shoreline change prediction (one-line) model formulation	To evaluate the effect of the various countermeasures by predicting the shape of the future shoreline when the countermeasures are performed or not.
Estimation of run-up height, wave overtopping quantity	To evaluate the necessity and effectiveness of countermeasures by reviewing the protection characteristic of each point of the beach
Sounding	Understanding of the seabed topographic change and basic data for shoreline change prediction (one-line) model, run-up height and wave overtopping quantity
Sediment survey	Understanding of the beach characteristics

Source: JICA Expert Team

4.3.3 Plan

As a result of understanding the sediment transport characteristic from aerial photograph analysis and shoreline change prediction (one-line) model, it is thought that a main factor of erosion is that sand from the beach was drawn into the shielded region of the breakwater by the construction of the Kuruwa fishing port and sand deposited in the fishing port was dredged in order to maintain the anchorage and was dumped offshore.

Therefore, it becomes impossible to satisfy run-up height and overtopping quantity. The beach, residences etc. suffered a great deal of damage, and countermeasures are needed. Three countermeasures are shown in Table 4.3.2. These were mentioned for the mechanism of erosion and coastal protection, and the working group which consists of residents, beach users, government personnel and academic experts was established and countermeasures were discussed.

It proved to be difficult to find middle ground over differences of opinion between the beach users who wanted to keep the beach in a natural state without structures and residents who wanted protection quickly. Consequently, a series of ten working group meetings was held over four years and a sense of a lack of progress arose combined with distrust of government. The meetings initially became a place which residents or beach users expressed their dissatisfaction at government, and the brunt of distrust also fell upon academic experts and the consultants. In response, government, academic experts and consultants responded earnestly and as a result, the meetings changed to a place of expressing constructive opinions from sometime around the fourth meeting, and ultimately, beach nourishment with gravel which can reduce the maintenance and does not build structures was adopted. The following requests were accepted with the adoption.

- Conservation of rich marine resources
- Conservation of coastal landscape
- Conservation of a beach form which will allow various beach activities
- Recovery of the beach use in the past by revival of the beach
- Prevention of coastal erosion from the 1970s
- Prevention of damage due to the high waves from stormy weather

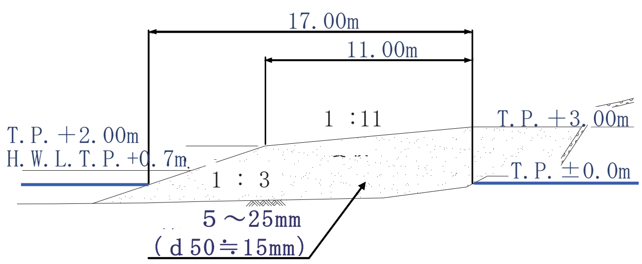
Table 4.3.2 Comparison of Countermeasures against Erosion

Countermeasures against erosion (example of construction)	Characteristic of countermeasures
	It is a structure which installed a wave dissipating concrete block and natural stone almost in parallel with the coastline. The main functions are wave dissipation and reduction of the sedimentation behind the detached breakwater and reduction of the littoral sediment transport rate associated with wave breaking effect.
	It is a structure which aims to prevent coastal sediment transport, and usually exerts the effect as a group.
	Headland (artificial cape) creates a system which stops littoral drift movement, and makes a statically stable beach where sand does not flow out of this system.

Source: Kanagawa Prefecture, Yokosuka engineering works office homepage; edited version of the handout of the first meeting

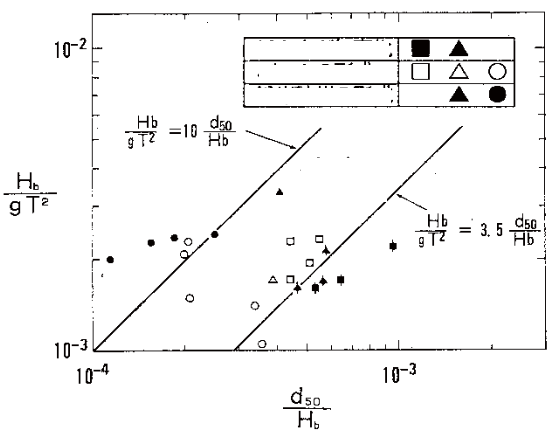
4.3.4 Design

The basic cross section of the beach nourishment with gravel is shown in Figure 4.3.3. If gravel nourished flows offshore, there is a danger that the coastal protection effectiveness of the nourishment will be diminished. In addition, gravel will bury any offshore seagrass beds and affect the fishery. Therefore, it was decided that grain size should be procured at about 15mm on the basis of local availability as well as satisfying a 9.7mm diameter which was calculated as the minimum size need to prevent washing offshore based on a) the generating classification of berm and longshore bar (Takeda and Sunamura, Figure 4.3.4), b) the classification of deposition and erosion of the foreshore (Uda et.al., Figure 4.3.5) and c) the classification of erosion and deposition of the beach (Horikawa et. al., Figure 4.3.6). The foreshore slope angle was set to 1:3 based on Uda and Ishikawa (see Figure 4.3.7). The backshore height was set to +3m based on physical and word-of-mouth (interviews with residents) evidence of the previous backshore height, and on the run-up height of waves which occur several times a year. The beach width was set as 11 m based on the present shoreline width (as of June 2006), as well as satisfying the beach width sufficient to prevent overtopping by wave run-up with a return period of 30 years. However, the backshore slope of 1:11 was established in consideration of use of the beach. From this, the amount of nourishment plan was calculated at 80,000m^3.



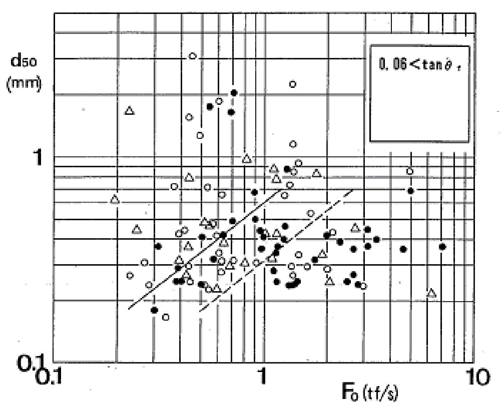
Source: Kobayashi, et. al., Journal of Japan Society of Civil Engineers, Ser. B3 (Ocean Engineering) Vol.67(2011) No.2

Figure 4.3.3 Basic Cross Section of Beach Nourishment with Gravel



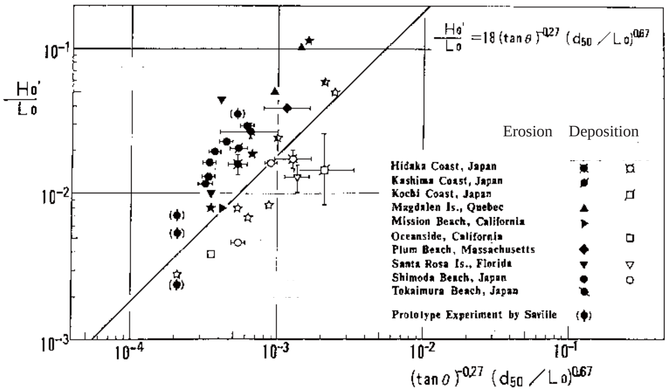
Source: Guidance of design of artificial reefs, Zenkoku Kaigan Kyokai, 1992

Figure 4.3.4 Generating Classification of Berm and Longshore Bar



Source: Guidance of design of artificial reefs, Zenkoku Kaigan Kyokai, 1992

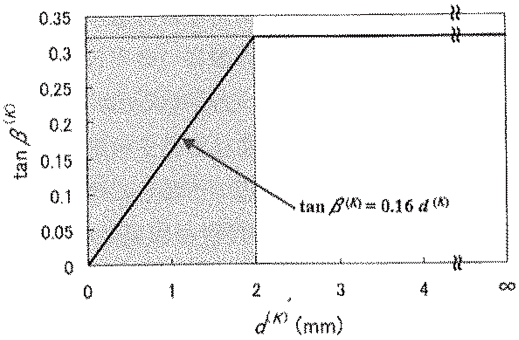
Figure 4.3.5 Classification of Deposition and Erosion of Foreshore (0.06≦tanθ)



H_b: breaker depth, T: wave period
d_{50}: sediment median grain size
Fo:1/8 ρ_w(Ho')^{2}Cgo
Cgo=gT/(4π)、 ρ_w: Specific gravity、
tan θ : The bottom slope

Source: Guidance of design of artificial reefs, Zenkoku Kaigan Kyokai, 1992

Figure 4.3.6 The Classification of Deposition and Erosion of Beach



Source: Uda, Ishikawa, Beach nourishment manual, Public Works Research Center

Figure 4.3.7 Relation between Grain Size and Foreshore Slope

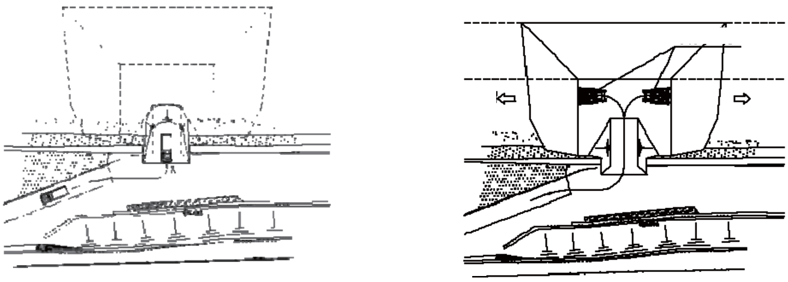
4.3.5 Construction

a. Procurement of gravel for beach nourishment

Gravel for beach nourishment was extracted from the river above the Sagami Dam so that the sand supply on the beach might not be affected. The extracted gravel was crushed to achieve a median grain size of 15mm, and was washed twice in water.

b. Procurement of gravel for beach nourishment

- The deposition of the gravel to the site was performed from land because the shallow water depth made it impossible to be conducted from sea.
- Since it was predicted that the nourished gravel would spread on both sides, the gravel deposition was performed from a temporary path in the central beach.
- A temporary platform (for dumping nourishment gravel) was gradually formed by backing up dump trucks and dumping and spreading loads of gravel further and further into the nourishment dumping zone (see Figure 4.3.8).



Source:Kanagawa Prefecture, Yokosuka engineering works office HP, beach nourishment with gravel test construction plan, 2006(draft)

Figure 4.3.8 Procedure of Gravel Nourishment at Akiya

4.3.6 Management

a. During implementation of beach nourishment with gravel

Beach nourishment with gravel started from 2007 and was carried out in January-March every year. The contents and the enforcement schedule of monitoring investigation are shown in Table 4.3.3. Survey results were explained in a meeting each year in October to gain the consent of the residents and beach users for the next stage of beach nourishment.

Table 4.3.3 Results of Monitoring

Items	Contents of investigation	Timing of implementation
Topographic survey	Sounding (20-40m interval)	Summer
	Shoreline survey (20-40m interval)	Summer & before the construction of beach nourishment with gravel
Sediment survey	Grain size analysis (33 points)	Summer
	Sediment photography (33 points)	
	Chemical analysis (7 points) (COD, ignition loss, sulfide)	
Biological survey	Benthos (7 points)	Summer
	Attached organism (6 points)	
	Fish egg, juvenile (2 points)	
	Line census (5 lines)	
Fixed point photography		7-10 times/year
Fishermen consultation		As needed

Source: Kobayashi, et. al., Journal of Japan Society of Civil Engineers, Ser. B3(Ocean Engineering) Vol.67(2011) No.2

b. After the end of beach nourishment with gravel

The following things were understood in the monitoring investigation:

- In general, the backshore height, the beach width, and the foreshore slope were formed just as planned.

- Gravel from beach nourishment moved in the direction of the coast earlier than the movement speed predicted by the shoreline change prediction model. The result of about 40m/year was observed.

- Gravel from beach nourishment did not flow out past 1 m from the offshore water depth -1m from the sounding and sediment survey.

- However, part of the gravel likely flowed out to the Kuruwa fishing port side.

- There were waves exceeding the planned waves (30-year return period), and gravel was run up by the waves and accumulated on the backshore. This resulted in crime-related problems for the residents, namely it became easier for people to climb over resident's fences.

As mentioned above, planning is underway to perform sand recycling, etc. to reverse the impact of gravel being washed towards the Kuruwa fishing port side. Therefore, shoreline surveys, photography of sediment, etc. is continuously under review.

4.3.7 Subjects and solutions

- Although the gravel outflow to Kuruwa fishing port side was predicted by the shoreline change prediction model, the movement speed exceeded predictions and maintenance management plans such as sand recycling is set to be discussed from now.

- Gravel run up to the backshore is dealt with by sand recycling, etc. However, more efficient methods are set to be examined because increasing maintenance costs are an issue.

If gravel nourishment is planned in Mauritius it has to consider the continuous supply of gravel if longshore sediment movement is active at the beach.

Chapter II

Technical Guideline for Beach Monitoring

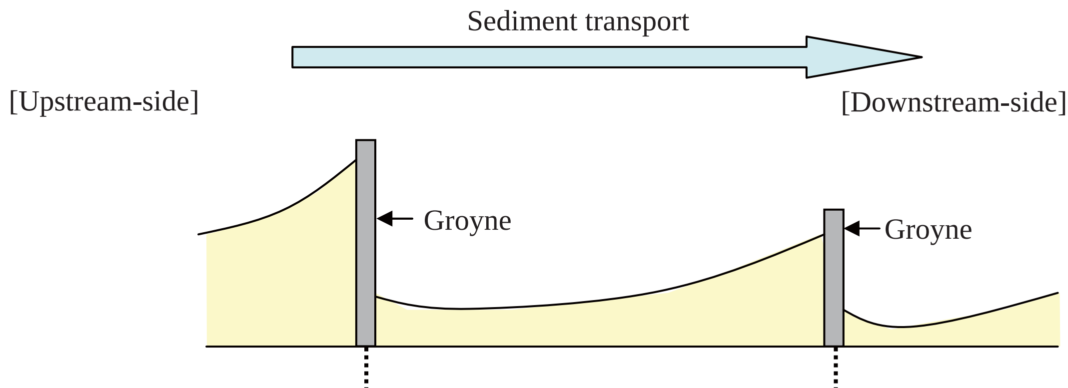
II. Technical Guideline for Beach Monitoring

The purposes of beach monitoring are the observation of the beach changes, waves and current for the understanding the coastal condition, the analysis of coastal changes, findings of erosion problems and its measures, and keeping the beach in desirable conditions. The items and responsible organizations of the monitoring are explained in the coastal conservation and management plan. The guideline explains the method of each monitoring items. The items are the observation of beach conditions, the monitoring of beach profile, the measurement of waves and currents, and the analysis of shoreline changes.

1 Field Investigation

1.1 Field Observation

The field observation is carried out in order to obtain the basic information for the coastal conservation such as the beach profile, structures, beach slope, grain size, and vegetation. When observing beach conditions at sites, it is very important to check conditions focusing on some points shown in Figure 1.1.1 instead of just looking around.



Beach profile	Accumulated	Eroded	Accumulated	Eroded
Grain size	Fine	Coarse	Fine	Coarse
Beach slope	Mild	Steep	Mild	Steep
Beach Scarp		○○○		○○○
Vegetation	○○○		○○○	

*The mark "○" shows areas which beach scarp or vegetation most likely exist

Source: JICA Expert Team

Figure 1.1.1 Important Points to be Checked in Field Observation

1.1.1 Beach Profile across the Structure (Groyne)

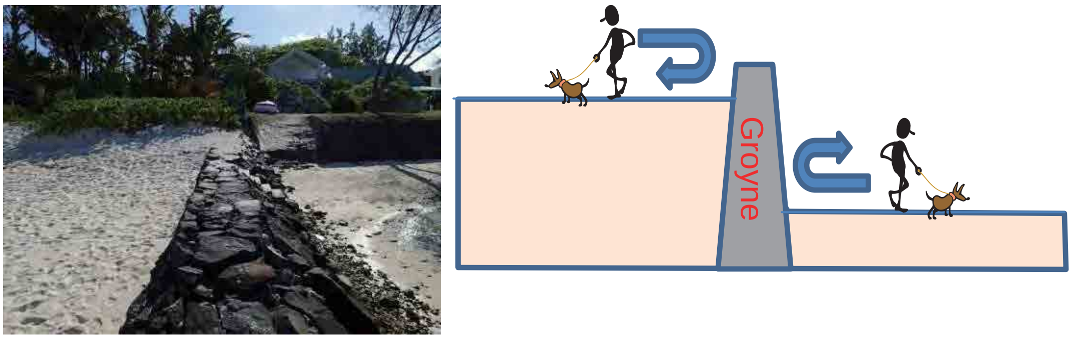
If some existing structures are interfering with the longshore sediment transport, accumulated (accreted) areas typically exist at the upstream side and eroded area exist at the downstream side. Here, the word "sediment transport" does not refer to a seasonal one, such as one limited to summer or winter seasons, but instead a dominant one for a long period. Figure 1.1.2 shows the differences of beach profile across the groyne in Pte. d'Esny. The downstream side of sediment transport has eroded and the other side has accumulated. There is a gap of beach height between the up- and down-stream sides, which can be obstacles for proper beach access (see Figure 1.1.3 for an image).

(Seaward)

(Landward)

Source: JICA Expert Team

Figure 1.1.2 Beach Profiles across the Groyne at Pte. d'Esny

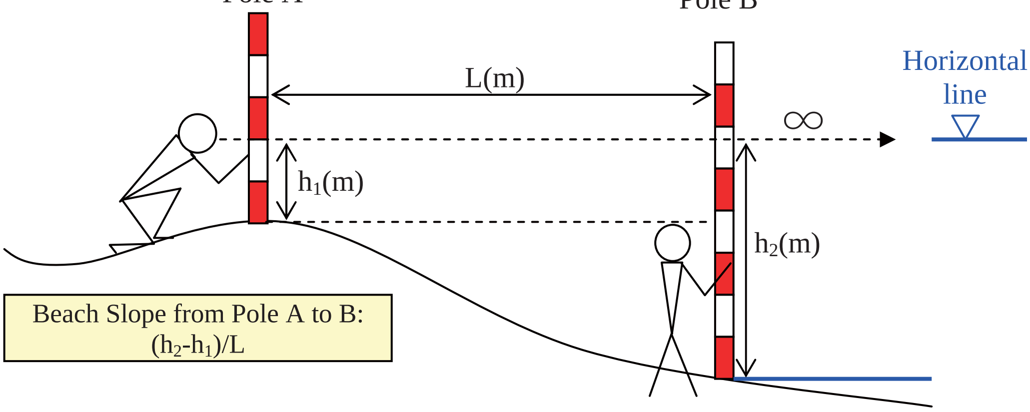


Source: JICA Expert Team

Figure 1.1.3 An Image showing how a Groyne Interferes with Beach Access

1.1.2 Beach Slope and Grain Size

In general, beach slopes get steeper at eroded areas and milder at accumulated areas. And there is a relationship between grain size and beach slope. The bigger the grain size becomes the steeper the beach slope it has, and vice versa. It is not so easy to define the beach slope just by looking at it. Here is a simple method to measure the beach slope at sites using only two poles, a tape measure and visible horizontal lines as shown in Figure 1.1.4.



Source: Manual for Beach Nourishment (2005, Public Works Research Center, JAPAN)

Figure 1.1.4 Simplified Method to Measure Beach Slope at Site

1.1.3 Beach Scarp

Beach scarp can be seen at the upstream side of sediment transport, especially just after structures or natural topography such as a cape or rocky beach interferes with sediment transport. The size of beach scarp decreases as it goes toward the downstream side as shown in Figure 1.1.5.

Beach scarp at the upstream side

No scarp at the downstream side

Source: JICA Expert Team

Figure 1.1.5 Beach Condition at Mon Choisy

1.1.4 Vegetation

If some vegetation area exists without beach scarp, this area is considered to be an area less affected by waves and is more stable compared to other areas with no vegetation. Figure 1.1.6 shows vegetation area at Pte. d’Esny.

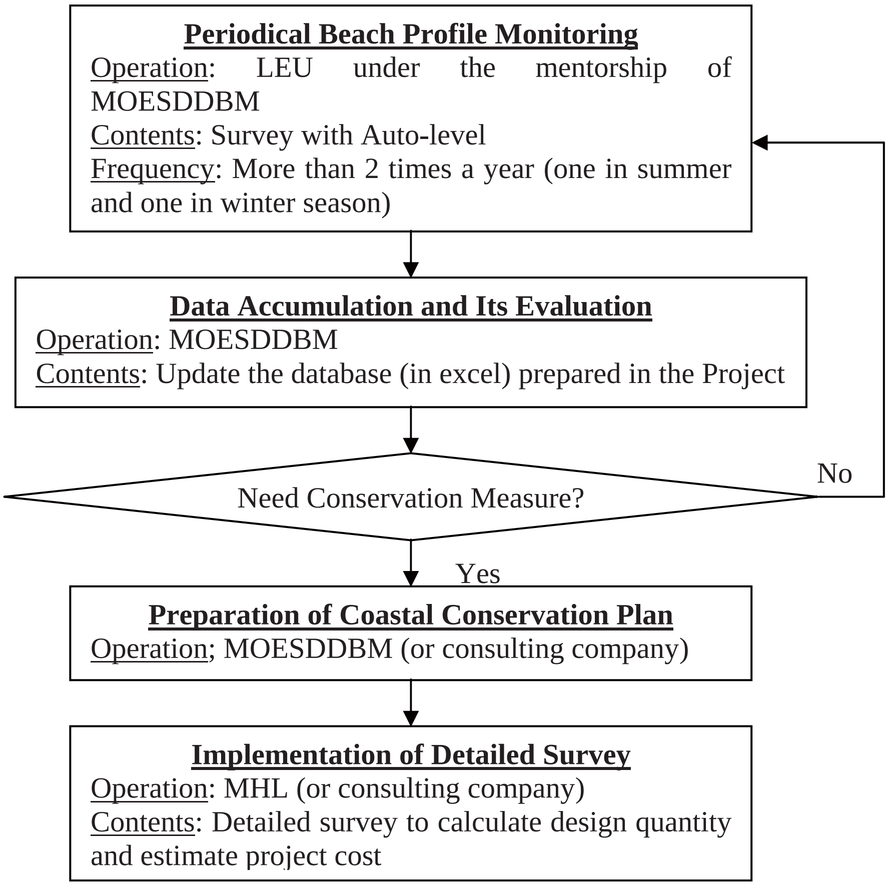
Source: JICA Expert Team

Figure 1.1.6 Vegetation Area at Pte. d’Esny

1.2 Beach Profile Monitoring

The objective of beach profile monitoring is to confirm changes to the beach periodically and to apply the results of the monitoring to the preparation of adaptive conservation measures. In Mauritius, dominant wind and wave direction changes occur in the summer and winter seasons. Therefore, it is proposed to conduct monitoring more than two times (i.e. once in summer and again in the winter season).

Since the purpose of monitoring is to check the changes of beach profile, high accuracy instruments such as the total station will not necessarily be needed. The most important thing is to continue this kind of monitoring with a certain accuracy for a long period to accumulate the data. If concrete countermeasures were required, then there would be a need for high accuracy instruments to calculate design quantity and project costs, as described in Figure 1.2.1.



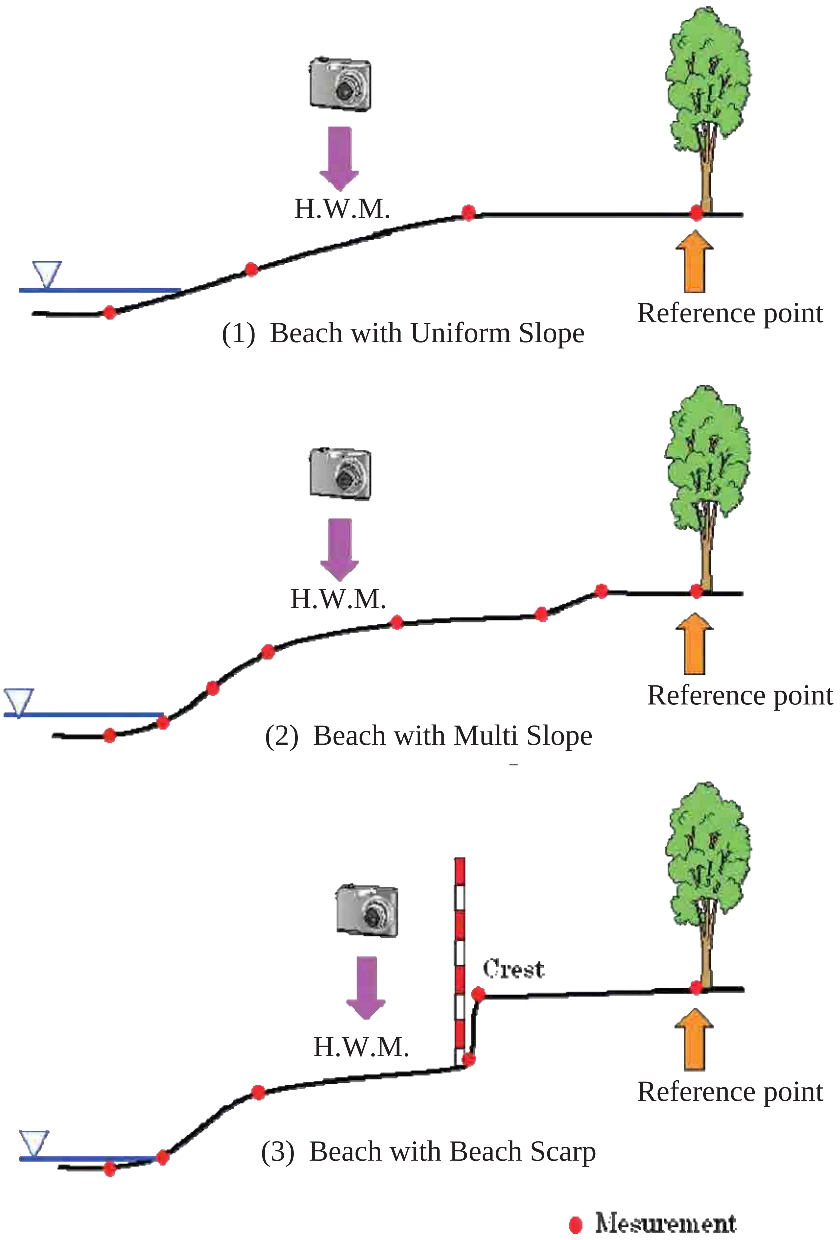
Source: JICA Expert Team

Figure 1.2.1 Proposed Implementation System of Beach Profile Monitoring

1.2.1 Cross-section Survey

a. Survey Points

It is very important to conduct surveys at the same line every time to obtain appropriate data to compare with. Typical survey points are shown inFigure 1.2.2. The reference point has to be placed on something stable such as trees and concrete basements. Once the reference points are set, the coordinates have to be recorded using GPS. Photos also have to be taken from a fixed point and angle. H.W.M. along the survey line is proposed as the location.



Source: JICA Expert Team

Figure 1.2.2 Typical Points for Survey and Taking Photos

b. Procedure of Beach Profile Monitoring

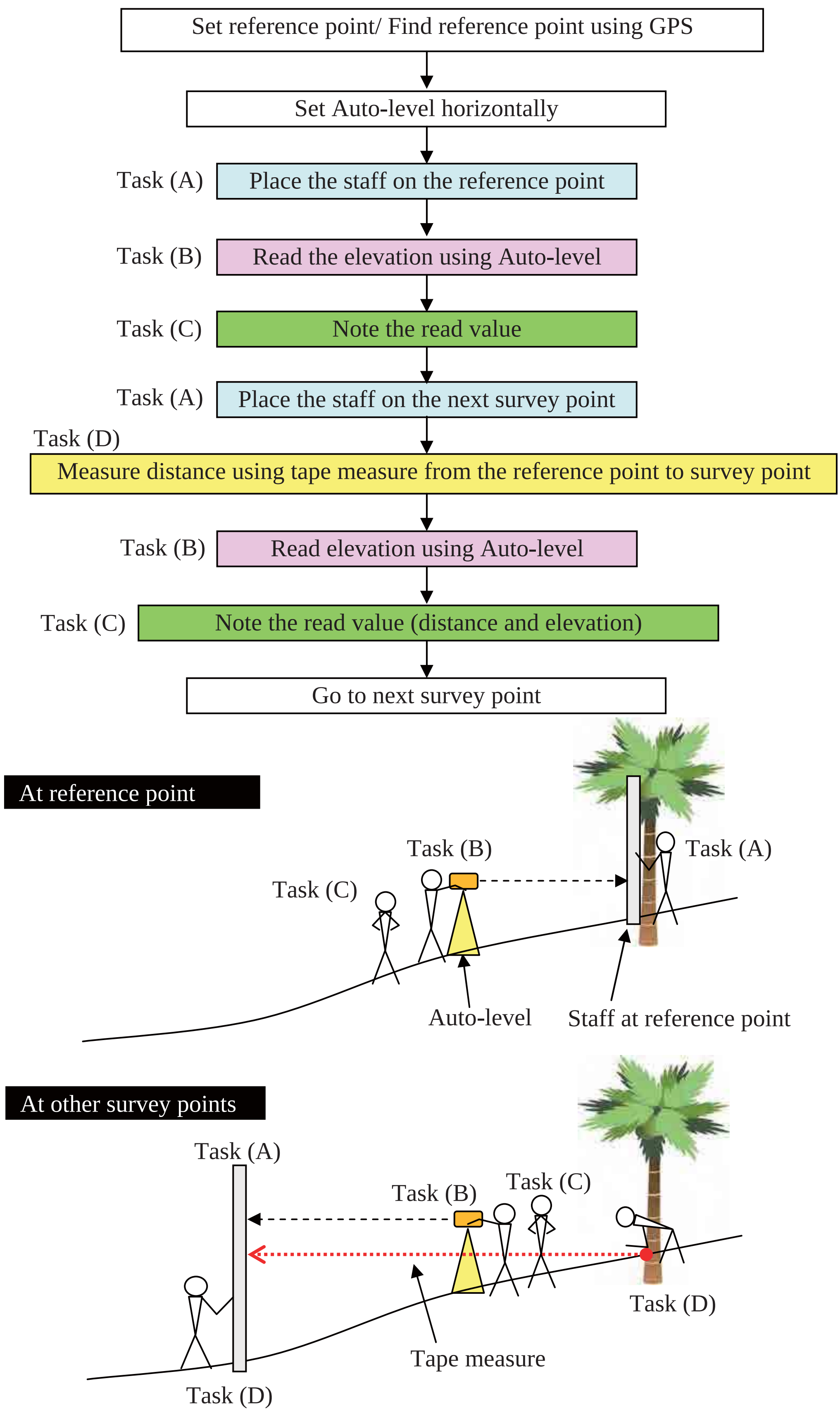
b.1 Beach Profile Survey

Instruments used for beach profile monitoring are listed as follows and these instruments have already been handed over to the MOESDDBM.

- Auto-level
- Staff(5m)
- Tape measure (50m)
- GPS
- (Notebook and pens)

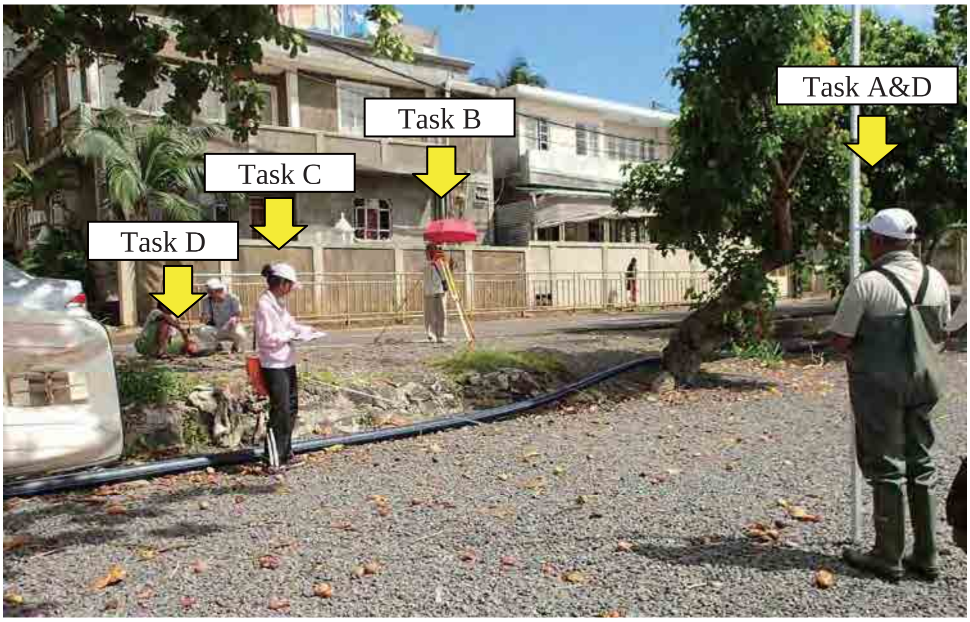
The procedure for beach profile monitoring is shown in Figure 1.2.3 andFigure 1.2.4. There are basically four tasks for the monitoring. Therefore, it is recommended to conduct monitoring by at least 4 people (5 people is more desirable). To secure the accuracy of the survey, Auto-level, staff, and tape measures have to be placed horizontally as much as possible. For Auto-level, the horizontal level can be checked by an air bubble attached to the instrument. Employing the staff and tape measure method is more difficult to ensure that the measurement is being taken horizontally, so there are two suggestions to improve this method. One is to have a person check from the measurement is being taken horizontally. Another is to read the minimum value of the elevation while moving the level staff back and forth as shown in Figure 1.2.5.

The survey line is generally set perpendicular to the shoreline. It is not a big issue when the survey distance is not so long. However, when the survey distance becomes longer, it becomes more difficult to survey on the same line every time. It is important in this case to confirm the visibility from the reference point to the end of the survey line. Visibility can be set on certain trees, big rocks, or capes, etc. as shown in Figure 1.2.6 and it is important to record these visibilities in the database.



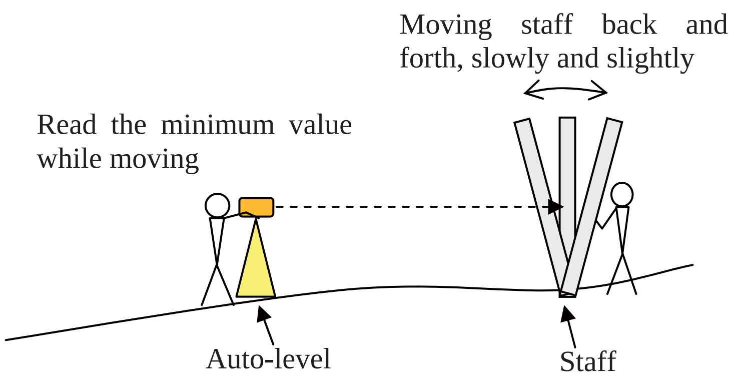
Source: JICA Expert Team

Figure 1.2.3 Procedure of Beach Profile Monitoring



Source: JICA Expert Team

Figure 1.2.4 Photo during Beach Profile Monitoring



Source: JICA Expert Team

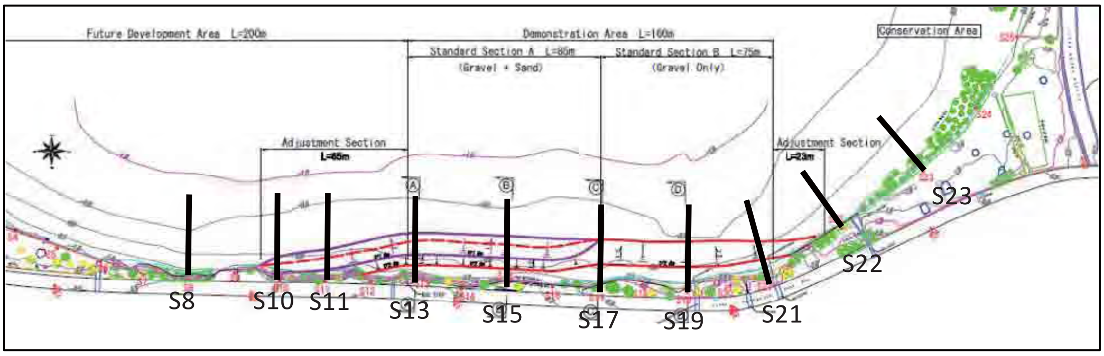
Figure 1.2.5 Tips for Reading Elevation of the Staff

Source: JICA Expert Team

Figure 1.2.6 Example of Photos to Show Visibility from Reference Point

b.2 Taking Photos at Fixed Point and Angle

Comparison of beach photos from fixed angles is helpful to understand how the beach profile has changed over a period of time. As shown in the previous figure, it is recommended to take photos for both sides that are parallel to the shoreline from H.W.M. Figure 1.2.7 shows a good example taken at Grand Sable. They were taken on 14th Feb. 2014, (just after the Pilot construction) and 13th Sep. 2014, respectively. Comparing these two photos, it shows that some gravel moved southward and covered existing beach areas during this period.



14 Feb 2014 at S8

13 Sep 2014 at S8

Source: JICA Expert Team and MOESDDBM (ICZM Div.)

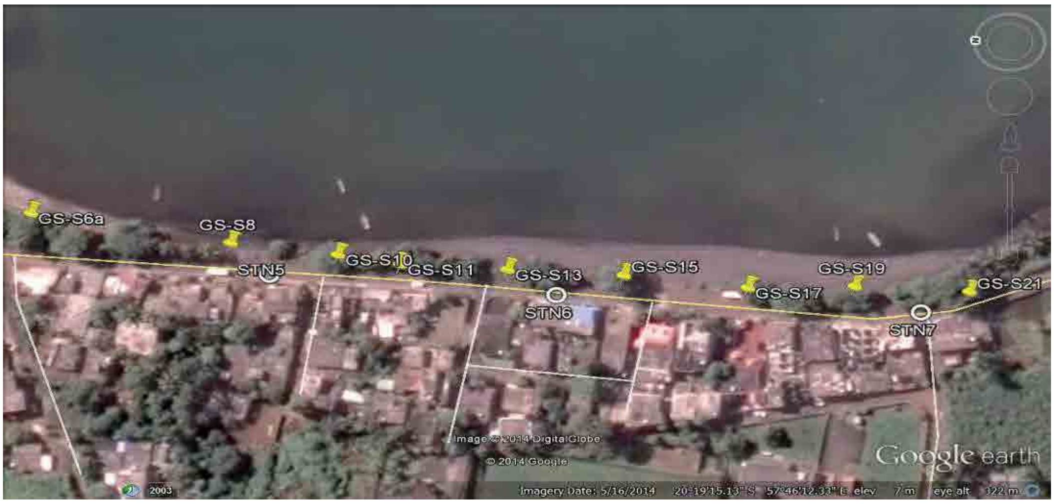
Figure 1.2.7 Comparison of Photos Taken at Fixed Point and Angle

1.2.2 Building Database

Surveyed data has to be organized so it can be referred to whenever necessary. The database of beach profile monitoring was prepared in the Project by JET and MOESDDBM (ICZM Div.). The main content of the database are presented as follows:

a. Location Map and Coordinates of Reference Points

Coordinates of reference points have to be recorded using GPS and to be marked on the map as shown in Figure 1.2.8. Google Earth can be used for this mapping. And coordinates of every baseline point can be summarized in Table 1.2.1.



Source: JICA Expert Team and MOESDDBM (ICZM Div.)

Figure 1.2.8 Mapping Example of Reference Points using Google Earth

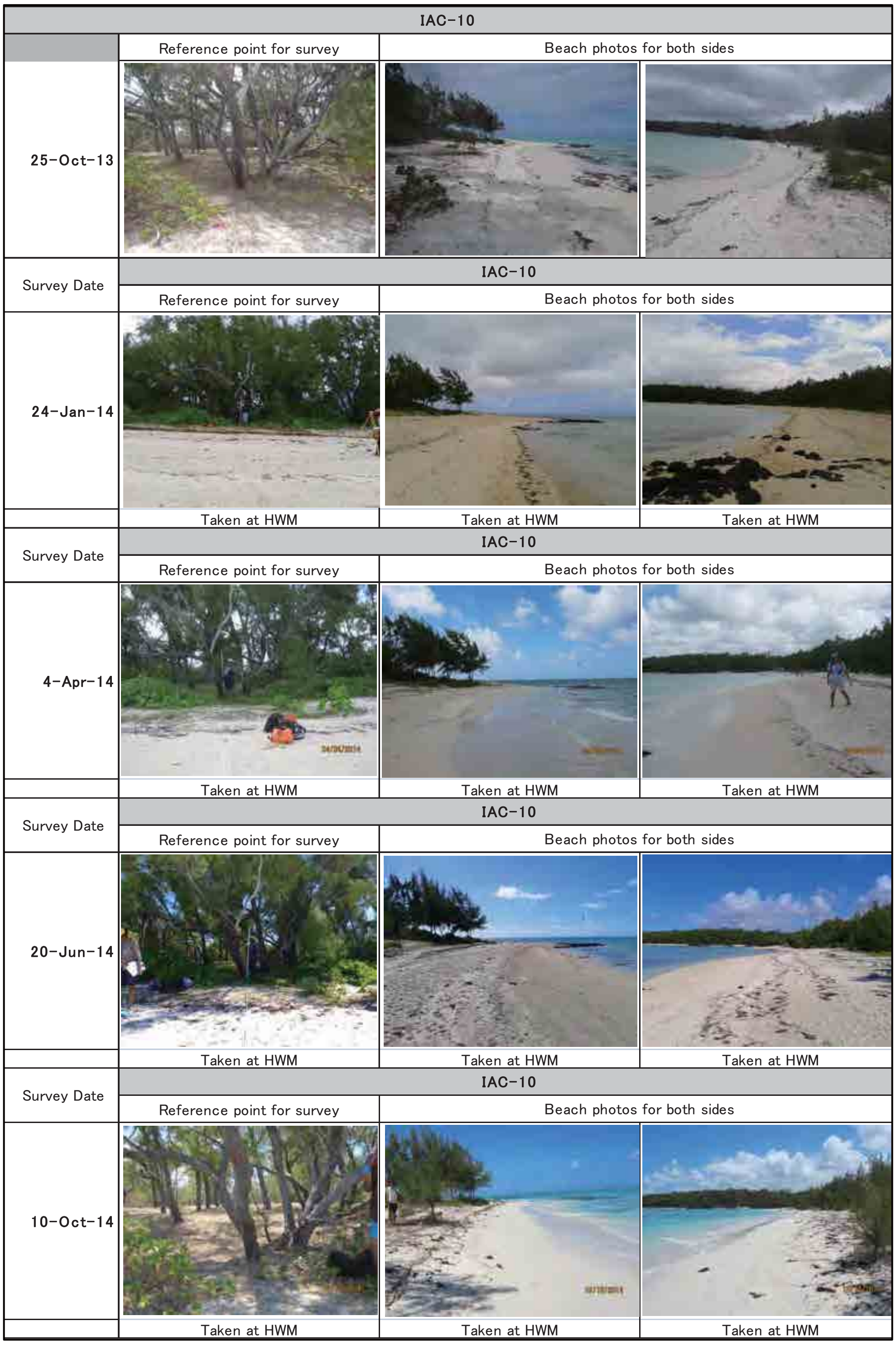
Table 1.2.1 Example of Organization of Reference Points

Field Survey Memo		Survey Point Name	Location	
			South latitude	East longitude
L1	179	S8	20° 19'11.60"S	57° 46'12.00"E
L2	181	S10	20° 19'12.90"S	57° 46'12.00"E
L3	182	S11	20° 19'13.60"S	57° 46'12.00"E
L4	184	S13	20° 19'15.50"S	57° 46'11.70"E
L5	185	S15	20° 19'14.80"S	57° 46'11.90"E

Source: JICA Expert Team and MOESDDBM (ICZM Div.)

b. Survey Photos

Comparison of beach photos from fixed angles is helpful to understand how the beach profile has changed over a period of time. Figure 1.2.9 shows a good example of organizing survey photos. Beach photos for both sides were taken from the H.W.M. on the beach every time.



Source: JICA Expert Team and MOESDDBM (ICZM Div.)

Figure 1.2.9 Example of Organization of Survey Photos

c. Survey data

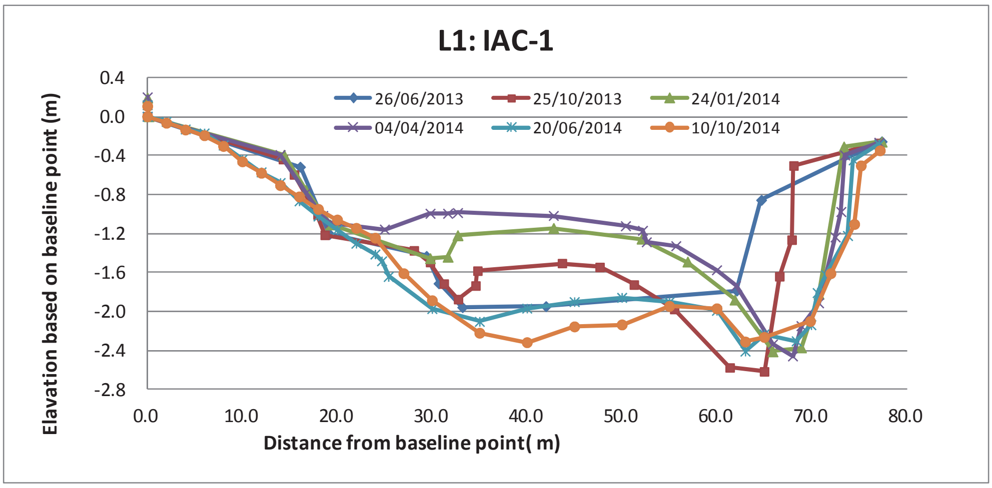
Table 1.2.2 shows examples for building a database for monitoring data. First, measured elevations during the survey are entered at the column “Elevation from survey”. Since those elevations change in every survey, they need to be converted into relative values against the reference point. In the example below, the elevation of the reference point is set as zero in every survey (see the column “Ground level based on the reference point”). Plotting those converted elevations and distances gives beach profiles to compare as shown in Figure 1.2.10. It is noted that in any survey profile, the reference point has to be plotted at zero in both elevation and distance as shown in the Figure. If not, that means some errors will occur in the process of conversion. As stated above, these elevations are not absolute values above M.S.L but relative values based on the reference point. Absolute elevations will be needed when detailed design is required. In that case, defining the absolute elevation above M.S.L. for each reference point will give absolute values for other survey points because differences based on the reference point are already known for other survey points.

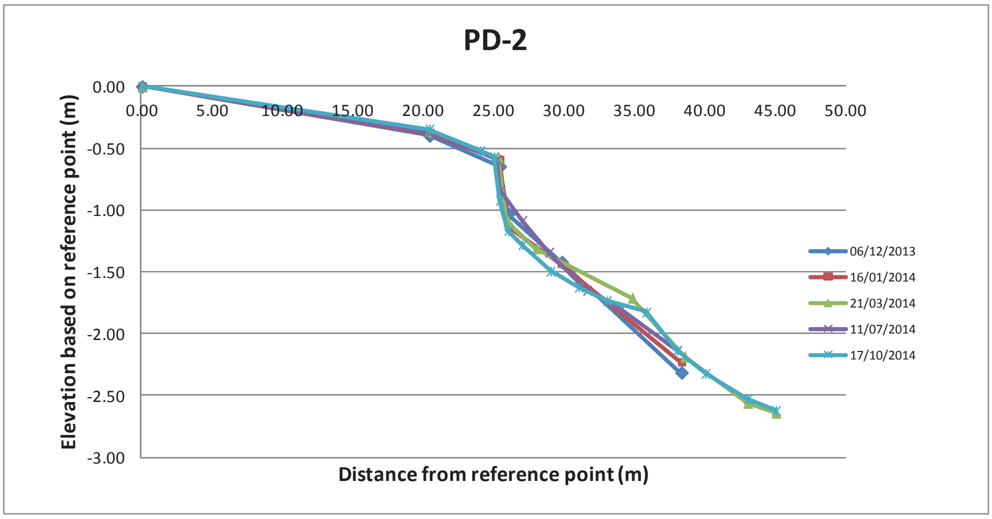
It is recommended to mark and record the time when surveying shoreline points as shown in Table 1.2.2. If tide level above M.S.L. is known at survey time, this also can be used to convert these relative values into absolute values, though it might not be so accurate compared to the above because the tide level changes more or less at locations.

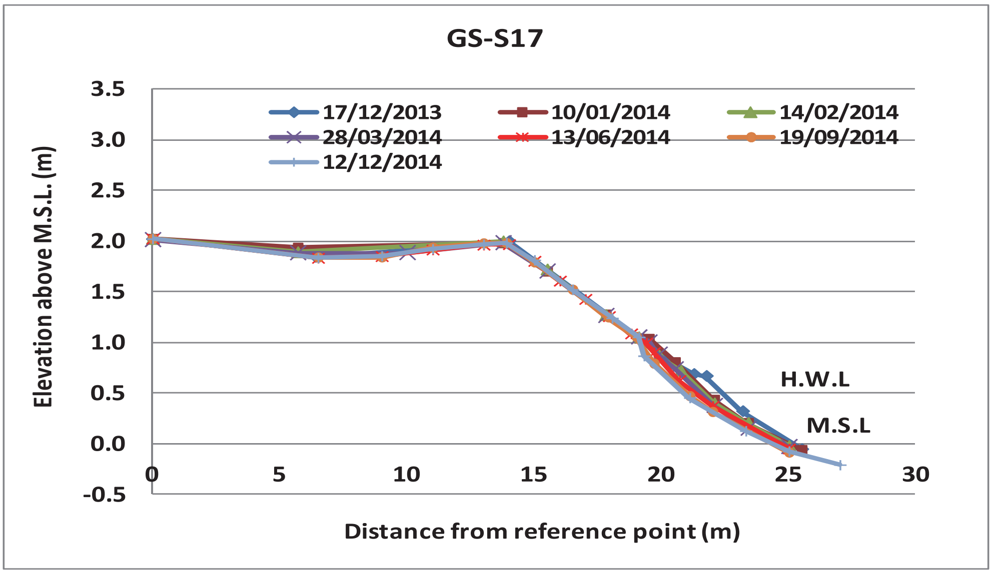
Table 1.2.2 Organization of Survey Data

Line No.	Point No.	Shoreline	Time	Elevation from Survey	Distance (m)	Ground level based on reference point
Survey Date: 06/12/2013						
2	1	–	–	0.822	0.00	0.000
	2	–	–	1.219	20.40	−0.397
	3	–	–	1.468	25.40	−0.646
	4	●	10:10	1.853	26.00	−1.031
	5	–	–	2.242	29.80	−1.420
	6	–	–	3.135	38.30	−2.313
Line No.	Point No.	Shoreline	Time	Elevation from Survey	Distance (m)	Ground level based on reference point
Survey Date: 16/01/2014						
2	1	–	–	1.054	0.00	0.000
	2	–	–	1.436	20.40	−0.382
	3	–	–	1.645	25.40	−0.591
	4	●	14:20	2.188	26.00	−1.134
	5	–	–	2.484	29.75	−1.430
	6	–	–	3.281	38.30	−2.227

Source: JICA Expert Team and MOESDDBM (ICZM Div.)







Source: JICA Expert Team and MOESDDBM (ICZM Div.)

Figure 1.2.10 Graphs to Compare the Beach Profile Changes (Top: Ile aux Cerfs, Middle: Pte. d'Esny, Bottom: Grand Sable)

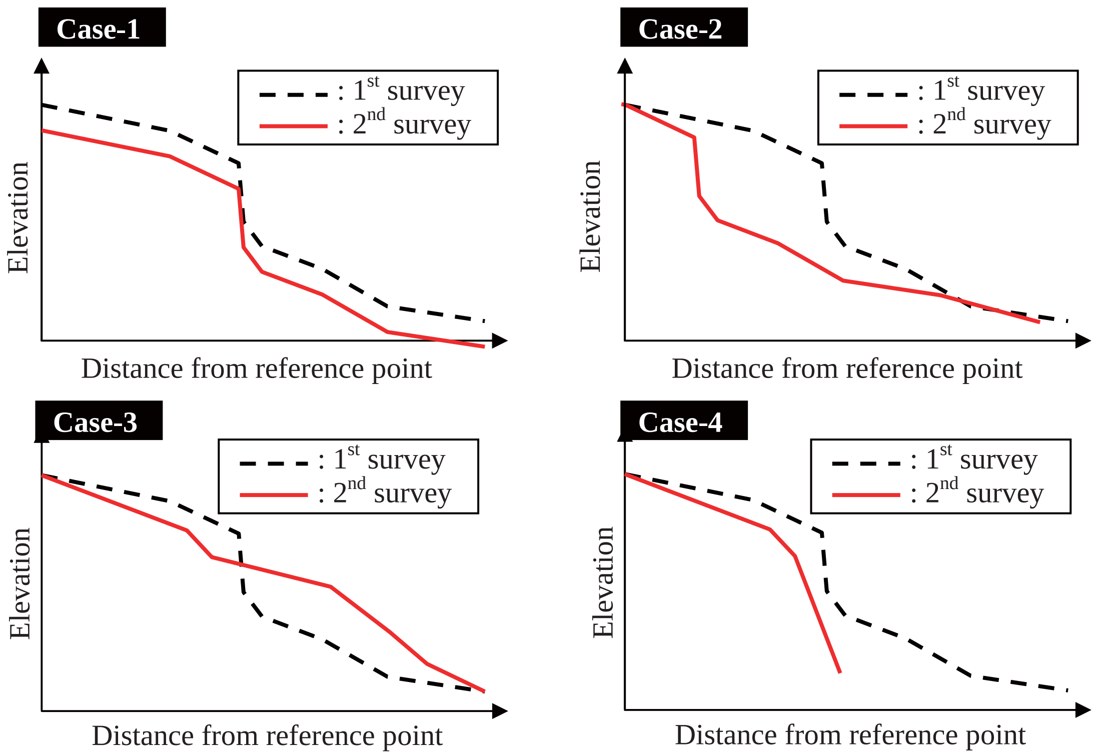
d. Typical Errors on Survey Data

Errors on survey data become more apparent when plotting on graphs. Figure 1.2.11 shows examples that might include some typical errors. In the Figure, the dotted line in black is supposed to be an example of a correct profile and the red line is supposed to be an example of a wrong profile. Table 1.2.3 shows possible causes of errors. It is noted that all cases except case-1 have a high risk of including some errors but this (including errors) is not necessarily the case. However, errors usually will not occur unless there are extreme weather conditions such as cyclones. Therefore, firstly, it is important to check the validity of data again if those kinds of beach profile changes were obtained from the monitoring survey.

Table 1.2.3 Possible Causes of Errors for Survey

Case Examples	Description	Possible causes of error
Case-1	Whole profile including reference point (at zero) shifted downward	· Data conversion from measured one to relative one was not properly conducted
Case-2	Both have similar profiles of beach scarp but its location is quite different.	· Reference point is different from 1^{st} survey · Some survey points are missing for 2^{nd} survey
Case-3	Beach profiles are quite different	· Survey line itself is different from 1^{st} survey · Visibility from reference point is quite different from 1^{st} survey(Even reference point is same as 1^{st} survey, end point of survey is quite different)
Case-4	Distance of beach profile is quite different	

Source: JICA Expert Team and MOESDDBM (ICZM Div.)



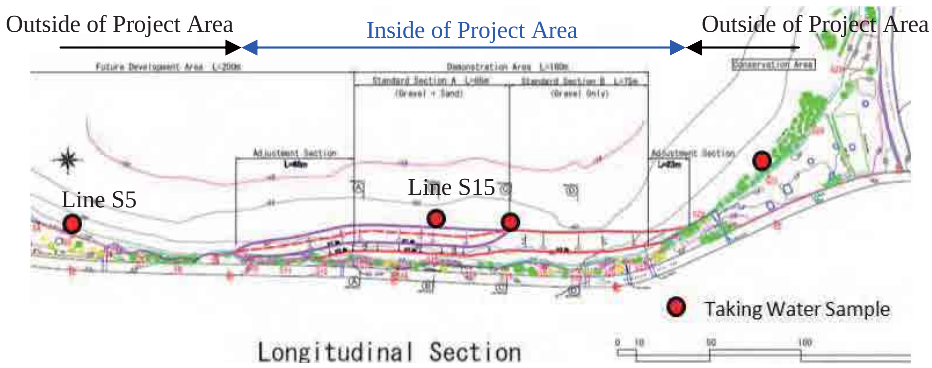
Source: JICA Expert Team and MOESDDBM (ICZM Div.)

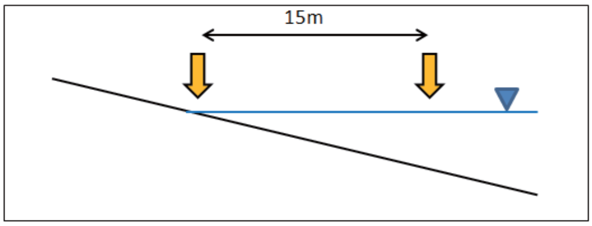
Figure 1.2.11 Plotting Examples that Might Include Some Errors

1.2.3 Other Monitoring Items

a. Transparency of Sea Water

Through the Demonstration Project at Grand Sable, residents reported that the transparency of sea water improved after the Project. To check the transparency of sea water, it is proposed to take some water samples from fixed points into cylinder and make a photographic record as shown in Figure 1.2.12. It is important to take records both inside and outside of target areas to compare the transparency (i.e. Project's effect)





(1) Line S5 (In front of North Public Beach, Out of Project Area)

(2) Line S15 (Project Area)

Source: JICA Expert Team and MOESDDBM (ICZM Div.)

Figure 1.2.12 Method to Check Water Transparency at Site

b. Vegetation

As mentioned in Section 1.1.4, the vegetation area can be considered to be an area less affected by waves and be more stable compared to other areas with no vegetation, which is very helpful to know for assessing the beach condition. Therefore, taking photographic records of vegetation at fixed points is recommended as a part of monitoring. Figure 1.2.13 shows the example at Grand Sable. The right-hand side photo, taken six months after the left-hand side photo, shows gravel beach works to improve the natural environment and this area is less affected by waves.

Source: JICA Expert Team and MOESDDBM (ICZM Div.)

Figure 1.2.13 Photographic Record of Vegetation at Fixed Points

c. Beach use

It is important to monitor and take photographic records of beach activities at beach areas. This information is needed to prepare coastal conservation plans, especially for beach use and coastal management.

(1) Boat Landing

(2) Recreational Fishing

(3) Recreation and Relaxation

Source: JICA Expert Team

Figure 1.2.14 Photographic Record of Beach Activities at Grand Sable

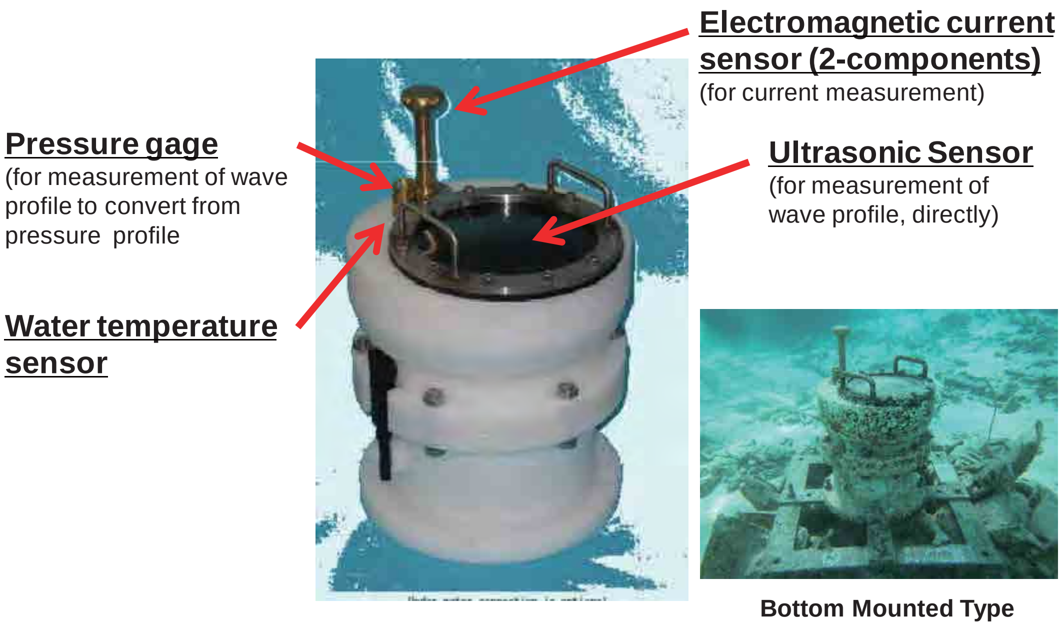
2 Wave and Current Measurement

2.1 Wave Measurement

2.1.1 Overview

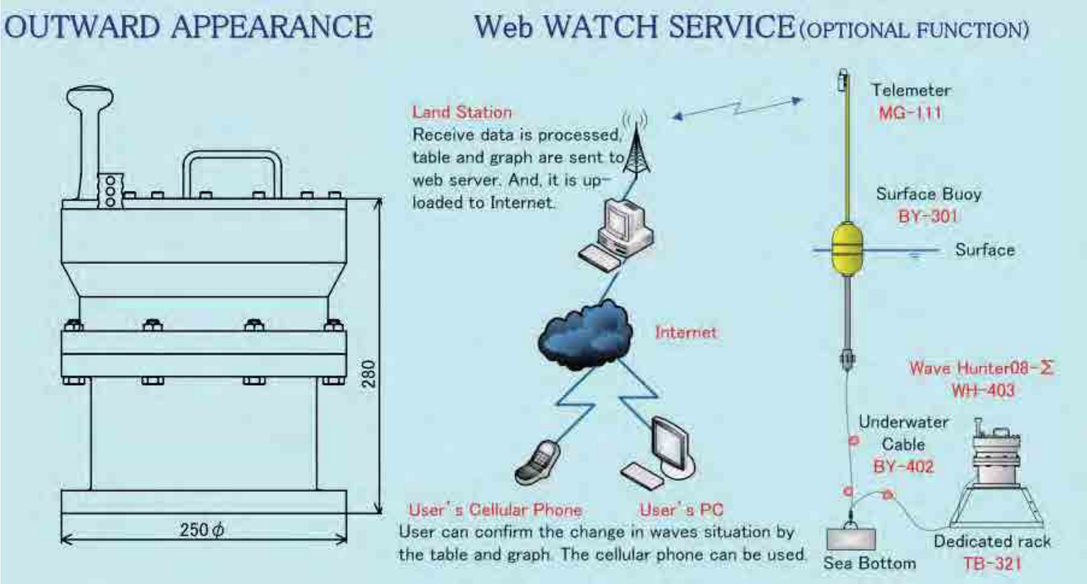
Wave measurement is carried out in order to make the wave conditions which cause beach changes and wave run-up. Here the measurement of waves is explained by using a wave gauge called Wave Hunter (product name) which was used and will be used in Mauritius.

The WAVEHUNTER is equipped with 1) Pressure gauge, 2) Ultrasonic sensor, 3) Electromagnetic current sensor, and 4) Water temperature sensor as shown in the Figure below. The present model needs to be removed from the site to collect recorded data. However, there is an optional function “Web WATCH SERVICE”, in which data can be obtained in real time using the internet.



Source: JICA Expert Team

Figure 2.1.1 Overview of WAVEHUNTER



Source: JICA Expert Team

Figure 2.1.2 Overview of Web WATCH SERVICE

The WAVEHUNTER data is presented as the following:

<Data obtained from WAVEHUNTER>

- Wave Data: $H_{1/3}$(significant wave height), $T_{1/3}$(significant wave period), H_{max}(maximum wave height), T_{max}(maximum wave period), Wave direction
- Wave Spectrum (Power Spectrum)
- Sea water level (tide level)
- Current speed and direction
- Water temperature

2.1.2 How to Use the Equipment

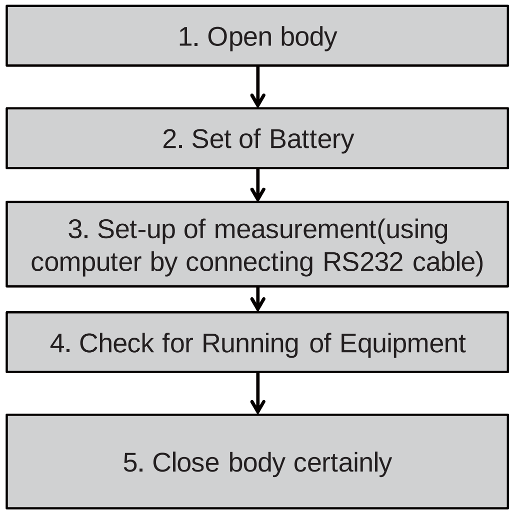
This section shows the step-by-step procedure for using the WAVEHUNTER.

a. Setup

There are some notes for setup work as listed below:

- Careful setting, especially in the interval time, the starting time, sampling interval, is important so as to avoid failure of measurement (See the manual for how to set up measurement conditions)
- It is necessary to firmly fix all bolts and paste silicon to O-ring to avoid leakage of seawater into the equipment
- After setting it up, it is necessary to confirm if the measurement is going well by checking the indicator lamp
- The instrument must not be laid on its side during transportation.

Setup procedure is shown as follows.



Source: JICA Expert Team

Figure 2.1.3 Setup Procedure

Photo.1 Bolt nuts (M10)

Photo.2 Pull it out slowlly

Photo.3 Lay a tank down

Photo. 4 Put sponge under the electromagnetic current speed meter

Source: JICA Expert Team

Figure 2.1.4 1st Step: Open Body

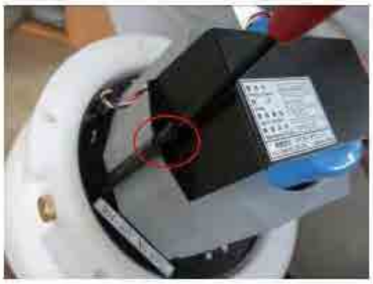


Photo.8 Taking off a settle board.

Photo.9 After taking off a settle board

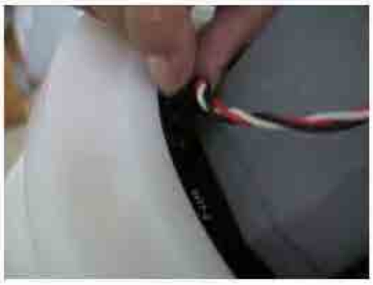


Photo.10 taking off the battery connecter

Photo.11

5

Photo.12

Source: JICA Expert Team

Figure 2.1.5 2nd Step: Set of Battery

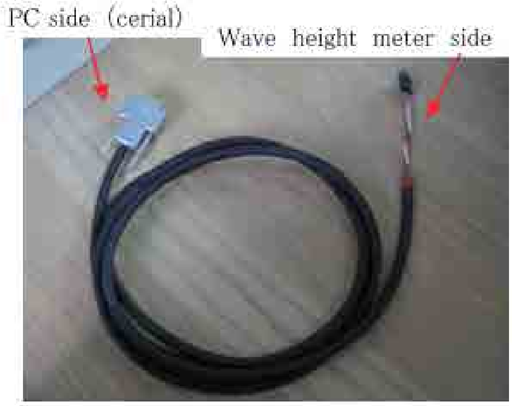


Photo.13 PC connection cable
(CA-410)

Photo.14 Connect PC connection cable.

Source: JICA Expert Team

Figure 2.1.6 3rd Step: Setup of Measurement (using computer by connecting RS232 cable)

Photo.5 Power switch

Photo.6 Function confirmation lamp

Source: JICA Expert Team

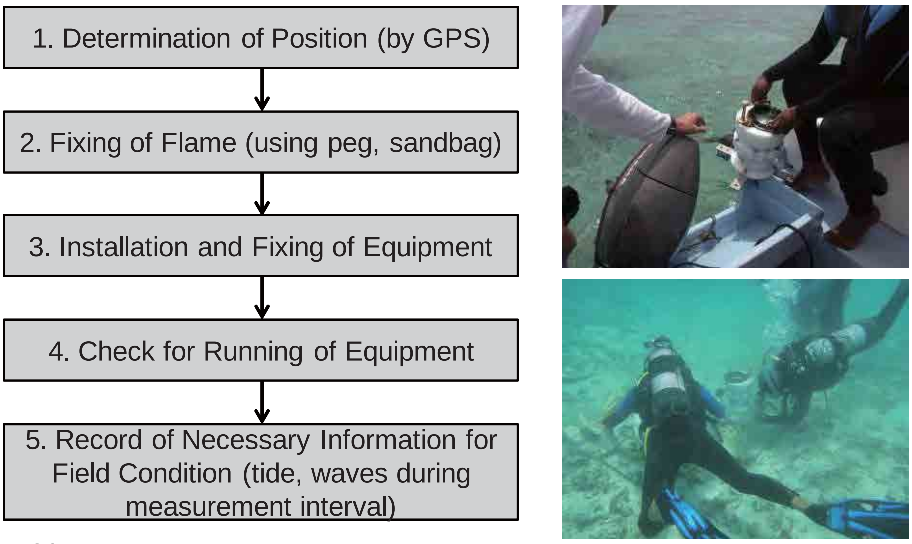
Figure 2.1.7 4th Step: Check for Running Equipment

b. Installation

Notes for installation work as listed below:

- The sensor portion shall be carefully handled, especially during pull down activity from the boat to the bottom using rope.
- Zinc plate shall be attached to the frame to avoid electric corrosion

Installation procedure is shown as follows:



Source: JICA Expert Team

Figure 2.1.8 Installation Procedure

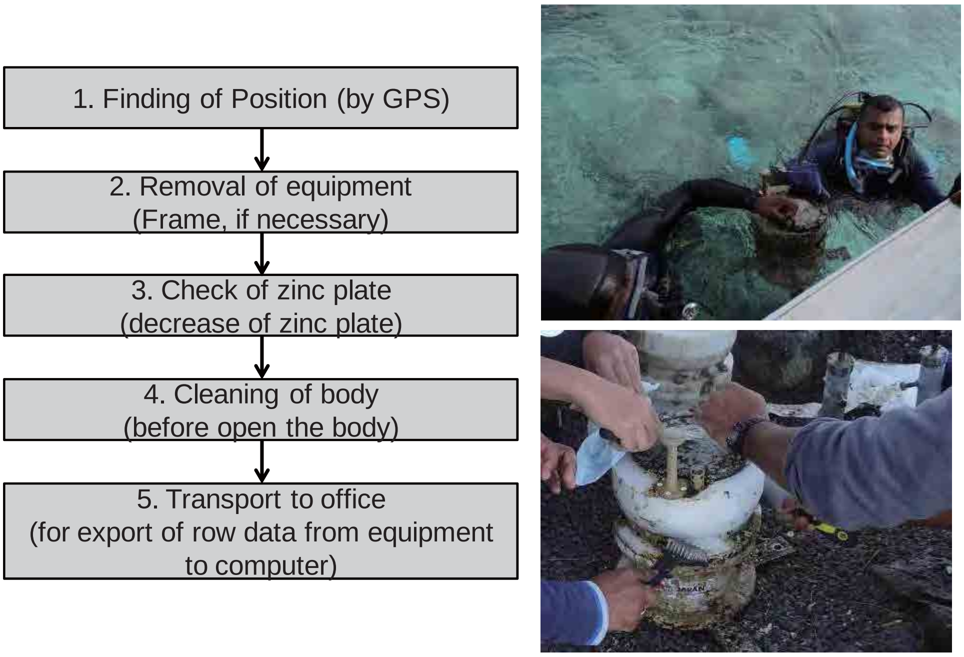
Source: JICA Expert Team

Figure 2.1.9 Step 2: Fixing of Frame

c. Removal Work

There are some notes for installation work as listed below:

- The sensor part shall be carefully handled, especially during pull up activity from the bottom to the working boat.
- Care must be taken not to damage the sensor during the cleaning work.

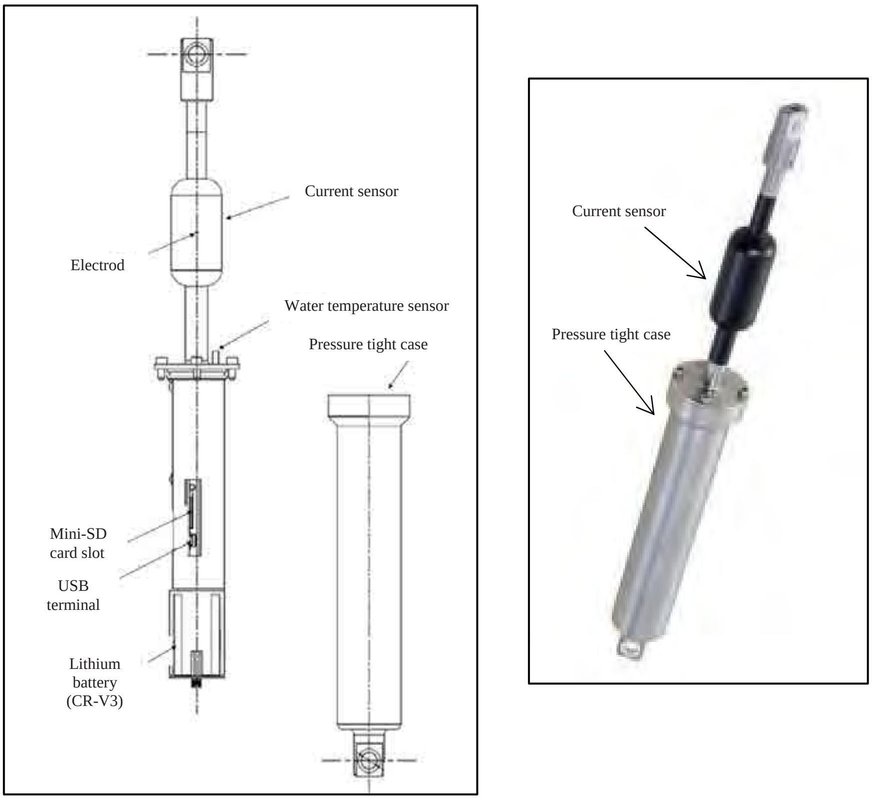


Source: JICA Expert Team

Figure 2.1.10 Removal Work Procedure

2.2 Current Measurement

The current is measured generally by a current meter to investigate the sediment movement in a sea bed. The current meter is equipped with 1) Electromagnetic current sensor and 2) Water temperature sensor as shown in the Figure below. The current meter is a bottom mounted instrument.



Source: JICA Expert Team

Figure 2.2.1 Overview of Current Meter

2.2.1 How to Use the Equipment

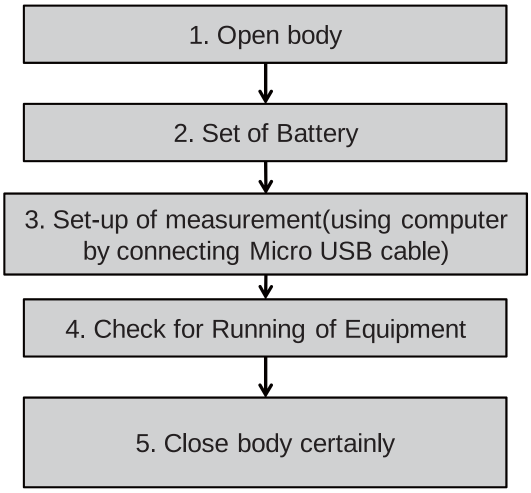
This section shows the procedure on how to use the current meter step by step.

a. Setup

There are some notes for setup work as listed below:

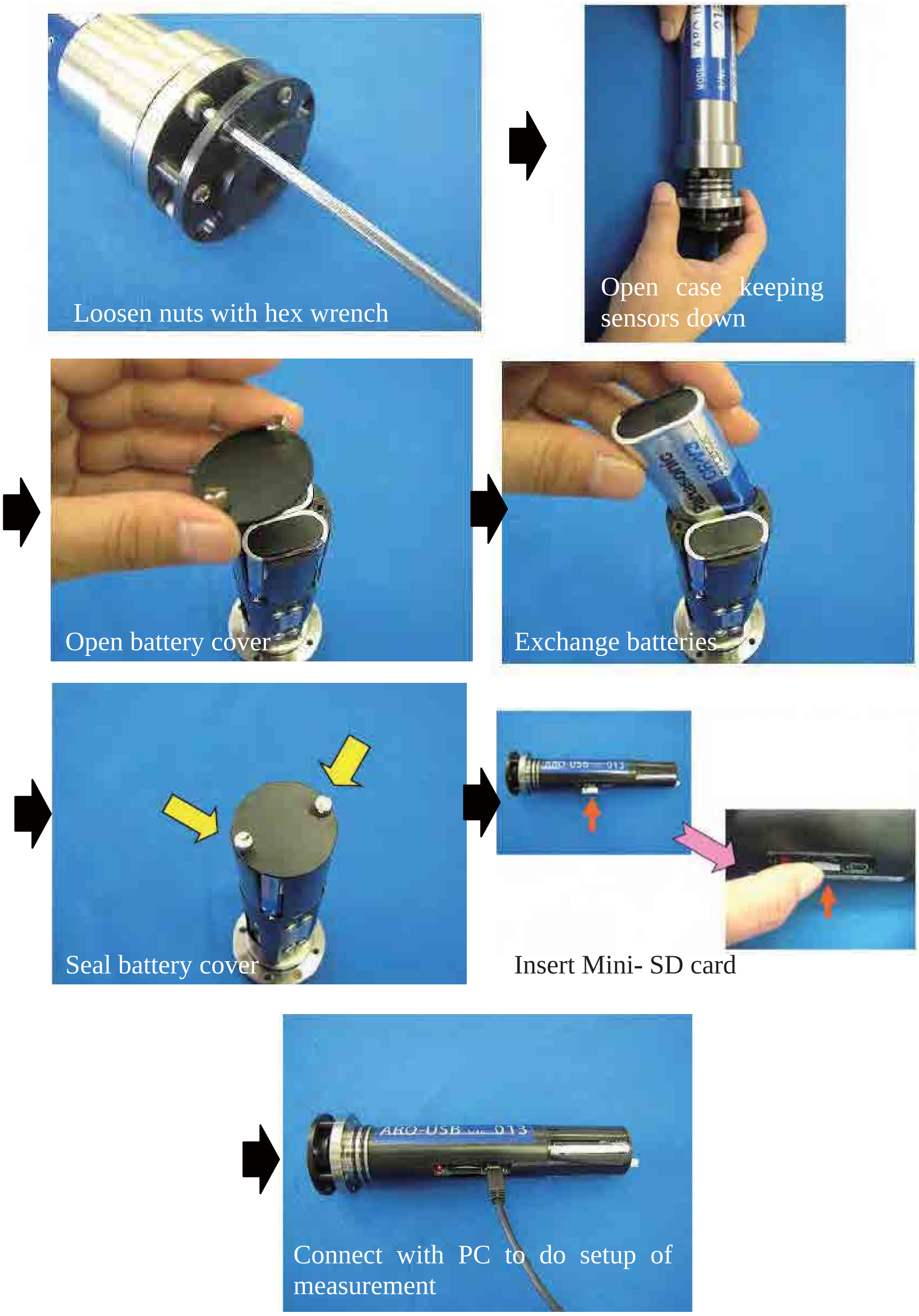
- Open the case keeping the sensor down.
- Careful setting, especially in interval times, starting times, and sampling intervals is important to avoid measurement failures (see the manual for how to set up measurement conditions)
- It is necessary to firmly fix all bolts and paste silicon to O-ring to avoid seawater leakage into the equipment
- After setting it up, it is necessary to confirm if the measurement is going well by checking the indicator lamp and buzzer.

The setup procedure is shown as follows:



Source: JICA Expert Team

Figure 2.2.2 Setup Procedure



Source: JICA Expert Team

Figure 2.2.3 Setup Procedure

2.3 Installation and Removal

There are some notes for installation work as listed below:

- The sensor portion shall be carefully handled especially during pull down and pull up between the boat and the sea bottom.
- Be careful not to cause any damage to the sensor part during cleaning work

Installation and removal procedure is shown as follows:

<Installation>

1. Determination of Position (by GPS)
2. Fixing of Flame (using peg, sandbag)
3. Installation and Fixing of Equipment
4. Record of Necessary Information for Field Condition (tide, waves during measurement interval)

<Removal>

1. Finding of Position (by GPS)
2. Removal of equipment (Frame, if necessary)
3. Cleaning of body (before open the body)
4. Transport to office (to export row data from equipment to computer)

Source: JICA Expert Team

Figure 2.3.1 Installation and Removal Procedure

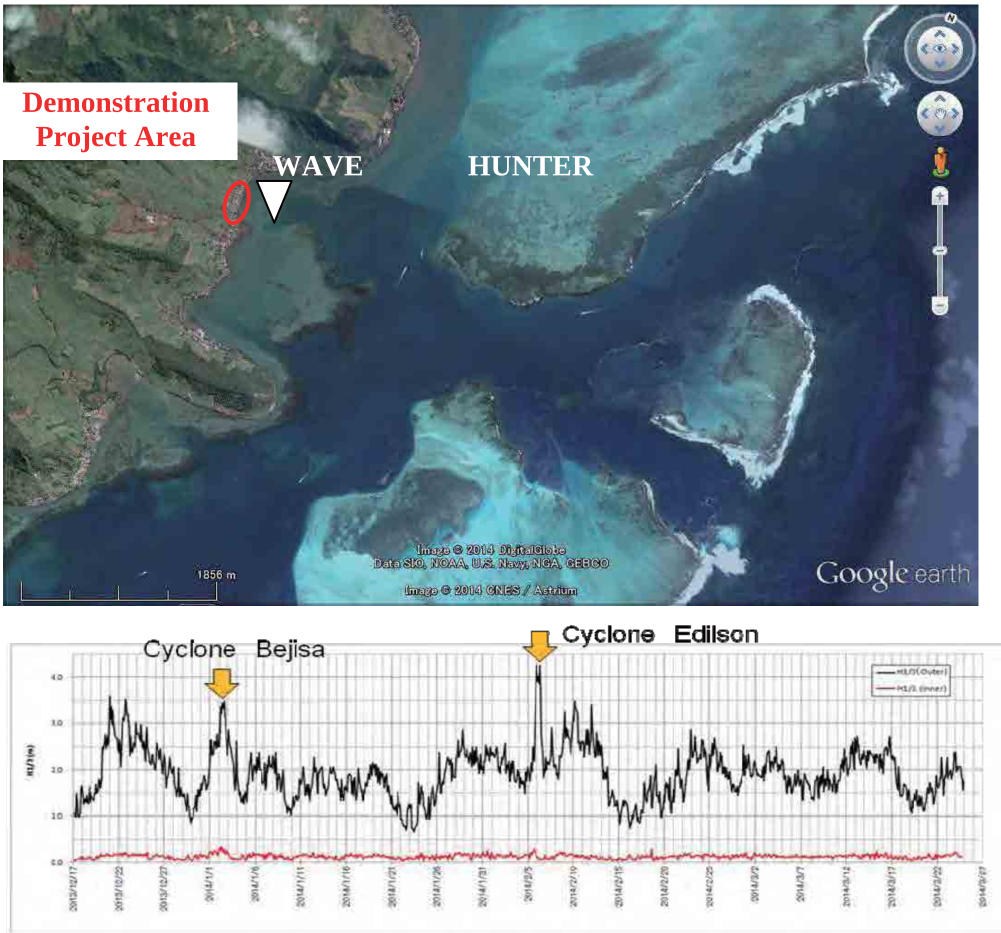
2.4 Examples of Data Analysis

This section shows some example of data analysis using data obtained by WAVEHUNTER and current meters.

2.4.1 Comparison of Wave Heights at Outer and Inner Reefs

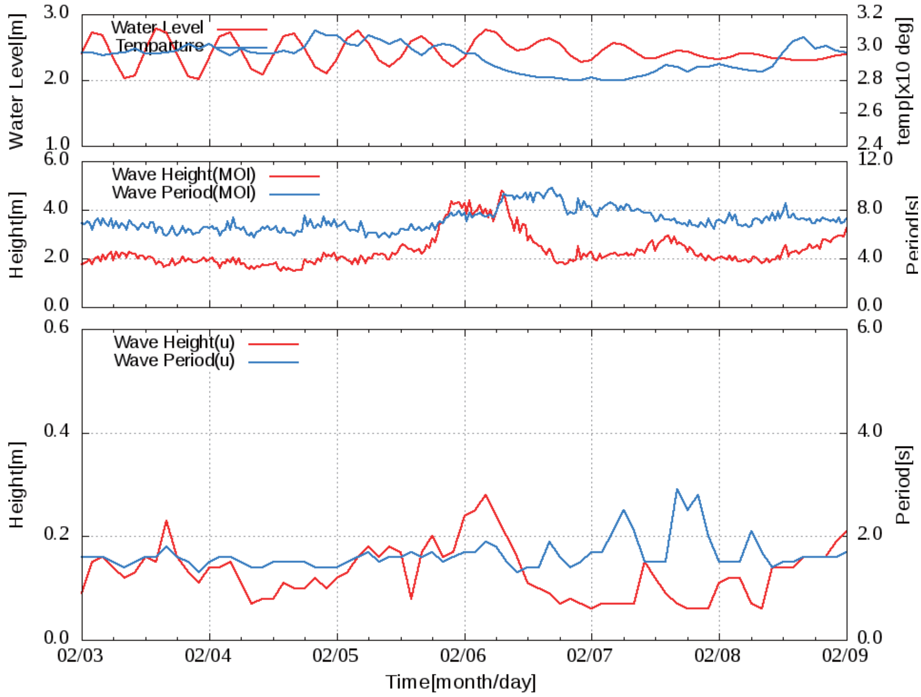
Figure 2.4.1shows the installation location of WAVE HUNTER at Grand Sable. In January and February in 2014, two cyclones (Cyclone Bejisa and Edilson) approached Mauritius and wave data during this period is shown in the figure, in which the black line shows significant wave height offshore recorded by MOI and the red line shows measures by WAVE HUNTER from inside the lagoon. Wave heights increased, ranging from 3.5m to 4.3m during these two cyclones at the outer reef. On the other hand, there was no major change for wave heights at the inner reef and the wave height maximum was 0.4m.

Figure 2.4.2 shows comparisons of wave heights and periods both at outer and inner reefs when Cyclone Edilson approached Mauritius. Waves at the inner reef increased a little when the cyclone approached and wave height was about 8% of that at the outer reef. Figure 2.4.3shows the relationship between the ratio of wave heights at the outer and inner reef, and water depth at the inner reef. From this Figure, a certain relationship between the ratio of wave height and water depth can be seen. Lack of concentrated data indicates that waves were affected by wind at the inner reef.



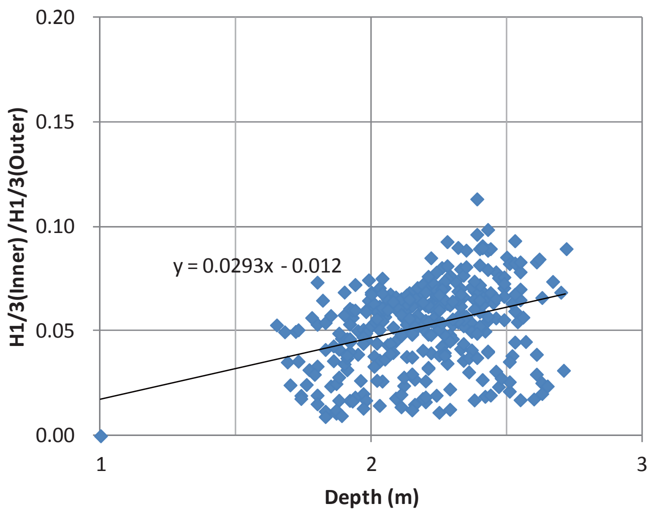
Source: JICA Expert Team

Figure 2.4.1 Wave Heights at Outer (Black Line) and Inner (Red Line) Reef at Grand Sable



Source: JICA Expert Team

Figure 2.4.2 Wave Heights at Outer and Inner Reef during the Cyclone (Edilson)

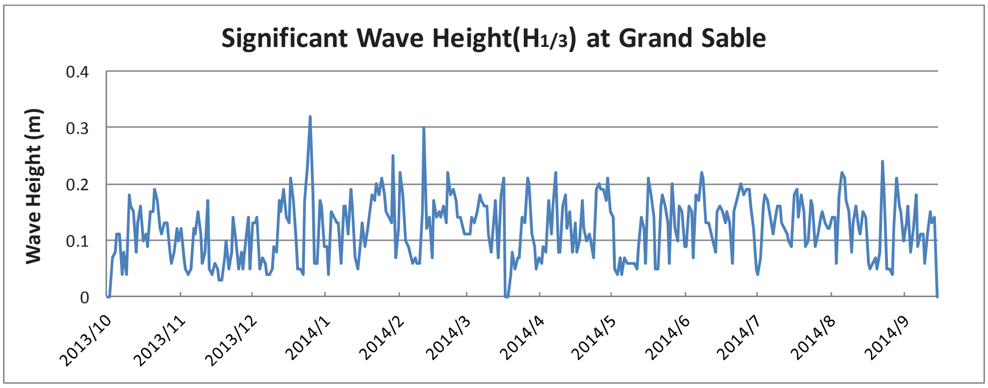


Source: JICA Expert Team

Figure 2.4.3 Relationship of Ratio of Wave Heights at Inner and Outer Reef, and Water Depth

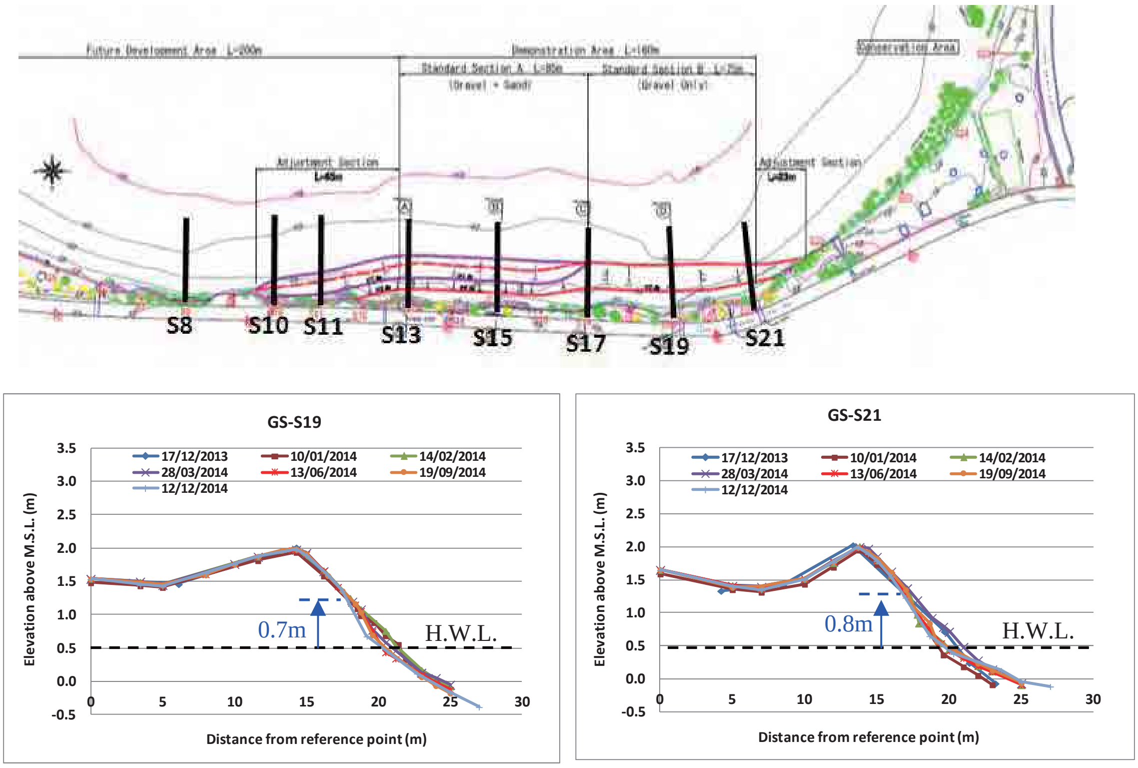
2.4.2 Comparison with Beach Profile Monitoring Data and Wave Height at Inner Reef

Figure 2.4.4 shows significant wave height at the inner reef during a one year monitoring period at Grand Sable. Maximum significant wave height during the period was less than 0.4m. Figure 2.4.5 shows results of the beach profile monitoring during the same period. From the monitoring results, the maximum height of the beach profile change can be seen around 0.7m-0.8m above H.W.L. Therefore, based on one year of monitoring data, it is estimated that the beach profile changes showed that the max. value of significant wave height nearly doubled above H.W.L. at Grand Sable.



Source: JICA Expert Team

Figure 2.4.4 Significant Wave Height ($H_{1/3}$) at Grand Sable during 1 Year



Source: JICA Expert Team

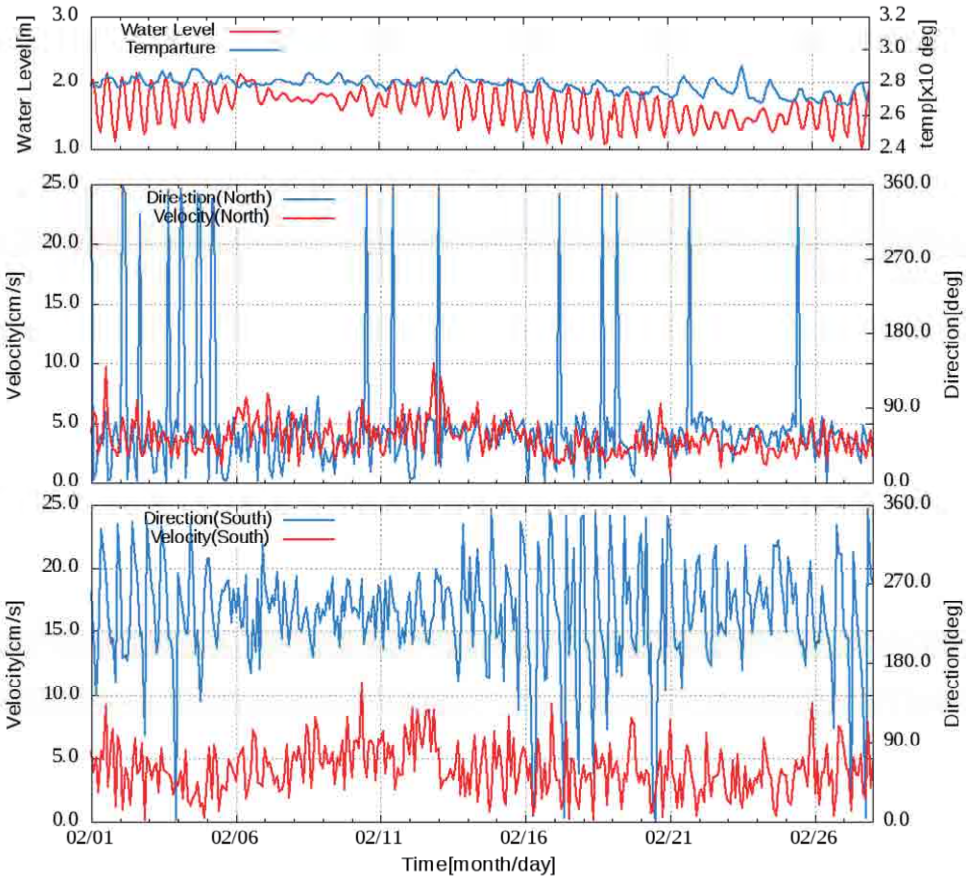
Figure 2.4.5 Beach Profile Change of Gravel Beach during 1 Year

2.4.3 Comparison of Wave Height at the Outer Reef and the Current at the Inner Reef

The current at the inner reef had been observed since February 2013 by two wave recorder stations and two current meter stations at Pointe d'Esny as shown in Figure 2.4.7. Flow velocity and flow direction (at two current meter stations) at the time of cyclone is shown in Figure 2.4.6. The result shows that no remarkable change is found on flow velocity before and after the cyclone. This means that flow velocity may not change by cyclone, but it is influenced by tide.

Vector of flow velocity in four observation points at the attack of cyclone Edilson is shown in Figure 2.4.7. The result shows that most of the velocity obtained is less than 10cm/s. The current meter in the northern part shows the current direction is facing north. It is thought that the shore current is developing at this point. While, current meter in the southern part shows current direction is mostly facing south to west. It is thought that it is not the shore current, but it is the effect caused by tide.

Finally, it is obvious that flow velocity at the lagoon is generally small and the shore current which is generated by offshore waves rarely occurs. The current occurs predominantly because of tide effects and/or wind disturbances.

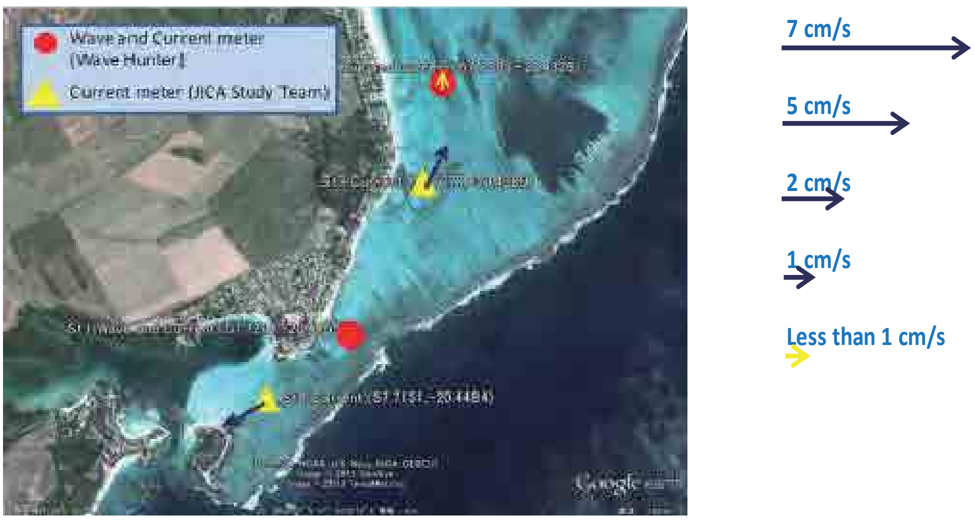


Source: JICA Expert Team

Figure 2.4.6 Flow Velocity and Direction observed at Pte. d'Esny in Feb. 2014

2014 2/5 8:00

2014 2/6 12:00



2014 2/7 12:00

Source: JICA Expert Team

Figure 2.4.7 Flow Velocity and Direction observed at Pte. d'Esny in Feb. 2014

3 Modification Analysis of Shoreline by Topographic Interpretation of Aerial Photos

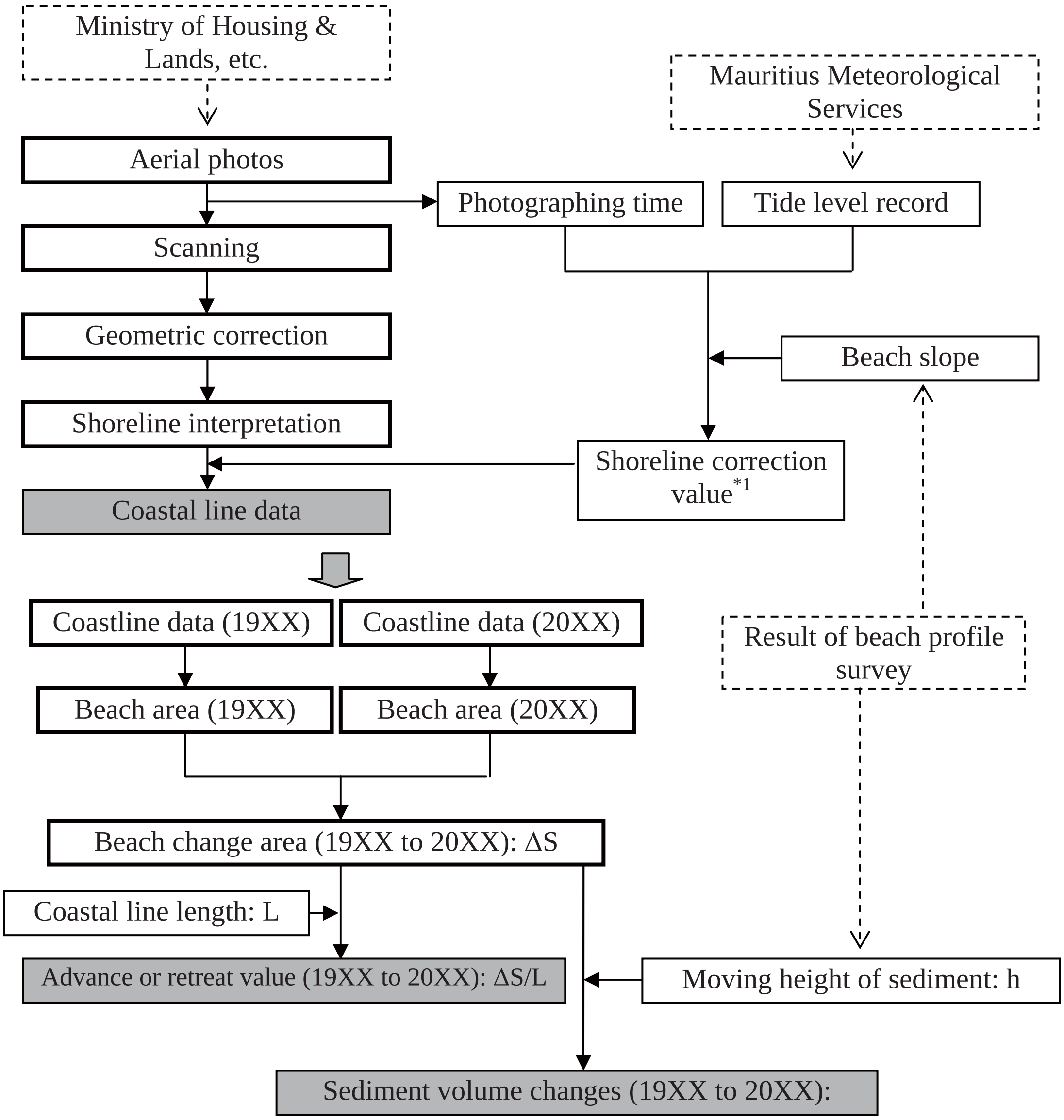
3.1 Outline

3.1.1 Objective

To understand the situation of long-term modification of shoreline

3.1.2 Work Flow

Below is the work flow for the modification analysis of shoreline by topographic interpretation of aerial photos.



*1: it is able to omit this measure, because the correcting value by tidal changes in Mauritius (maximum 0.5m) is small.

Source : JICA Expert Team

Figure 3.1.1 Work Flow of Modification Analysis of Shoreline

3.2 Collecting Aerial Photos

3.2.1 Variety of Aerial Photos

There are two varieties of aerial photos. These are photos taken from space satellites (satellite image) and photos and taken from aircraft (aerial photos). Photos taken from space satellite are relatively recent.

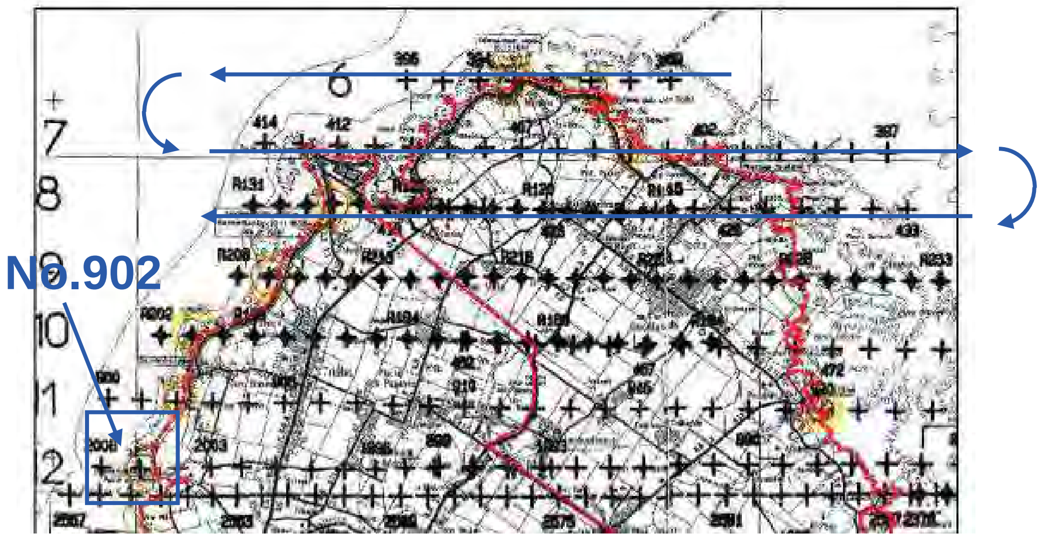
3.2.2 Photographing from Aircraft and Index Map

For photographing from aircraft, firstly choose a subject area and work on an aerial photography plan that incorporates overlapping photos (traveling direction: standard overlap is over 60%, course interval direction: standard overlap is over 30%) and photography scale with number of photographed pictures and photo course along with the area. After making a flight plan for aerial photography and index map (refer to Figure 3.2.2), photographing is initiated after the proposal is approved followed by preparing the supplies and other preparations.

Generally, index maps are archived with aerial photos. Firstly, collect index maps and take notes of the serial numbers of photos that will be analyzed.

Source : The Geographical Survey Institute website

Figure 3.2.1 Photographing from an Aircraft



Source : Arranged by JICA Expert Team based on data of Ministry of Housing and Lands in Mauritius

Figure 3.2.2 Example of the Index Map

3.2.3 Examination of Scale and Photography Date

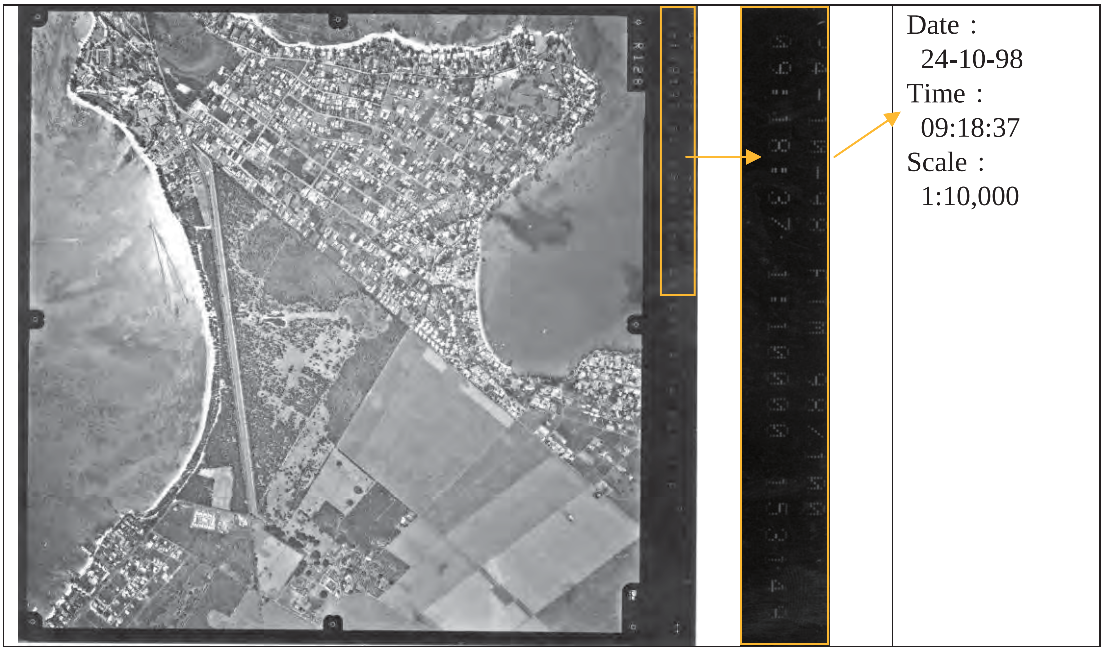
a. Scale (photographing altitude)

It is necessary to take into consideration that it might be difficult to read shorelines because of the scale (photographing altitude) and issues of the brightness of photos taken from aircraft in the distant past. Therefore, it is preferable to select aerial photos with higher resolution, approximately 1/10,000 scale.

b. Photographing Date and Time

It is necessary to correct the shoreline location based on tide level data in the photographing time because it changes by the tidal variation. Therefore, even though aerial photos should be able to analyze long-term changes of shoreline, it is necessary to know the photographing time in a day.

However, with Mauritius, tidal changes are less than about 50cm. Therefore, concerning the accuracy of interpreting shorelines, the tidal changes can be disregarded.



Source : Arranged by JICA Expert Team based on data of Ministry of Housing and Lands in Mauritius

Figure 3.2.3 Aerial Photo

3.2.4 Scanning

Analogue printed aerial photos have to be digitalized by scanner. A resolution of more than 600 dpi is desirable. Moreover, a scan of the date and time in a blank space should be included.

3.3 Geometric Correction

3.3.1 Objective of Geometric Correction

Digitalized aerial photos don't yet have geometric coordinates. To make exact comparisons of photos between different periods, it should be geometrically corrected to exactly overlap with the reference data and given coordinates by GIS software.

3.3.2 Reference Data

The satellite image in 2008 (Ortho-image, available at Ministry of Housing & Lands) shall be used as reference data. This is converted in an image without distortion and gives information on the exact location.

3.3.3 Correcting Method

Image data needs to be selected with the correcting method (transformation method) under the photographic condition. The following are the correcting methods provided in GIS software.

(1) Affine Transformation

(2) Adjust Transformation

(3) Spline Transformation

(4) Projective transformation

Which method should be used depends on the photographing altitude of aerial photos. Affine transformation is used for aerial photos taken in low altitude. On the other hand, projective transformation is used for photographing in high altitudes or by Google satellite image.

3.3.4 Number of Reference Marks

A reference satellite image from 2008 was prepared in rectangular coordinates. Therefore, theoretically, a minimum of 4 points is enough to give coordinates and a reasonably accurate image. However, it is desirable to equally add more points along the shoreline in order to prepare the image with highly accurate data.

(1)Geometric correcting aerial photo (2) Reference data (satellite image)

Source : Arranged by JICA Expert Team based on data of Ministry of Housing and Lands in Mauritius

Figure 3.3.1 Reference Locations

3.3.5 Reference Location

A reference location should be selected from the closest surface of the Earth. It should be a road or coastal shore. White lines on roads are particularly useful since they stand out (+ mark in map below). Buildings are not suitable because their photos tend to be shown diagonally.

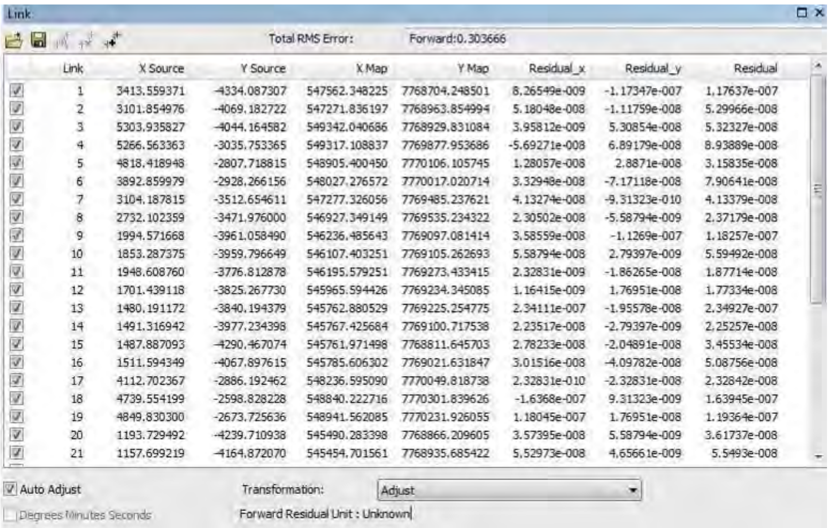
(1) Geometric collection aerial photograph (2) Reference data (satellite image)

Source : Arranged by JICA Expert Team based on data of Ministry of Housing and Lands in Mauritius

Figure 3.3.2 Reference Locations

3.3.6 Validation of Geometric Correction

It is necessary to verify that the location is converted exactly on the geometrically corrected image. It can be compared between the images which are given coordinates and the reference image. Overlapping the two images using the overlay function of the software. Also it should be confirmed that the selected location, road or coastal structures are correctly overlapped. Moreover, ArcGIS can show a data error chart (called Link Table, refer to Figure 3.3.3) to validate the accuracy of geometric corrections and given coordinates. Locations with large errors should be arranged as exactly as possible by insertion or deletion of reference points.



Link

Total RMS Error: Forward:0.303666

Link	X Source	Y Source	X Map	Y Map	Residual_x	Residual_y	Residual
1	3413.559371	-4334.087307	547562.348225	7768704.248501	8.26549e-009	-1.17347e-007	1.17637e-007
2	3101.854976	-4069.182722	547271.836197	7768963.854994	5.18048e-008	-1.11759e-008	5.29966e-008
3	5303.935827	-4044.164582	549342.040686	7768929.831084	3.95812e-009	5.30854e-008	5.32327e-008
4	5266.563363	-3035.753365	549317.108837	7769877.953686	-5.69271e-008	6.89179e-008	8.93889e-008
5	4818.418948	-2807.718815	548905.400450	7770106.105745	1.28057e-008	2.8871e-008	3.15835e-008
6	3892.859979	-2928.266156	548027.276572	7770017.020714	3.32948e-008	-7.17118e-008	7.90641e-008
7	3104.187815	-3512.654611	547277.326056	7769485.237621	4.13274e-008	-9.31323e-010	4.13379e-008
8	2732.102359	-3471.976000	546927.349149	7769535.234322	2.30502e-008	-5.58794e-009	2.37179e-008
9	1994.571668	-3961.058490	546236.485643	7769097.081414	3.58559e-008	-1.1269e-007	1.18257e-007
10	1853.287375	-3959.796649	546107.403251	7769105.262693	5.58794e-008	2.79397e-009	5.59492e-008
11	1948.608760	-3776.812878	546195.579251	7769273.433415	2.32831e-009	-1.86265e-008	1.87714e-008
12	1701.439118	-3825.267730	545965.594426	7769234.345085	1.16415e-009	1.76951e-008	1.77334e-008
13	1480.191172	-3840.194379	545762.880529	7769225.254775	2.34111e-007	-1.95578e-008	2.34927e-007
14	1491.316942	-3977.234398	545767.425684	7769100.717538	2.23517e-008	-2.79397e-009	2.25257e-008
15	1487.887093	-4290.467074	545761.971498	7768811.645703	2.78233e-008	-2.04891e-008	3.45534e-008
16	1511.594349	-4067.897615	545785.606302	7769021.631847	3.01516e-008	-4.09782e-008	5.08756e-008
17	4112.702367	-2886.192462	548236.595090	7770049.818738	2.32831e-010	-2.32831e-008	2.32842e-008
18	4739.554199	-2598.828228	548840.222716	7770301.839626	-1.6368e-007	9.31323e-009	1.63945e-007
19	4849.830300	-2673.725636	548941.562085	7770231.926055	1.18045e-007	1.76951e-008	1.19364e-007
20	1193.729492	-4239.710938	545490.283398	7768866.209605	3.57395e-008	5.58794e-009	3.61737e-008
21	1157.699219	-4164.872070	545454.701561	7768935.685422	5.52973e-008	4.65661e-009	5.5493e-008

Auto Adjust Transformation: Adjust
Degrees Minutes Seconds Forward Residual Unit : Unknown

Source : Arranged by JICA Expert team

Figure 3.3.3 An Example of ArcGIS Link Table

3.4 Shoreline Interpretation

3.4.1 Software

In order to make shoreline data, GIS software is used. For GIS software, ArcGIS and QGIS (free software) are typically used.

3.4.2 How to Interpret Shorelines

a. Importing Raster Data

Import the geometrically corrected aerial photos into GIS software.

b. Interpreting Shorelines

Make a new shapefile, interpret the shoreline on the aerial photo and make data by drawing the shoreline using a mouse.

Source : Arranged by JICA Expert Team based on data of Ministry of Housing and Lands in Mauritius

Figure 3.4.1 Shoreline Interpreting Example (red line)

3.5 Analysis

3.5.1 Examination of Analyzing Condition

a. Tidal Level Correction

Correct interpreted shoreline location on the basis of the average tide level (refer to 3.5.2).

For instance, assuming the average tidal level is CDL+0.3m and the tidal level of the photographing time is CDL+0.8m. And if the beach slope (tanθ) is 1/10[*1], the shoreline location can be corrected to offshore as (0.8-0.3)*10 = 5m. Conversely, if the tidal level is lower than the average, for example, CDL+0.1m, the shoreline location should be corrected to onshore as (0.3-0.1)*10=2m.

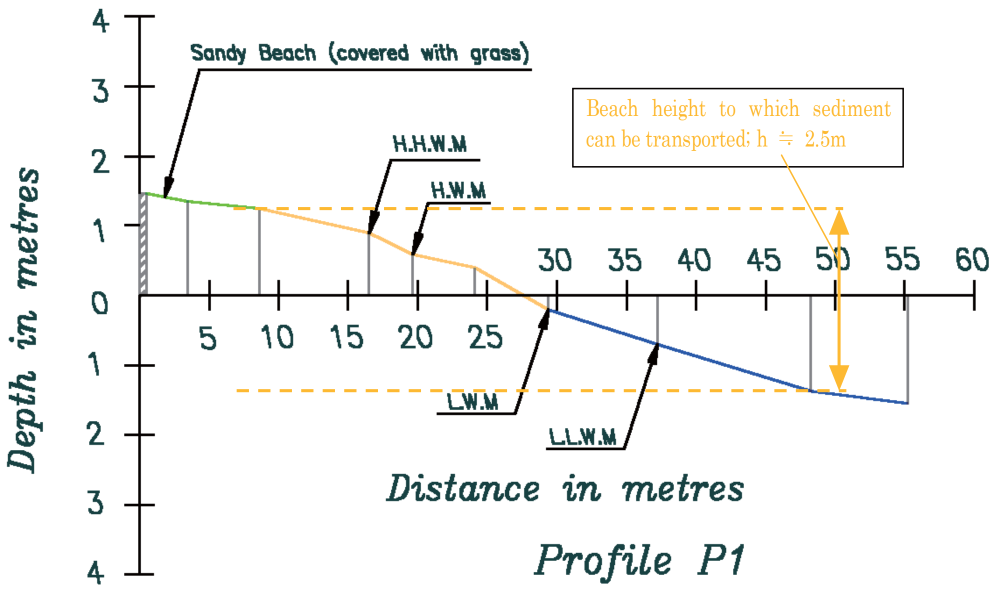
However, this measure can be omitted, because the interpreting error by photo resolution and correcting value by tidal changes in Mauritius (maximum 0.5m) are almost equal.

*1: In advance, examining the average beach slope is necessary for analyzing area by results of the beach survey and so on.

b. Moving Height of Sediment

In order to estimate sediment budget changes, it is necessary to set the moving height of sediment in a vertical direction. The moving height of sediment is basically the vertical distance from the critical depth for sediment moving to the wave run-up height.

Practically, the height can be estimated based on the beach profile survey. Figure 3.5.1 shows the result of the beach profile survey in Pointe d'Esny. The moving height of sediment is estimated at about 2.5m based on the figure.



Source: This figure was arranged by JICA Expert Team based on "W.F. BAIRD & ASSOCIATES COASTAL ENGINEERS LTD. (2003), Study on Coastal Erosion in Mauritius"

Figure 3.5.1 Beach Profile at Pointe d'Esny (Baird, 2003)

c. Regions subject to Analysis

Each Sediment Cell has to be divided into some analyzing blocks (Sub Cells) with separating points for the rocky point, river mouth, jetty, and other inflection points of shoreline changes. And, the length of each Sub Cell (***L***) has to be examined for analysis.

Figure 3.5.2 shows an example of a region subject to analysis (around Pointe aux Sables in the west of Mauritius Island).

Source: JICA Expert Team

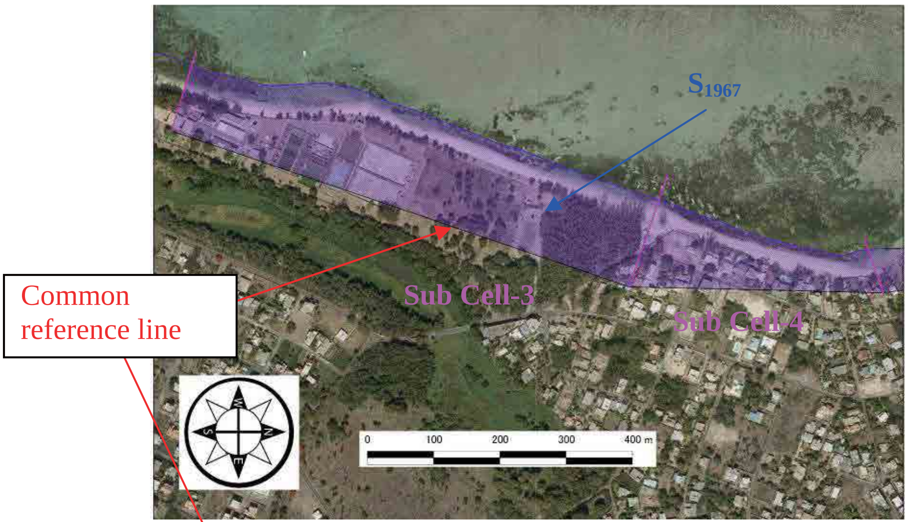
Figure 3.5.2 An Example of Region Subject to Analysis (Pointe aux Sables)

3.5.2 Beach Area

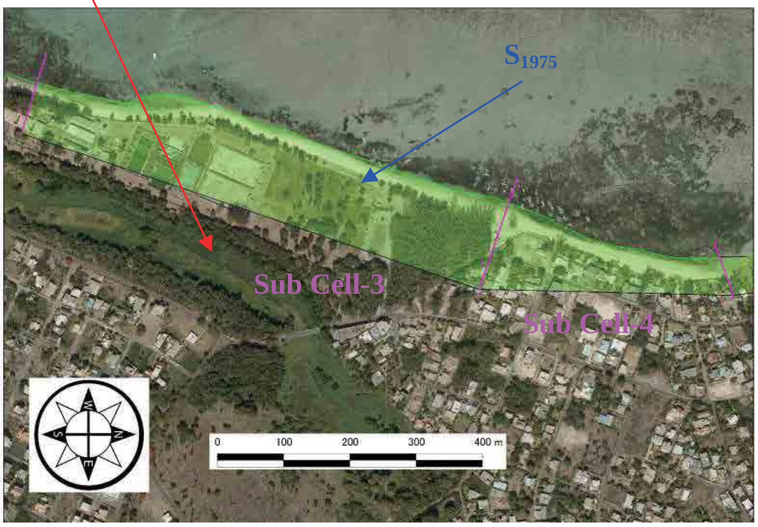
The area (***S***) between the shoreline on each date and the fixed common baseline on the land side was measured (refer to Figure 3.5.3). In cases of necessary tidal correction, the beach area was corrected as below.

$$S + L * dT/\tan\theta \quad \text{or} \quad S - L * dT/\tan\theta$$

Where, ***dT*** is the tidal level correction and **tan*θ*** is the beach slope.



Source : Arranged by JICA Expert Team based on data of Ministry of Housing and Lands in Mauritius



Source : Arranged by JICA Expert Team based on data of Ministry of Housing and Lands in Mauritius

Figure 3.5.3 Shoreline at Albion in 1967 (upper) and Shoreline at Albion in 1975 (lower)
(Background is reference image in 2008.)

3.5.3 Spatial Averages of Shoreline Changes

The spatial average on each analyzing block was analyzed with the advancing and retreating of the shoreline.

To calculate the advance or retreat of the shoreline, the change in areas (***dS***, $dS=S_{1975}-S_{1967}$ in Figure 3.5.3) can be divided by the shoreline length (***L***).

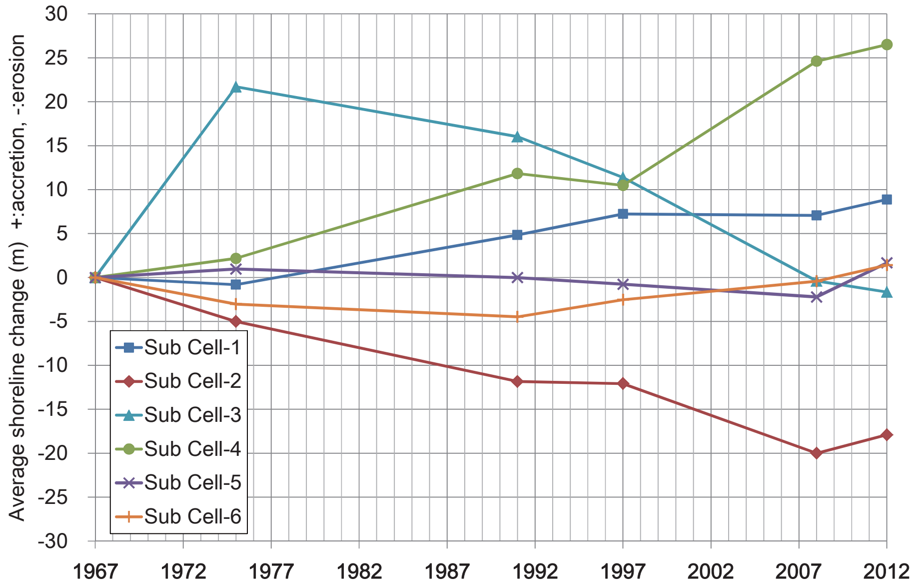
3.5.4 Changes in Volume (Sediment Budget)

Volume of sediment transport (***dV***) is calculated multiplying the changes in coastal areas (***dS***) by the moving height of sediment (***h***).

3.5.5 Organization of Results

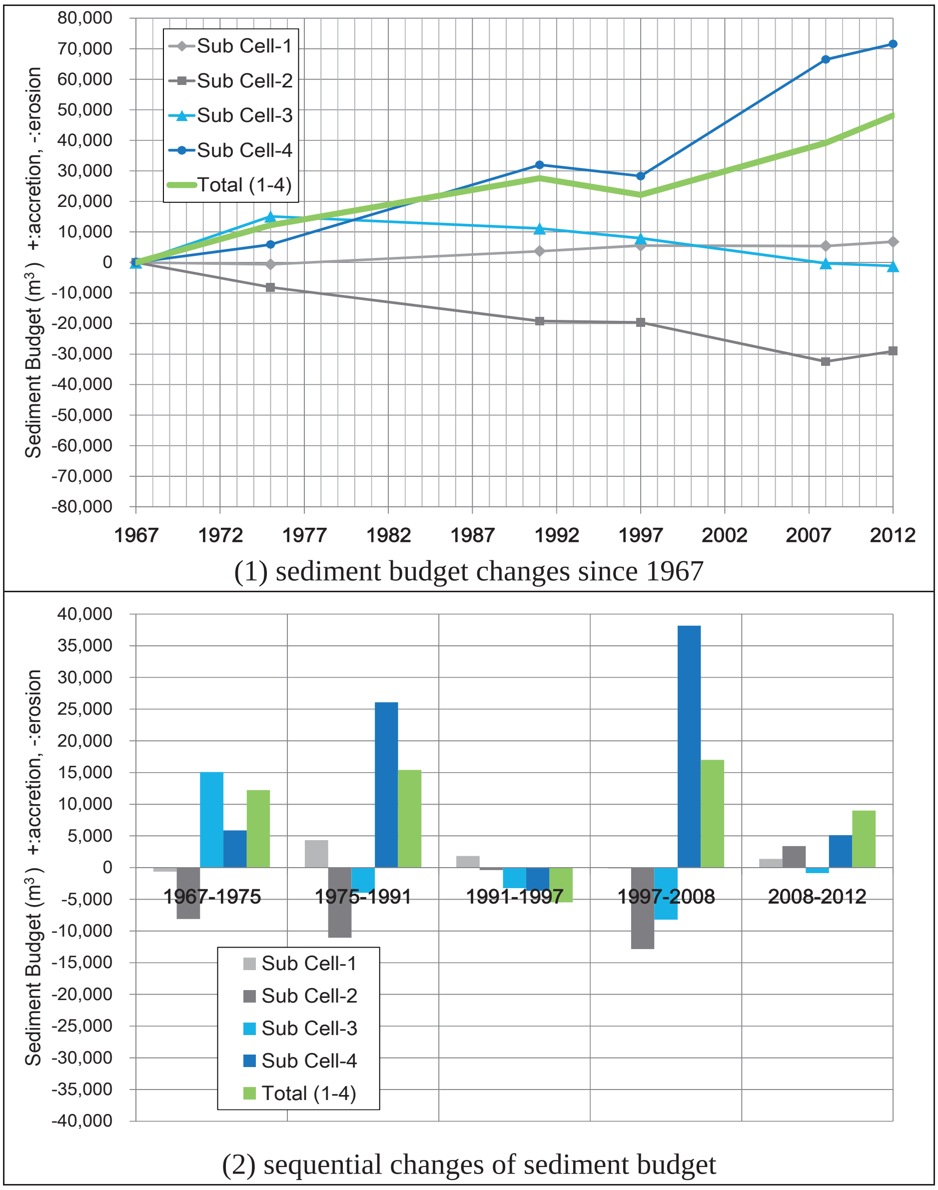
In order to grasp the long-term modification of the shoreline, each shoreline change and coastal volume change has to be plotted and compared.

Figure 3.5.4 is an example of the results of analysis of spatial averages for shoreline changes since 1967 in six sections around Point aux Sables. And, Figure 3.5.5 shows the result of the coastal sediment budget in that coast.



Source: JICA Expert Team

Figure 3.5.4 An Example of the Results of Spatial Averages of Shoreline Changes (around Pointe aux Sables, refer to Figure 3.5.2)



Source : JICA Expert Team

Figure 3.5.5 Coastal Sediment Budget in Pointe aux Sables (refer to Figure 3.5.2)

Chapter III

Reef Environment Conservation Guideline

III. Reef Environment Conservation Guideline

1 Objective and Summary of the Guideline

As described in Vol. I *6.4 Reef Environment Conservation Plan*, the main points of the plan are as follows:

1. Monitoring surveys for understanding the present conditions of reef environment
2. Control of human activities for protecting coral reef and seagrass bed, and for protecting water quality
3. Coral plantation and multiplication for reef generation/ increase in seagrass bed

Only a summary of the methods of implementing the plan is described in Vol. I 6.4. In this "Reef Environment Guideline", we suggest in detail on the monitoring methods and coral-plantation methods for regeneration of coral reefs.

Regarding the monitoring method for coral reefs, we suggest "Spot-check method" which is very simple and adequate for monitoring wide area. With respect to the water quality analysis, we suggest an adequate method for mitigating the eutrophication problems appeared in the lagoons of Mauritius. Also, with regard to regeneration of coral reefs, we introduce the simple direct-transplantation method using asexual reproduction.

On the other hand, long-term monitoring survey using line-transect method has been carried out at 12 sites from 1998 by AFRC and MOF. From those results the degradation of coral became clear. Each method has it characteristics and has to choose by the purpose of the survey. The newly proposed "Spot-check method" is for analyzing the relationship among corals coverage, mortality factors and recruitment. It will be carried out at the 13 existing CCP or the newly added CCP sites. If necessary it is recommended to make the guideline for the line-transect method by AFRC and MOF because they have enough experiences.

2 Spot-check Method

2.1 Outline

The spot-check method introduced here is a part modification of the spot-check method Ver.4 (2009) adopted by Ministry of the Environment, Japan, "Monitoring Site 1000" project, for Mauritius (no English website).

The spot-check method is a monitoring method for coral reef by which an observer directly observes bottom conditions in a 15-minute observation using a snorkel. The merits of this method are as follows:

1) Carried out by a few observers (3 people),

2) Less labor (observation time is only 15 minutes, data processing such as coral coverage is simple),

3) Special ability is not needed (no need for SCUBA license or specific knowledge on coral taxonomy),

4) Wide observation area (ca. 50 m x 50 m = 2,500 m^2) and the capacity to collect various

information (can collect various information not only from corals but also from coral reefs).

While, the demerit of this method is as follows: the observation is subjectively carried out by the direct visual census, so the accuracy of this method is lower than other objective methods such as LIT. Despite the fact this method has merits and demerits, it seems to be an adequate method for observing a wide area of coral reefs because it is very simple and it is possible to obtain a variety of information.

2.2 Objective and Method of Survey

Main objective of the spot-check method (SC method) is to measure the coverage of living corals (percentage of the area covered by living corals to the bottom area observed). Simultaneously, the observer records on mortality factors such as coral bleaching events, *Acanthaster planci*, predacious gastropods, broken colonies by typhoon or divers, and coral disease.

2.3 Area of Survey

SC method is fundamentally a visual census of coral coverage using snorkeling for 15 minutes. Empirically, 15 minutes swimming covers an area of 50 m x 50 m, namely ca. 2,500 m^2.

2.4 Frequency of Survey

It is desirable that the monitoring by SC method carried out once a year in early autumn. The coral bleaching among items of monitoring survey is observed in summer when seawater temperature is highest, and its serious effect appears in autumn. While, predation activities by *A. planci* and coral eating snails are high also in summer. According to the survey items, it is desirable that the monitoring survey will be carried out in late summer when the seawater temperature is still high.

2.5 Monitoring Survey

2.5.1 Location of Monitoring Sites

It is desirable that the monitoring survey is carried out at the location of the 13 selected coasts as shown in Table 2.5.1. If the site is seagrass bed, the observer needs to change the monitoring site to an area covered by living corals. Therefore, it is important that the observer makes sure the exact latitude and longitude using satellite photos before starting observation.

Table 2.5.1 Latitude and Longitude of Selected Monitoring Sites on Corals and Seagrass

No.*	Name of Beach	Latitude	Longitude	Remarks
	Baie du Tombeau	20° 06' 31.46"S	57° 30' 35.68"E	
14	Mon Choisy	20° 00' 57.18"S	57° 33' 22.19"E	Seagrass bed
15	Pointe aux Cannoniers	20° 00' 07.75"S	57° 24' 10.09"E	
35	Bras d'Eau	20° 08' 32.89"S	57° 44' 49.63"E.	Seagrass bed
44	Q. Cocos	20° 14' 03.50"S	57° 48' 22.68"E	
	Ile aux Cerfs (Rock reef)	20° 15' 50.18"S	57° 48' 25.89"E	Rock reef
	Pte. d'Esny (Back reef)	20° 26' 47.81"S	57° 43' 13.90"E	
70	Bel Ombre	20° 30' 22.55"S	57° 24' 05.05"E	Seagrass bed
75	P. G. Le Morne (near Berjaya Hotel)	20° 27' 01.46"S	57° 18' 29.77"E	
82	Flic en Flac	20° 16' 41.98"S	57° 21' 54.05"E	
84	P. G. Albion (Back reef)	20° 12' 44.44"S	57° 24' 00.39"E	
89	Pointe aux Sables (near Fisheies Post)	20° 09' 42.63"S	57° 28' 01.89"E	
48	Grand Sable	20° 19' 13.35"S	57° 46' 18.02"E	

* No. is followed by the declared public beaches of Mauritius.

Source: JICA Expert Team

The object corals of SC survey are normally the coral communities in the lagoon, but if SC survey is needed to be carried out at back reef and fore reef in the future, extra-surveys will be added at both reefs. If the functional role of seagrass bed in the lagoon needs to be analysed, the monitoring survey using SC method must be carried out also in the seagrass bed.

During the monitoring survey, if possible, the observers are to use a boat and record the exact location using GPS. If there is no boat, the observers enter to the monitoring site from the nearest beach and record the location of entry beach using GPS. After the monitoring survey, the exact location of monitoring is to be determined using the location of entry beach and using Google Earth.

If necessary, new sites are added to the 13 beaches shown in Table 2.5.1.

2.5.2 At the Monitoring Site

Table 2.5.2 Check Sheet for Recording Monitoring Results by SC Method

Check sheet of monitoring by the spot check method

Area : Year : Observer :

Study stes				Date ad Time	Method	Corals					*Acanthaster panci*			Snails		Fish mer 30 c
No.	Name o ara latitude, longitude	Types of Bottom	Depth o observation			Coverage	% o Bleaching (% dad)	Growth form	Juvenile of *Acropora*	Tabular type *Acropora*	No. fr 15 minutes	Size o mode	Feeding rate	Feeding rank	Rank	
	①	②	③	④	⑤	⑥	Total ( ) *Acropora* ( )	⑨	⑩	⑪	⑫	<20 20–30 30< cm	⑬	1:NO 2:little 3:medeam 4:large	⑭	⑮
Remarks		⑯														
Study stes				Date ad Time	Method	Corals					*Acanthaster panci*			Snails		Fish mer 30 c
No.	Name o ara latitude, longitude	Types of Bottom	Depth o observation			Coverage	% o Bleaching (% dad)	Growth form	Juvenile of *Acropora*	Tabular type *Acropora*	No. fr 15 minutes	Size o mode	Feeding rate	Feeding rank	Rank	
							Total (*Acropora* (					<20 20–30 30< cm		1:NO 2:little 3:medeam 4:large		

Source: JICA Expert Team

The SC method is very simple and the observer only has to record various items on an underwater check sheet (Table 2.5.2) (English manual of the SC method has already been given to the counterparts as an electronic file).

Before starting observation, the observer writes the name of sea area (lagoon name in the case of Mauritius), year of survey and the name of observer at the upper part of check sheet (Table 2.5.2). Then, the observer records the name of monitoring site in the space ①, and also records the latitude and longitude measured by GPS.

The following items are recorded during observation. In space ② is written bottom conditions such as coral reef (fore reef, back reef, shore reef), rock reef, sand and sand-mud. Space ③ is depth of the exact observing site (3 m, 2 – 5 m). Space ④ is for date of the survey, and space ⑤ is recorded by snorkel or SCUBA (if used by the observer). Space ⑥ is the most important space. The observer records coverage (%) of living corals.

Space ⑦ and space ⑧ are the items related to coral bleaching. Percentage of dead corals after coral bleaching event and percentage of dead *Acropora* are recorded respectively. Space ⑨ is recorded dominant life form such as tabular type, branching type, massive type and corymbose type. The density of juvenile corals (normally juvenile *Acropora* less than 5 cm in diameter) in the space ⑩. If possible, 10 quadrats of 1 m x 1 m are set for this survey. Space ⑪ must be filled the diameter of tabular corals, normally top 5 colonies (*Acropora cytherea* is the most dominant tabular coral in Mauritius). Number of *Acanthaster planci* or crown-of-thorns starfish (hereinafter COTS) observed within the 15 minutes is recorded in space ⑫. *A. planci*, COTS is nocturnal by nature, so during the day it mostly hides under the coral colonies. We need a kind of technique (experience) to find them in daytime. The space beside ⑫ is for recording the number of individuals in the categories of diameter, < 20 cm, 20 cm << 30 cm, 30 cm <. The percentage of corals preyed on by COTS recently (i.e. area of white skeleton to the area of living corals) is recorded in space ⑬. The colonies predated by COTS look like the colonies infested by white syndrome, so the observer needs attention to the difference from the colonies infested by white syndrome. Space ⑭ is filled as percentage of predation by coral eating gastropods (*Drupella cornus*). Fish larger than 30 cm in standard length must be recorded in the space ⑮. In the remarks section (⑯) will be recorded the presence of seagrass or macro-algae, coral disease, damages of coral by cyclone or heavy storms, also including damage by divers. Also, the siltation shown in 4.3.a and

Figure 4.3.1 must be recorded in this space.

After mastering the SC method, it is desirable that the following table (Table 2.5.3) is added in the space of remarks and the coverage of corals, soft-corals and macro-algae are recorded each five minutes (15 minutes in total).

Table 2.5.3 Additional Table for the Coverage of Corals, Soft Corals and Macro-Algae

	5 minutes	5 minutes	5minutes
Coverage of corals (%)			
Coverage of soft corals (%)			
Coverage of macro-algae (%)			

Source: JICA Expert Team

3 Data analysis

3.1 Coverage of Living Coral

The most important index obtained by this monitoring method is the coverage of living corals. The health condition of coral reef is evaluated by this coverage of living corals. The newest standard of evaluation is as follows (Table 3.1.1) :

The value obtained by the baseline survey (**Vol.1, 2.6.2 a.2**) for example, was 27.2% on average, so the present condition of coral reefs in Mauritius are evaluated as “poor”.

As mentioned above, the results of each observer are sometimes different because of their experience and swimming course. So, it is important to use the average value of the results obtained by each observer.

Table 3.1.1 Evaluation on the Health of Coral Reef by the Ranks of Living Coral Coverage

Coverage of living corals (%)	Evaluation
0% to under 10 %	Very poor
10 % to under 30 %	Poor
30 % to under 50 %	Fair
%0 % to under 80 %	Good
Over 80 %	Excellent

Source: The Ministry of Environment, Japan

3.2 Coral Bleaching, Crown-of-thorns Starfish, Coral Eating Gastropods

These items are mortality factors of living corals. If coverage of living corals decreases in a year, these are important items for analyzing its cause.

Source: JICA Expert Team

Photo 3.2.1 Crown-of-thorns Starfish

Source: JICA Expert Team

Photo 3.2.2 Coral Eating Gastropods

Coral bleaching events seems to be increasing as a result of global warming. In Mauritius, coral bleaching occurs when a seawater temperature over 27 degrees Celsius continues for a few weeks. Consequently, zooxanthellae leave the tissue of coral polyps, meaning the white-colored coral skeleton, $CaCO_3$, can be seen directly through the transparent coral polyps. The coral does not die at this stage. But, this condition continues a few more weeks, when eventually the coral dies because its source of nutrition, from zooxanthellae, is stopped. The coral bleaching event is closely related to the seawater temperature; therefore we need to measure the seawater temperature.

Photo 3.2.1 and Photo 3.2.2 shows the crown-of-thorns starfish (COTS = *Acanthaster planci*) and coral eating gastropod (*Drupella cornus*). The white parts are where the coral has already been eaten. The feeding scar by COTS is larger than by *Drupella*, and *Durpella* cannot feed on the inside of the coral colony. *Durpella* has a habit to be assembled as shown in Photo 3.2.2. Feeding scars by COTS are sometimes confused with coral bleaching, especially in the case that COTS is not observed around the white coral colony. In such cases, the seawater temperature is an indicator of judgement.

Table 3.2.1 Evaluation Standard on the Outbreak of COTS

Number of COTS per 15 minutes	Rank on outbreak
0 –1	Normal
2 –4	Warning
5 - 9	Semi-outbreak
Over 10	Outbreak

Source: The Ministry of Environment, Japan

Table 3.2.1 shows the evaluation standard on the outbreak of COTS. If we observe 2 or more COTS within the 15-minute monitoring survey, we need to take measures against the outbreak quickly. Crown-of-thorns starfish usually spawn in early summer, so it is important that we carry out the measures to exterminate them before their period of reproduction.

3.3 Cyclone and Human Impact

There is no specific space for this item in the check sheet shown in Table 2.5.2. When a cyclone attacks, the effect of cyclone must be monitored after the cyclone. We must record the effects of each cyclone, such as the number of colonies turned over and chipped colonies.

On the effect of human impacts, it is important to survey especially in the area of marine sports. We need to carry out the detailed monitoring survey on the destruction of living corals in the area of marine sports. This item is very important for argument on adequate control and regulation of marine sports.

3.4 Coral Disease

Many coral diseases are recognized in many coral reefs recently and they are becoming a new menace with COTS and coral bleaching. In the back reef of Pre, d'Esny, white syndrome was observed in some tabular-type coral colonies of *Acropora cytherea* by the monitoring surveys using SC method carried out in February 2013 (Photo 3.4.1).

It is also observed that cyanobacteria covered fragments of branching corals at Albion Lagoon in October 2014 (Photo 3.4.2). Cyanobacteria sometimes cover also living corals in other coral reefs. We do not have enough information about coral diseases such as their causes, so we have also added this item to the monitoring survey.

Source: JICA Expert Team

Photo 3.4.1 White Syndrome

Source: JICA Expert Team

Photo 3.4.2 Cyanobacteria

Coral disease is introduced at the following web site:

http://oceanservice.noaa.gov/education/kits/corals/coral10_disease.html

4 Water Quality Monitoring

4.1 Necessary Conditions for Water Quality Monitoring

As for the water quality monitoring, continuation and consistency are the most important keywords. Continuous monitoring is essential for the construction of a water quality database, because the existence of a database on the conditions in the past and at present makes the efficient and effective time-series data comparison possible. It is important for the comparison of the monitoring data to use the same sampling and analysis methods. The use of identical methods is a precondition for the continuous meaningful data comparison. Sampling and analysis methods selected for this project shall satisfy the international standards and shall be the methods which produce useful data for international comparisons. As for the long-term monitoring for marine recreational activities and conservation areas conducted by MoF, these data shall be used as basic data for planning various measures such as setting and revision of environmental standards (guidelines).

4.2 Contents of Water Quality Monitoring

a. Monitoring Parameters

The basic parameters to grasp the degradation state of corals due to the eutrophication of reef environment are shown in Table 4.2.1.

Table 4.2.1 Basic Parameters for Water Quality Monitoring in Lagoon

Basic parameter	Water Temperature, Salinity, Chlorophyll-a, Turbidity, Transparency, pH, DO, NH_4-N, NO_3-N, NO_2-N, T-N, PO_4-P, T-P, Total coliform bacteria, Fecal coliform bacteria

Source: JICA Expert Team

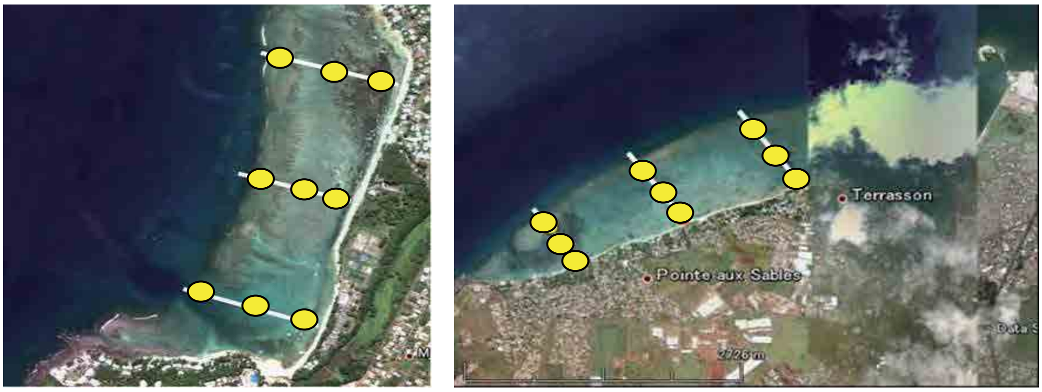
4

b. Frequency and Timing of the Monitoring

It is advisable to carry out the monitoring of the basic parameters four times a year (twice each in the rainy and dry seasons) so that their seasonal changes can be revealed. It is advisable to carry out the coastal monitoring simultaneously with the surface water (river) monitoring so that the spread of water pollution from land to sea can be revealed. The coastal monitoring shall be conducted during ebb tide (time from high to low tide) on a calm and dry day in a period of spring tide, in principle.

c. Monitoring Points

As for the monitoring points, it is necessary to be selected with the shape of water body and the influx of river water taken into consideration so that the water quality of an entire lagoon can be deduced from the analysis of water samples taken at those points. Figure 4.2.1 shows a typical arrangement of water quality monitoring points in a lagoon.



Source: JICA Expert Team

Figure 4.2.1 Typical Arrangement of Water Quality Monitoring Points in a Lagoon

d. Monitoring Methods

Water sampling layer

Water samples taken from the surface layer shall be used for the analysis of the basic parameters, in principle.

Water sampling depth

A layer of water from the surface to the depth of 0.5m shall be considered as the surface layer, in principle.

Water samplers

Van Dorn water samplers shall be used for the water sample collection. As for the water samplers to take the water samples at the required depth, in addition to the above, several methods (Kemmerer bottle, Bacon bomb sampler, Ruttner sampler, Niskin sampler, Automatic sampler, etc.) have been introduced by EPA and APHA.

4.3 Analytical Methods

The analytical methods and detection limits of basic parameters to be conducted as the water quality monitoring in the lagoon are shown in Table 4.3.1.

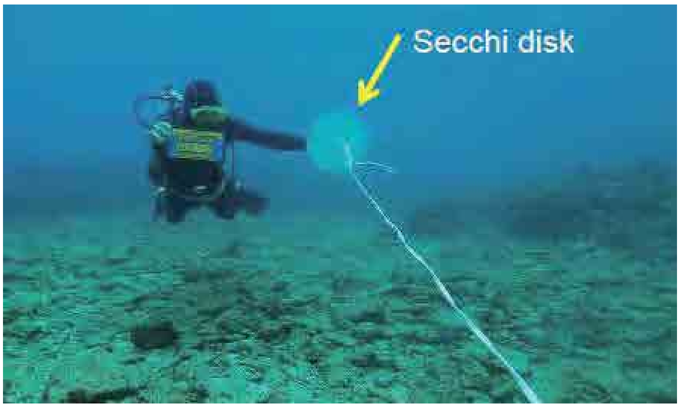
Table 4.3.1 Analytical Methods and Proposed Detection Limits of Basic Parameters

Parameter	Unit	Analytical Method	Proposed Detection Limit
NH_4-N	mg/l	SM-4500-NH_3	0.01
NO_3-N	mg/l	EPA-0353.3	0.01
NO_2- N	mg/l	EPA-0353.3	0.005
T-N	mg/l	EPA-0351.3	0.01
PO4-P	mg/l	EPA-0365.3	0.005
T-P	mg/l	EPA-0365.3	0.005
Chlorophyll-a	ug/l	Multi Water quality meter UNESCO Method (1966)*	0.01
SST	°C	Multi Water quality meter	0.1
Turbidity	FTN	Multi Water quality meter	0.01
Transparency	m	Secchi Disk	1
Salinity	psu	Multi Water quality meter	0.01

Source: JICA Expert Team

a. Measurement of horizontal transparency in lagoons

Horizontal transparency that affects coral coverage represents the cleanliness in waters just as turbidity does and it indicates the horizontal distance visible in waters (unit: m). Generally, horizontal transparency is visually measured by scuba divers and as such, it involves large measurement errors due to the difference in perception between individual divers. Therefore, for the measurement of horizontal transparency, the method of measuring the limit distance at which a white disc of 30cm in diameter (Secchi disk) placed in the horizontal direction is recognizable to the naked eye is recommended as it is simple and accurate.



Source: Institutes of Health, Okinawa Prefecture

Figure 4.3.1 Measurement of Transparency by Secchi Disk in Lagoon

b. Analytical method of chlorophyll a

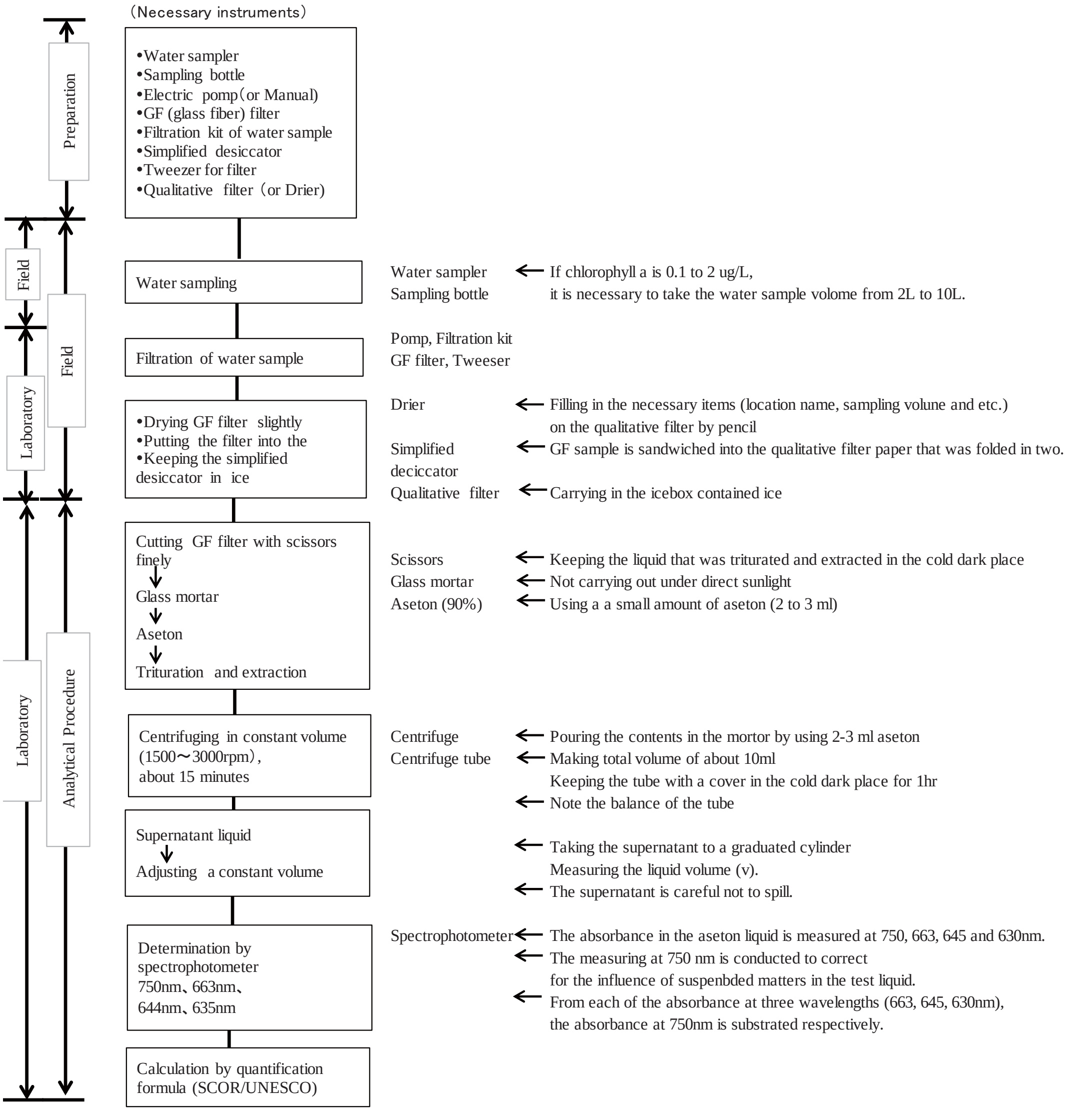
Chlorophyll is an indicator of the biomass of phytoplankton. Of the different types of chlorophyll, chlorophyll a is commonly contained in all algae. To quantify chlorophyll a, 1) spectrophotometry and 2) fluorescence spectrophotometry are used. The spectrophotometry by acetone extraction, which is applied more commonly, is described here. The acetone extraction method, which is based on the method proposed by Strickland and Parsons (1966), was used as a standard by UNESCO-SCOR and has since been used by many researchers and institutes. Figure 4.3.2 shows the procedure. Chlorophyll a concentration in the extract (test liquid) is determined by the following formula, subtracting the absorbance for the wavelength of 750nm from the absorbance of three wavelengths (663, 645 and 630nm), respectively.

$$\text{Chlorophyll a } (\mu g/ml) = 11.64E_{663\text{-}750} - 2.16E6_{45\text{-}750} + 0.10E_{630\text{-}750}$$

If the chlorophyll a concentration in the extract determined from the above formula is x, chlorophyll a concentration in the test water C can be obtained from the following formula.

$$C\ (\mu g/L) = (x \times v) / V$$

Here, v is the total amount of acetone extract (ml) and V is the amount of filtered test water (L).



Source: The SCOR/UNESCO Working Group on Photosynthetic Pigments;" Monographs on Oceanographic Methodology" No.1 p69 (1966)

Figure 4.3.2 Analytical Procedure for Chlorophyll a by Acetone Extraction Method

c. Chlorophyll a by on-site water quality meter

The chlorophyll sensor incorporated into multi-parameter water quality meter measures the intensity of chlorophyll fluorescence that is always discharged by phytoplankton in photosynthesis. The fluorescence intensity is almost dependent on the concentration of chlorophyll a, which is a photosynthetic pigment essential to phytoplankton. Therefore, it is possible to determine if the chlorophyll a concentration, which is an indicator of the biomass of phytoplankton, has increased or decreased by measuring the intensity.

The chlorophyll fluorescence intensity measured by on-site water quality meter relatively shows the increase or decrease of the intensity of chlorophyll fluorescence discharged by phytoplankton. As such, to determine the chlorophyll a concentration based on the fluorescence intensity measured by the measuring instrument, it is necessary to calibrate the measurement by creating the calibration curve of chlorophyll a concentration after comparing the analytical values of chlorophyll a concentration (determined by an analysis laboratory using randomly obtained test waters) and output values. The chlorophyll fluorescence intensity varies with a strong dependence on chlorophyll a concentration and it is also known to be affected by the type and the physiological characteristics, such as photosynthetic activity, of phytoplankton. Therefore, if a reliable chlorophyll a concentration is needed, it is essential to calibrate with the test water from the site as described above.

d. Turbidity by on-site water quality meter

Turbidity is known to correlate with SS (suspended solids). However, turbidity measured by on-site water quality meter also depends on the particle shape and size of suspended solids in water to some extent. Therefore, to estimate SS based on the measurement of turbidity, it is necessary to create the calibration curve by comparing the measurement of turbidity using the test water and the SS values from an analysis laboratory, as is the case with the chlorophyll sensor.

5 Transplantation of Coral Fragments

The following paper on transplantation method is directly cited from N. Okubo as appeared in M. Omori and S. Fujiwara (eds.) “Manual for restoration and remediation of coral reefs” published by Ministry of the Environment, Japan in 2004. The numbering of figures uses the same numbering as in the paper.

This method seems to be the most adequate method for the present condition of Mauritian coral reefs.

It is desirable that the transplantation projects are developed by taking full advantage of the experiences that have been obtained, also to help to enhance knowledge on the transplantation sites, period, locations, fixing method, substrates, and other factors through experiments based on the well planned methods and long-term observations.

5.1 Sampling of Fragments from Donor Coral

The most important matter here is that not to many fragments should be collected from a single donor colony at a time, to minimize the effect of collection on the colony. There is little physiological knowledge about the effects of the collection of the fragments on the reproduction of donor colony (Szmant-Foelich 1985, Smith and Hughes 1999, Koji and Quinn 1985, Zakai et al 2000).

When collecting the fragments from a donor colony for transplantation, the colony and the fragments are not damaged severely if a wire cutter or underwater scissors are used for branching corals or a hammer and a chisel are used for tabular, corymbose, massive or other forms of corals, to break them with a blow. It may be possible to use the fragments broken by typhoon or other natural causes for the transplantation. Bruckner and Bruckner (2001) conducted transplantation of fragments generated by ship groundings. The result is that surviving fragments (57%) were larger than dead fragments (26%).

5.2 Size of Suitable Fragments

Generally, it is expected that the larger the transplantation fragments are, the higher the survival rate is. However, because taking larger fragments can damage the donor colonies, the most important point in the future experimental transplantation will be to define the minimum acceptable size which allows a survival rate of 100%. To achieve this, the environmental conditions, such as the time for transplantation, which are discussed later in this document, should be taken into consideration (case examples described in Chapter 6-2).

So far, fragments of 2 to 30 cm long or in diameter, or colonies of these sizes (entire donor colonies) have been transplanted. As a result of transplantation of fragments of *Montastrea faveolata,* which forms settling type massive colonies, with diameters ranging from 2.5 to 5.1 cm, the survival rate at 9th month after the transplantation was 75%, and thus, Becker and Muller (1999) estimate that even the colonies of diameters less than 2.5 cm can be transplanted.

However, for the transplantation of *Acropora echinata* and *Pavona cactus* colonies consisting of three size groups, 5 to 10 cm, 10 to 15 cm, and 15 to 25 cm, and the fragments consisting of two size groups, 2 to 4 cm, and 3 to 6 cm, no difference of mortality rate were seen among the three size groups of the colonies, but the mortality rate of many of the fragment groups were higher than that of the colony groups (Plucer-Rosario and Randall 1987). As a result of the experiment that compared three size groups of fragments *Acropora prolifera*, 3 to 5 cm, 8 to 12 cm, and 15 to 22 cm, smaller fragments clearly showed higher mortality rate (Bowden-Kerby 1997). According to these results, it can be said that the survival rate can be higher when the coral is transplanted in colonies than when transplanted in fragments, and the rate can be higher when the coral is transplanted in large fragment sizes.

5.3 Transportation

Regarding the method of transportation, not much difference can be seen among the researchers (Okubo and Omori 2001). The principal methods include the use of divers, who carry fragments in containers without taking them out of the water if the destination is near (Dodge et al. 1999), or, if the destination is far, a boat is used to carry the fragments in wire mesh bag or net bags hung in the water from the boat (Dodge et al. 1999; Munoz-Chagin 1997). The fragments may be carried in water-filled buckets on deck (Bowden-Kerby 1997), however, when using this method, it is necessary to be careful that the water in the bucket is not warmed up during transportation in a hot season.

Basically, it is desirable to transport the fragments without taking them from the sea. The possibility that the transplantation fragments can survive transport in the air varies among the coral species. Fragments of *Acropora gemmifera* and *Favia stelligera* can be transported out of the water if the period is up to approximately 2 hours, but *Stylophora pistillata* or *Rumphella* sp. must be transported while submerged in water (Kaly 1995). Urabe et al. (2003) reported that the tolerance of coral communities to drying is higher for *Fungia* or massive corals and lower for branching corals, and as a general tendency, watering is effective, but mere light shielding is not effective.

5.4 Fixation Methods and Choice of Fragments

Some methods of fastening coral fragments that have been used are listed below (Figure 5.4.1).

1) In many cases, epoxy waterproof cement is used for fastening fragments on the substrate. First, remove algae and other foreign matters from the substrate by using a wire brush or other means. Place the fragments on the substrate vertically or horizontally and adhere them with epoxy cement. In some past cases, regular industrial cement was used instead of the waterproof cement. Since the transplanted corals can easily come off the substrate when only this method is used, some supplemental methods are used additionally (Figure 5.4.1-a).

2) Put a small plant pot in the hole made on the coral rocks used as the substrate, insert a coral fragment into each pot, and fix them by using cement that has already been mixed with freshwater on land beforehand (Auberson 1982) (Figure 5.4.1-b). 3) Put the cement with retardant in a small polyethylene bag, and then put the bag on a concrete mat. Then, insert the fragments or colonies into the cement in the bag and fix them. For the fragment of 10 cm or longer, put concrete nails in the bag and fasten the fragment to the nails (Clark and Edwards 1995) (Figure 5.4.1-c).

4) Put the cement with retardant in a nylon bag, insert the fragments into the bag, attach a hook for securing the bag to the substrate, and then, keep the bag in the water tank until the cement hardens. When the cement has hardened, fasten the bag to the base rock by using the hook and a rope (Clark 1997) (Figure 5.4.1-d).

5) Put nails in the substrate for transplantation, and fasten the coral fragments to the substrate with wires or cable ties (Iliff et al. 1999; Okubo and Omori 2000; Okubo et al. 2001, 2002) (Figure 5.4.1-e).

6) Skewering: Drill a hole at the center of each coral fragment, and run a bamboo skewer through the hole. Make holes on the substrate for transplantation by using an underwater drilling machine, and put the bamboo skewers with the fragments in the holes (Nishihira 1994) (Figure 5.4.1-f).

When fragments are attached to the nails that have been put on the substrate and fixed with cable ties (Figure 5.4.1-e), the fragments of some species that do not settle on the substrate easily because of their mode of growth can increase the risk of the nails dislodging from the substrate as the years pass after the transplantation. Since the nails do not come off after the cable ties are cut, the loss of the fragments can be prevented more surely by fastening the nails to the substrate with epoxy cement. Since the chemical effects of epoxy cement on transplanted fragments have not been assessed, segments should be transplanted after the cement has hardened. Before applying the waterproof cement, it is necessary to remove the algae and other foreign matter from the substrate by abrasion, using a wire brush. A vertical orientation of fragments, fixed to the substrate is recommended to minimize the deposit of sediment (Okubo and Omori 2000; Okubo et al. 2001, and Okubo et al. 2002).

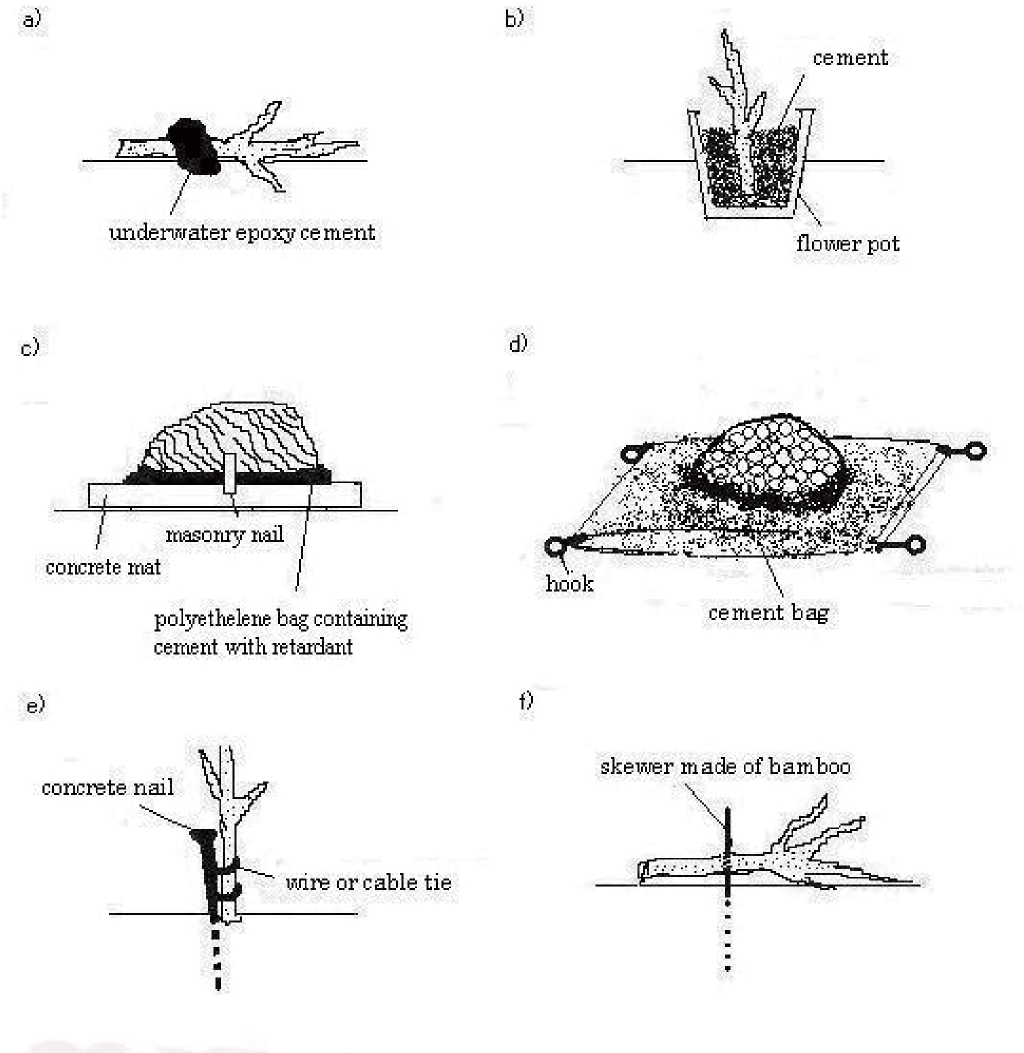


Figure 5.4.1 Method of Fastening Coral Fragments

5.5 Choice of Place

Since the optimal growing conditions of corals vary among the species, it is necessary to investigate the location that the donor colony inhabits, which is the source of the fragments, and the location to which the fragments are transplanted, with attention to their respective physical condition (wave, tidal current, turbidity, depth, light intensity, amount of sediments, salinity etc.) prior to the transplantation. The survival rate of transplantation is higher when the environmental characteristics of the two locations are similar, and it is lower when the fragments are transplanted to an unfamiliar environment (Auberson 1982; Marine Parks Center of Japan 1993, 1994, 1995). It is also necessary to investigate the location to which the fragments are transplanted in order to discover whether marine life such as crown-of-thorns starfish or coral-eating gastropods that predate the corals are present. For the marine park zone in Ashizuri Uwakai National Park, Kochi Prefecture, Japan, the survival rate at the first year after the transplantation was 0% in the past three attempts because of mass populations of coral-eating gastropods in the location (Ashizuri Uwakai National Park, personal communication). One experiment placed fragments collected from three forms of *Acropora*, ie. *Acropora intermedia* (branching), *A. millepora* (corymbose form) and *A.*

hyacinthus (tabular), on the reef flat, reef ridge and reef slope, without fixing them (Smith and Hughes 1999). Their survival rates at the 17th month later were 37% on the reef flat, 15% on the reef ridge, and 10% on the reef slope. Rates of settlement on the substrate were 39% on the reef flat, 31% on the reef ridge, and 4% on the reef slope. The exposition of these results noted the following matters: the growth rate of the fragments placed on the reef flat is higher than that on the reef ridge, because the chance that the fragments placed on the reef flat are shielded from the sunshine by the surrounding tabular corals is less; the fragments can easily settle on the reef flat, which consists of the coral rocks with the hard sediment; and thus, the number of fragments that are killed by the covering sediments is less.

5.6 Preferable Substrate

When it is necessary to transplant coral fragments on the underwater structures, it is very useful to understand what kind of substrate can permit the corals to settle easily. There was an experiment for comparing the suitability for settlement among five types of substrates, including ferrite-containing concrete, unglazed tiles, concrete blocks and iron that are frequently used for underwater structures, and natural coral rocks (Okubo 2003). As a result of this experiment, the fragments that showed the higher settlement rates were those transplanted on the concrete and ferrite-containing concrete. Ikeda and Iwao (2001) transplanted 10cm fragments of *Acropora. formosa* on the substrate for transplantation that was made of concrete mixed with coal ash, which is an industrial by-product, using the method just described. As a result, the settlement rate was nearly equal to the fragments that were transplanted on regular concrete. Based on both of these results, it is estimated that the coral fragments can settle on concrete substrates easier than on other materials, for reasons as yet unknown.

5.7 Preferable Season

Most transplantation has been performed in warm periods when the monthly average air temperature is in the range from 24 to 28 °C. However, since the locations, coral species, their fixing methods and other factors affecting past transplantations are different from each other, it is impossible to compare them in order to fix the most suitable time for the transplantation. Thus, the present author has performed experiments using the same materials and methods, and only changing the transplantation time, which are discussed in Chapter 6-2.

Four experiments were carried out in the subtropical region where the range of water temperature is relatively large (the monthly average air temperature is in the range from 26.6 to 28.3 °C) in a warm season, using the fragments of nearly the same size and the similar methods. Though the species were different, the average survival rate at the 3rd month after the transplantation was 98.5% in a total of 13 species including *Dichocoenia stoksii*, *Montastrea cavernosa* and *Porites astreoides*, etc. (Dodge et al. 1999), and the survival rate at 43rd month after the transplantation of *Acropora formosa* was 69% (Okinawa General Bureau, Okinawa Development Agency 1997). For *Acropora echinata*, the rate at an unknown time after the transplantation was 46% (Plucer-Rosario and Randall 1987). Thus, the results vary much among the species.

As a result of investigations of the relationship between the mortality and temperature and positive correlation was shown (Yap and Gomez 1984; Yap et al. 1992). The mortality is raised in a high water temperature period by the stress from the transplantation and bleaching.

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6 Other Coral Transplantation Methods

Coral farming and transplantation have been carried out by MoF (AFRC) since 2011. The method is that fragments collected were set on the basal table with a net. This method is slightly different from the direct transplantation method mentioned above but it is classified as asexual method (see Final Report of Coral Farming Project in Mauritius and Rodrigues, November 2012, Ministry of Fisheries, 10 pp.). This method is also promoted to be continued and to be expanded.

Coral farming by MoI was carried out using aquaria set on land and many coral fragments were planted in some lagoons since 2011. This project is already finished. However, if there is a possibility to reopen this project, this method is also promoted to be continued and to be enlarged.

A sexual-reproduction method was tentatively carried out by MoF (AFRC) in 2014 (see Luchmun *et al. Coral spawning event in Mauritius* (2014). Ministry of Ocean Economy, Marine Resources, Fisheries, Shipping and Outer Islands, 10pp.). Slicks of eggs and sperm appear on the sea-surface in the lagoons for one or two days after the spawning of corals (mainly genus *Acropora*). Slick is collected and is scattered in the target lagoon. Normally, larvae are settled within 10 days as juvenile corals. So, this is a very simple method using sexual reproduction. Other sexual and asexual methods were introduced in a guidebook (Omori, M. and S. Fujiwara (eds.) 2004 *Manual for restoration and remediation of coral reefs*. Nature Conservation Bureau, Ministry of Environment, JAPAN 84 pp.), and this guide book was already distributed to the related organizations as an electronic file.

Sexual methods are better than asexual methods mentioned above from the viewpoint of biodiversity, but it takes much time due of the need of conducting preliminary surveys on spawning period, on settlement place and period, etc. So, if possible, coral transplantation mentioned above and preliminary surveys of sexual methods should be carried out simultaneously.

7 Transplantation Method of Seagrass and Mangrove

There is limited information on the plantation of tropical or subtropical seagrasses. Because seagrass is a seed plant, in general there are two transplantation methods. Namely, after collecting the seed, the seed is sown directly to the target sea bottom. Another method is to collect the whole plants with rootstocks and transplant these in the target sea bottom. Unfortunately, we do not have the know-how on the plantation of seagrass under the environment of Mauritian lagoon, so fundamental studies are proposed to be carried out by the related organizations.

On the plantation of mangroves, AFRC has already carried out and has acquired the know-how on its plantation. So the plantation activity by AFRC must be promoted.

Chapter IV

Technical Guideline for EIA on Coastal Conservation Project

IV. Technical Guideline for EIA on Coastal Conservation Project

1 Introduction

In Mauritius, since the Environment Protection Act 2002 came into force as the basic law, environmental and social considerations have been made in earnest and a variety of laws and regulations concerning the environment have been established based on this basic law. Environmental Impact Assessment (EIA) is an important tool for environmental management. The EIA system of Mauritius is specified by the Government Notice concerning Part IV of the Environment Protection Act. The list of undertaking which warrants an EIA is listed as per part B of the fifth schedule of the EPA.

Of the projects requiring the EIA, those relating to the coastal areas are as follows:

7. Construction of breakwaters, groynes, jetties, revetments and seawalls
9. Construction of marina
15. Construction of fishing port
17. Harbour dredging operation, construction and development
19. Hotel or Integrated Resort Scheme, including extension, with first boundary within 1km from the high water mark
23. Lagoon dredging and reprofiling of sea bed
31. Repair work with respect to existing shorelines, such as beach reshaping, nourishment, shore protection and removal of rocks near the seashore
33. Offshore sand collection

The EIA guidelines are a tool to support project proposers and consultants in creating comprehensive EIA documents including necessary information for appropriate implementation of the EIA. With respect to projects relating to the coastal areas, there are existing EIA guidelines only for the Construction of marinas and Hotel construction along the seashore.

Referring to these guidelines, the JICA study team reviewed the environmental impacts caused by a variety of coastal structures that have so far been built along the coast of Mauritius and has drafted a technical EIA guideline for coastal protection and rehabilitation projects in accordance with the results of the review.

This guideline (draft) has been summarized with concentrating on the projects for construction of coastal structures and repair works with respected to existing shoreline.

2 Policy, Legal and Administrative Framework

The project for coastal protection and coastal rehabilitation is a scheduled undertaking requiring an EIA. This section of the EIA should indicate compliance of the project with the relevant plans, policies, national laws, standards, guidelines, regulations and /or subsequent relevant amendments, and the protection of sensitive areas and how these are being addressed. These include, inter alia:

- The EPA 2002, the National Environmental Standards, Guidelines and Regulations under the EPA e.g. Guidelines for Coastal Water Quality;

- Pas Géométriques Act, State Land Act, Wildlife and National Parks Act, Rivers and Canals Act, Forests and Reserves Act, Local Government Act, Fisheries and Marine Resources Act, the Maritime Zone Act, Beach Authority Act, Tourism Authority Act;
- Plans and policies such as the National Oil Spill Contingency Plan, the Integrated Coastal Zone Management Framework (2010), SEA (Strategic Environment Assessment) for the Identification of Potential Sites for Marinas, Ski Lanes and Bathing Areas in Mauritius in 2005, Study on Environmentally Sensitive Areas for Mauritius and Rodrigues, National Climate Change Adaptation Policy Framework for the Republic of Mauritius (2012), National Development Strategy, Coastal Development Guidelines prepared by the Ministry of Housing and Lands e.g. Planning Policy Guidance 2004 (Design Guidance for Coastal Development, Design Guidance Marina Development), Study on Disaster Risk Reduction;

The promoters/consultants should ensure that the necessary permits/clearances/authorizations from relevant authorities have been obtained including clearance from the Ministry of Housing and Lands and authorization from the Prime Minister’s Office for any development in the public domain, clearance from Forestry Services for felling down of any trees as well as any authorization from the Customs Department and Immigration Office (as applicable). And also, particulars of any consultation should be held with the public in the area where the undertaking is to be located.

3 Site Description and Surrounding Environment

3.1 Site and Surrounding Environment

This chapter should provide a detailed investigation of the site, the surrounding environment and the sensitivity of the site. It should include, inter alia, the following:

a) Location of the site;
b) Exact land extent. The site should be indicated on a map along with aerial photographs and/ or satellite images;
c) Comprehensive legible Site Location Plan or as appropriate, drawn and duly certified by a Sworn Land Surveyor with appropriate landmarks as reference points. It should clearly provide indication of:
   - Distance from the nearest settlement boundary;
   - Nearest residential areas/built up environment and any existing development in the vicinity;
   - Environmentally sensitive areas (if any);
   - Water bodies (if any);
   - Cultural and heritage sites(if any);
   - Designated sites of interest; and
   - Future/ forthcoming development projects.
d) Existing land use and constraints;
e) Description of the site characteristics in terms of site location (GPS coordinates of the boundaries delimiting the site), landform, topography (supplemented by 1.0m interval contour map in case the site is sloppy), geology, soil type and characteristics, presence of any watercourse and natural drain, any environmentally sensitive area, present and past land use, vegetation cover, flora and fauna, amongst others, and surrounding environment at least 500m on each side;

f) A full terrestrial ecological survey describing the types, distribution and abundance of flora and fauna, Environmentally Sensitive Areas (sand dunes, inter-tidal mud flats, wetlands, mangroves, rivers), any protected, rare or endangered species, location of habitats (areas for feeding, refuge, reproduction or nesting for migrating species);
g) Description of the shore types (sandy, muddy, rocky, cliffs, mixed, calcareous lime stone shore),length of the shoreline, beach frontage and their characteristics, landform, topography, elevation, magnitude of slope, slope stability, erosion, escarpments and landslide risks supplemented by 0.5 - 2.0m interval contour map;
h) Details of any existing structure within the site and vicinity;
i) The state of the marine environment along with a full marine ecological survey, describing the types of flora and fauna and indicating on maps Environmentally Sensitive Areas(corals, sea grasses, fishing reserve/marine park, mangroves, islets) and fishing areas;
j) A Bathymetric Map of the site and its surroundings supplemented by 0.5 - 1.0m interval contour map showing the zoning of the lagoon and indicating swimming areas and etc.;
k) Description of the hydrographic conditions to include wave regime (patterns, height, frequency and direction), currents direction and speed, tidal water levels including the probability of extreme conditions and potential for waves and surges;
l) Description of the sedimentology in terms of present onshore and offshore sand movement, erosion and accretion;
m) Vulnerability of the site to natural hazard, storm surges or climate change impacts like sea level rise, inundation or flooding.

3.2 Description of the Present Socio Economic Values of the Site and its Surroundings

a) Socio-cultural value of the site;

b) Socio-economic importance of the site e.g. recreational, any public beach and public access, any agricultural activity, fishing activity, nautical activity;

c) Socio economic profile of the local community;

d) Historical and cultural heritage value of the site.

4 Description of the Existing Baseline Conditions

This is a record of the site condition used as a benchmark against which to measure environmental changes following the implementation of the project. For the collection of baseline information, proponents/consultants should provide the sampling points locations, test parameters and methodologies. Some factors to be considered in describing the baseline environment should, inter alia, include:

a) Baseline data on the basic land and hydrographic condition of the site, inter alia, in terms of soil conditions (soil classification, suitability for method of sewage disposal);water quality, streamside condition (as applicable), presence of any borehole, river, marshland, drain, height of water table and areas vulnerable to erosion and other impacts from natural hazards or climate change; and

b) Data on the marine and freshwater ecological environment of the site, relevant meteorological data such as annual average rainfall (frequency, duration and quantity), strength and direction of prevailing wind(velocity and intensity), tidal regime and existing nuisances such as odour and noise level.

5 Project Description

This chapter should provide a detailed description of all the activities that would be carried out and should include amongst others:

5.1 General Requirements

a) A general description of the project and the different components;
b) Type of coastal protection countermeasure, its design, size and scale;
c) Detailed Site Layout Plan:
- Site boundaries as per Title Deed or Lease Agreement;
- All existing development/ structure on site (if any);

d) Detailed Layout Plans of structure (if any);
e) Detailed architectural drawings (if any);
f) Detailed description of the different project components including any dredging works envisaged.

5.2 Marine Engineering Aspects

a) Detailed methodology and scope of works including the type of machinery and equipment to be used for construction of breakwaters, sea walls, reclaimed land and so on; disposal of dredged material and or reuse of same;
b) Dredging works envisaged, including scope, quantum of dredged materials and mode of disposal;
c) Any land reclamation work envisaged and if so, to indicate exact location on a plan drawn to appropriate scale, giving a description of the site as at present including biodiversity;
d) Any maintenance dredging work required and frequency;
e) Coastal works envisaged i.e. hard and soft structures.

5.3 Terrestrial Engineering Aspects

a) Detail methodology and scope of works and type of machinery;
b) Transportation and mode of storage of construction materials;
c) Details on proposed access roads including width, length, etc.;
d) Legible plan showing the road networks including the entry and exit;
e) Details on the presence of watercourses, natural drains, canals, etc., within the site and measures envisaged to safeguard the watercourses;
f) Any provision for drains and management of storm water runoff;
g) Legible plan showing the proposed drainage network;
h) Fuelling facilities for vessels;
i) Generation of solid waste and wastewater; and
j) Mode of disposal of solid waste and wastewater.

5.4 Climate Change Issues

a) Details on the engineering design of the structure taking into consideration the vulnerability of the site to natural hazard, sea surges or climate change impacts like sea level rise, inundation or flooding; and
b) Details justifying how the development will be climate proof.

5.5 Traffic Implications

Details on the traffic to be generated during construction works.

5.6 Other Aspects

a) Proposed implementation schedule;
b) Duration of works (construction and operation phases);
c) Capital investment;
d) Employment opportunities.

6 Categorization and Method for Identification of Environmental Impacts

The consultant should identify impacts which may, inter alia, be categorized as follow;

Table 6.1.1 Categorization of Environmental Impacts and Typical Impact Items

Categorization of environmental impacts	**Typical impact items**	**Categorization of environmental impacts**	**Typical impact items**
Negative	e.g. degradation of the ecosystem, conflict among existing businesses	Positive	e.g. job creation, tourism and people influx
Direct	e.g. displacement of people	Indirect	e.g. reduction in living standards for the displaced people
Short term	e.g. noise and dust from construction works and vehicular movement	Long term	e.g. degradation of aquatic habitats which might affect the aquatic food webs
Recurring	e.g. noise from motor driven boats	Non-recurring	e.g. noise from drilling
Cumulative	e.g. destruction of sea grass or mangroves affecting aquatic food web and thus commercial fishery	Non-cumulative	whereby impacts do not accumulate in space and in time
Reversible	e.g. erosion and sand deposition, beach nourishment	Irreversible	e.g. elimination of wildlife habitats like destruction of corals and sea grass bed

Source: Sectorial guideline No.1 December 2013, [Guideline on the content of an environment impact assessment report for construction of Marinas]

Proponents/consultants should demonstrate methods used to identify impacts which may, inter alia, include interaction matrices, Geographic Information Systems (GIS), modelling, ranking and weightage.

7 Impacts and Proposed Mitigating Measures

Impacts on the environment may occur during land clearing and site preparation, construction, as well as operational phase of the project. The proponent/consultant should propose feasible precautionary and mitigate measures to reduce the adverse impacts and enhance the positive impacts.

7.1 Impacts during Site Preparation Phase

7.1.1 Terrestrial

a. Loss of biodiversity

Removal of vegetation and felling of trees may cause loss of natural habitat and degradation or destruction of environmentally sensitive areas like wetland and sand dunes. The proposed mitigating measures should include preservation and transplantation of trees, and compensation measures.

b. Machinery /equipment

Machinery / equipment, stand-by generators and diesel storage tanks on-site may pose the risks of hydrocarbon spills and contamination of soil, underground /surface water and lagoon. Necessary mitigating measures should be included in the EIA report to address the above impact.

c. Noise and dust nuisances and air emissions from machinery and transport vehicles

Dust generated by earth-moving machinery, wind blowing upon the cleared site and stockpiled materials may be a cause of concern. In addition, vehicles and earth-moving equipment also emit exhaust fumes. Machinery and transport vehicles are also associated with noise nuisances.

Mitigating measures should be taken so as not to cause any nuisance by way of dust and air emissions to the nearby residents, beach users, public and surrounding environment. These include, amongst others, water spraying of stockpiles, access road and the construction site; regular maintenance of all heavy machine and vehicles.

Noise reduction options include, amongst others, fencing to screen noisy operations, the maintenance of machinery and installation of silencers to reduce noise emission.

d. Preservation of drains and watercourses

Tampering with natural watercourses and drains can have the potential risks of flooding of the site and its adjoining areas. Natural watercourses and drains should be preserved and maintained.

e. Solid waste/ demolition waste

Solid waste may include green wastes from land clearing, demolition debris and inert construction materials, amongst others. Best Management Practices to minimize solid waste and demolition waste include inter alia:

- Stockpiling of solid waste in a central area, away from water bodies;
- Re-use of demolition waste as backfill material;
- Collection, transportation and disposal of solid waste and demolition waste to the satisfaction of the Local Authority.

7.1.2 Marine

Impacts on the marine ecosystem relates mostly to the loss of biodiversity. The mitigating measures should include proposals for the translocation of benthic organisms identified in the marine ecological survey that are likely to be affected by the project. These include, amongst others:

- Any live sedentary organisms should be hand-picked and transferred from the project site to safer areas in the lagoon prior to start of works.
- All rubbles that are supportive of live coral should be manually and carefully displaced in an appropriate locality for their growth.

No mangroves should be destroyed during the course of the development.

7.2 Impacts during Construction Phase

7.2.1 Terrestrial

a. Machinery /equipment

Machinery / equipment, stand-by generators and diesel storage tanks on site have the risk of hydrocarbon spills and contamination of soil, underground /surface water and lagoon.

Necessary mitigating measures should be included in the EIA report to address the above impact.

b. Noise and dust nuisances and air emissions from machinery and transport vehicles

Dust, noise and air emissions during the construction phase from stockpiled materials, trucks, excavators), loaders, bulldozers, piling machine and cranes can be a source of nuisance to the nearby residents, beach users, public and surrounding environment.

Mitigating measures include, amongst others, water spraying of stockpiles, access road and the construction site; regular maintenance of all heavy machine and vehicles.

Noise reduction options include, amongst others, fencing to screen noisy operations, the maintenance of machinery and installation of silencers to reduce noise emission.

c. Solid waste and construction debris

Solid waste may comprise domestic solid waste and construction waste materials, amongst others.

Measures to minimize the above impacts include:

- Sorting out at source and proper collection of all recyclable wastes for eventual recycling;
- Composting of all green and biodegradable wastes;
- Disposal of other solid wastes and non-compostable wastes to the satisfaction of the Local authority.

d. Wastewater

Wastewater from the workforce during the construction phase can be a potential impact causing ground/ surface water and lagoon pollution. Mitigating measures include the provision of on-site wastewater disposal facilities and carting away to the satisfaction of the Wastewater Management Authority.

e. Hours of Operation

All works should be carried out during normal working hours. Works in the lagoon should be undertaken at low tide between sunrise and sunset. The operations should be interrupted during rough seas or adverse climatic conditions.

7.2.2 Marine

a. Machinery

Machinery for dredging, excavation and piling works have the risk of hydrocarbon spills and risks of contamination of soil, underground /surface water and lagoon. Dust, noise and vibration are also nuisances associated with machinery.

Necessary mitigating measures should be included in the EIA report to address the above impact, including amongst others, all machinery should be in good running conditions, regular servicing and maintenance.

b. Dredging/Nourishment

Dredging to create, deepen or maintain structures and navigational channels or nourishment to put sand involves a number of environmental effects like destruction to corals and marine habitats, siltation, sedimentation, turbidity and entrainment of sediment plume.

Mitigating measures should include:

- Selection of excavation and dredging methods with minimal suspension of sediments and destruction of benthic habitat;
- The type and amount of dredged or nourished material;
- Proper siting of dredged spoils or nourished sand away from sensitive resources and habitats and propose safe disposal methods for the dredged materials;

The site and its adjoining areas should be effectively protected against sediment entrainment with geo-textile screen of appropriate mesh size, installed in double layers in the lagoon and regularly maintained.

7.3 Impacts during Operation Phase

Impacts during the operation phase essentially relate to damage of the marine ecosystems associated with anchoring and beach use.

7.3.1 Marine and Beach Environment

Impacts to the marine environment include amongst others, obstruction to boat movement and public amenities/ public beach in the area, damage to the marine ecosystem by anchoring as well as coastal water quality degradation. The mitigating measures should include the clear demarcation of navigational channels with buoys so as not to interfere with boat movements.

Structures like jetties may cause changes to tidal flushing and current patterns and cause erosion problems.

Structures like revetments or groynes may cause beach changes on the surrounding beaches. Vertical revetments cause scouring in front of the revetment and erosion at the boundary between the revetment and the natural beach. On the coast existing longshore sediment movement is impaired by the presence of structures which cause erosion at the down drift side and accretion at the up drift side. The impact extends to the entire littoral cell where sediment is moving. The mitigating measures should include to minimize impacts on surrounding beaches such as the gentle slope revetment, set backed revetment, sand by passing from accreted to eroded area, sand nourishment on the eroded beach.

7.4 General Impacts

7.4.1 Storm Water Management

If the marina is associated with significant land based activity, then due consideration should be given to the management of storm water. Storm water runoff which contains suspended sediments, petroleum hydrocarbons and other pollutants can contaminate the lagoon.

The EIA report should, include, inter alia:

- Consideration for sustainable materials which minimize surface run-off, e.g. porous concrete, grass;

7.4.2 Visual Impact (Visual Environment and Aesthetics)

This chapter should indicate the intention to incorporate landscaping and embellishment works in the structure project and how the development architecture, materials and paintings will blend with the natural landscape. It should be ensured that the water in the structure is visually clean and mitigating measures should be taken to prevent any pollution by way of oil, litter and sewage.

7.4.3 Impact on Heritage, Historical and Cultural Features

The impacts on physical and cultural resources should be avoided by encouraging their conservation and enhancement. Measures should be proposed to avoid damaging significant cultural property and beliefs and measures to be taken to protect same, including buffer zones.

7.4.4 Consideration for Beach Users and Boat Operators

Conventionally, coastal protection facilities such as breakwaters, groynes and revetments, because it does not assume the use, were often those lacking water amenity. When performing the constructions of the new coastal facilities or the repair works with respect to existing shorelines, it should consider the establishment of conscious structure and safety measures facilities for coastal users and boat operators. As competition with coastal users and boat operators does not occur, it should be considered for placement of the facilities.

8 Public Consultation

According to Section 19(1) (b) of the EPA, an EIA report shall enclose particulars of any consultation held with the public in the area where the undertaking is to be located.

Consultation is required for information purposes and details on the project are explained to the public.

This section of the EIA report should indicate:

- Any interaction and outcome of consultation with the relevant Ministries/Authorities/Institutions including consultation with the Ministry responsible for Fisheries, Beach Authority, Mauritius Oceanography Institute, Traffic Management and Road Safety Unit (as applicable).
- Stakeholders and communities likely to be affected by the project (NGOs, Force Vive, locally registered fishermen, local inhabitants, beach users etc.).

The following should also be provided:

- Establishment and record of procedure (e.g. notes of meetings, leaflets, public display, questionnaires, letters) by which the interested and affected parties were afforded the opportunity to participate;
- A brief about the interactions detailing the areas of concern, the list of issues identified and how these have been addressed in the EIA e.g. trade off;
- A description of the public participation process followed by a list of stakeholders and their comments, the venues and times of consultation should be included as an appendix. The outcome of consultative meeting should be provided.

9 Alternatives

The EIA report should provide details on any alternative manner in which the undertaking may be carried out to cause less harm to the environment including the “no-development option”.

10 Environmental Monitoring Plan and Environmental Management Plan

10.1 Environmental Monitoring Plan (EMoP)

An Environmental Monitoring Plan (EMoP) is required under Section 18(2) (*l*) of the EPA. This EMoP is indicative and should provide an indication of all the parameters which need to be monitored including noise and air quality, coastal water quality, river water quality, ground and surface water quality, etc.

Once an EIA License is granted, a proper EMoP has to be submitted to the Ministry of Environment & Sustainable Development for approval taking into considerations the list of conditions attached to the EIA License as well as the proposals made in the EIA.

The EMoP puts responsibility on proponent to carry out monitoring exercise to verify:

- Successful implementation and effectiveness of mitigate measures to address impacts as spelt out in the EIA document.
  Note: list of all mitigate measures as spelt out in the EIA document and corresponding

monitoring exercise to check effectiveness of measures should be submitted in a tabular form.

- Compliance with EIA license conditions, standards, guidelines and regulations.

The monitoring plan should comprise of baseline environmental parameters of the receiving media of the site and the surrounding environment prior to start of the project. The following additional aspects, where relevant, should, inter alia, be addressed in the description of the monitoring activities:

- Institutional arrangements for carrying out the work, responsibility for monitoring;
- Indicators to be measured, monitoring methods, equipment and calibration details to be used;
- Specific parameters to be monitored, monitoring locations and control stations; monitoring frequency and duration;
- Standards and guidelines to be used to compare monitoring results;
- Name of environmental consultant and accredited laboratory conducting environmental monitoring, analysis of environmental samples.

10.2 Decommissioning

The EPA requires an EIA to include information pertaining to the decommissioning of the project at the end of its life cycle and associated impacts, proposed measures to return the site as far as possible to its former state, or rehabilitation measures.

11 Expertise of Consultant/ Consultancy Team

EIA requires a multi-disciplinary approach and involves expertise in various fields. This chapter should indicate the details about the composition of the consultancy team in terms of academic background, experience, area of study, contact details (complete address, phone and fax numbers).

12 Conclusions

The final chapter of the EIA report should deal with the recommendations and conclusions which justify the acceptability of the proposed project in relation to the proposed mitigative measures.

13 Conclusions

13.1 Environmental Checklist for Scoping

"Scoping" means choosing alternatives for analysis, a range of significant and potentially significant impacts, and study methods. The results of scoping are used to prepare TOR (Terms of Reference) for EIA study.

As for the scoping for coastal protection and rehabilitation projects, It is advisable to conduct the scoping for these projects, using examples from the environmental checklist in JICA guideline for environmental and social considerations (2010) shown in Table 13.1.1 to Table 13.1.3.

Table 13.1.1 Environmental Checklist for Coastal Protection and Rehabilitation Projects (1)

Category	Environmental Item	Main Check Items	Yes: Y No: N	Confirmation of Environmental Considerations (Reasons, Mitigation Measures)
1 Permits and Explanation	(1) EIA and Environmental Permits	(a) Have EIA reports been already prepared in official process? (b) Have EIA reports been approved by authorities of the host country's government? (c) Have EIA reports been unconditionally approved? If conditions are imposed on the approval of EIA reports, are the conditions satisfied? (d) In addition to the above approvals, have other required environmental permits been obtained from the appropriate regulatory authorities of the host country's government?	(a) (b) (c) (d)	(a) (b) (c) (d)
	(2) Explanation to the Local Stakeholders	(a) Have contents of the project and the potential impacts been adequately explained to the Local stakeholders based on appropriate procedures, including information disclosure? Is understanding obtained from the Local stakeholders? (b) Have the comment from the stakeholders (such as local residents) been reflected to the project design?	(a) (b)	(a) (b)
	(3) Examination of Alternatives	(a) Have alternative plans of the project been examined with social and environmental considerations?	(a)	(a)
2 Pollution Control	(1) Air Quality	(a) Is there a possibility that air pollutants (SOx, NOx dust etc.) emitted from the project related sources such as ships, vehicles and adjoining facilities will affect ambient air quality? Does ambient air quality comply with the country's air quality standards? Are any mitigating measures taken?	(a)	(a)
	(2) Water Quality	(a) Do general effluents from related facilities comply with the country's effluent standards and ambient water quality standards? (b) Do effluents from ships and adjoining facilities (docks) comply with country's effluent standards and ambient water quality standards? (c) Are any mitigation measures that oils and harmful materials do not flow out to the surrounding water area taken? (d) Do change of waterfront line, disappearance of existing water, creation of new water and etc. generate the change of water current conditions and the decrease of seawater exchange, or cause the change of water temperature and water quality? (e) When performing a landfill, are any mitigation measures that the seeping water from a landfill does not contaminate the surface water, seawater and groundwater taken?	(a) (b) (c) (d) (e)	(a) (b) (c) (d) (e)
	(3) Wastes	(a) Are wastes generated from the project facilities, such as ships, vehicles and adjoining facilities, properly treated and disposed of in accordance with the country's regulations? (b) Are dumping of dredged soil and offshore disposal soil so as not to affect the surrounding waters, are properly treated and disposed of in accordance with the country's regulations? (c) Are any mitigation measures that harmful materials do not flow out to the surrounding water area taken?	(a) (b) (c)	(a) (b) (c)
	(4) Noise and Vibration	(a) Do noise and vibrations from the vehicle and train traffic comply with the country's standards?	(a)	(a)
	(5)Ground subsidence	(a) When pumping large quantities of groundwater, is there a possibility that subsidence occurs?	(a)	(a)
	(6) Bad odor	(a) Is there is a bad odor source? Are the odor protection measures taken?	(a)	(a)
	(7) Sediments	(a) Are any mitigation measures that harmful materials emitted from the project related sources such as ships and adjoining facilities do not contaminate the surrounding sediments taken?	(a)	(a)
3 Natural Environment	(1) Protected Areas	(a) Is the project site located in protected areas designated by the country's laws or international treaties and conventions? Is there a possibility that the project will affect the protected areas? (b) Whether the site is an ESA or not? (c) As per the ESA recommendations, can the site be developed?	(a)	

Table 13.1.2 Environmental Checklist for Coastal Protection and Rehabilitation Projects (2)

Category	Environmental Item	Main Check Items	Yes: Y No: N	Confirmation of Environmental Considerations (Reasons, Mitigation Measures)
3 Natural Environment	(2) Ecosystem	(a) Does the project site encompass primeval forests, tropical rain forests, ecologically valuable habitats (e.g., coral reefs, mangroves, or tidal flats)? (b) Does the project site encompass the protected habitats of endangered species designated by the country's laws or international treaties and conventions? (c) If significant ecological impacts are anticipated, are adequate protection measures taken to reduce the impacts on the ecosystem? (d) Is there fear adversely affect aquatic organisms? If the projects adversely affect the aquatic organisms, are any mitigating measures taken? (e) Is there fear adversely affect coastal vegetation and wild organisms? If the projects adversely affect the coastal vegetation and wild organisms, are any mitigating measures taken?	(a) (b) (c) (d) (e)	(a) (b) (c) (d) (e)
	(3) Hydrology	(a) Is the change of water system caused by the installation of coastal protection structures? Do the structures adversely affect the current conditions, wave conditions and tidal currents?	(a)	(a)
	(4) Topography and Geology	(a) Is the large-scale modification and changes of topography and geology or disappearance of natural beach in the surrounding area caused by the installation of coastal protection structures? (b) Whether as per the DRR study is the site prone to flood or inundation?	(a)	(a)
4 Social Environment	(1) Resettlement	(a) Is involuntary resettlement caused by project implementation? If involuntary resettlement is caused, are efforts made to minimize the impacts caused by the resettlement? (b) Is adequate explanation on compensation and resettlement assistance given to affected people prior to resettlement? (c) Is the resettlement plan, including compensation with full replacement costs, restoration of livelihoods and living standards developed based on socioeconomic studies on resettlement? (d) Are the compensations going to be paid prior to the resettlement? (e) Are the compensation policies prepared in document? (f) Does the resettlement plan pay particular attention to vulnerable groups or people, including women, children, the elderly, people below the poverty line, ethnic minorities, and indigenous peoples? (g) Are agreements with the affected people obtained prior to resettlement? (h) Is the organizational framework established to properly implement resettlement? Are the capacity and budget secured to implement the plan? (i) Are any plans developed to monitor the impacts of resettlement? (j) Is the grievance redress mechanism established?	(a) (b) (c) (d) (e) (f) (g) (h) (i) (j)	(a) (b) (c) (d) (e) (f) (g) (h) (i) (j)
	(2) Living and Livelihood	(a) Where flexible revetment is newly installed, is there a possibility that the project will affect the existing means of transportation and the associated workers? Is there a possibility that the project will cause significant impacts, such as extensive alteration of existing land uses, changes in sources of livelihood, or unemployment? Are adequate measures considered for preventing these impacts? (b) Is there any possibility that the project will adversely affect the living conditions of the inhabitants other than the target population? Are adequate measures considered to reduce the impacts, if necessary? (c) Is there any possibility that diseases, including infectious diseases, such as HIV will be brought due to immigration of workers associated with the project? Are adequate considerations given to public health, if necessary? (d) Is there any possibility that the project will adversely affect road traffic in the surrounding areas (e.g., increase of traffic congestion and traffic accidents)? (e) Is there any possibility that flexible revetment will impede the movement of inhabitants? (f) Is there any possibility that structures associated with flexible		

		revetment (such as bridges) will cause a sun shading and radio interference?		

Table 13.1.3 Environmental Checklist for Coastal Protection and Rehabilitation Projects (3)

Category	Environmental Item	Main Check Items	Yes: Y No: N	Confirmation of Environmental Considerations (Reasons, Mitigation Measures)
4 Social Environment	(3) Heritage	(a) Is there a possibility that the project will damage the local archeological, historical, cultural, and religious heritage? Are adequate measures considered to protect these sites in accordance with the country's laws?	(a)	
	(4) Landscape	(a) Is there a possibility that the project will adversely affect the local landscape? Are necessary measures taken?	(a)	
	(5) Ethnic Minorities and Indigenous Peoples	(a) Are considerations given to reduce impacts on the culture and lifestyle of ethnic minorities and indigenous peoples? (b) Are all of the rights of ethnic minorities and indigenous peoples in relation to land and resources to be respected?	(a) (b)	
	(6) Working Conditions	(a) Is the project proponent not violating any laws and ordinances associated with the working conditions of the country which the project proponent should observe in the project? (b) Are tangible safety considerations in place for individuals involved in the project, such as the installation of safety equipment which prevents industrial accidents, and management of hazardous materials? (c) Are intangible measures being planned and implemented for individuals involved in the project, such as the establishment of a safety and health program, and safety training (including traffic safety and public health) for workers etc.? (d) Are appropriate measures being taken to ensure that security guards involved in the project not to violate safety of other individuals involved, or local residents?	(a) (b) (c) (d)	
5 Others	(1) Impacts during Construction	(a) Are adequate measures considered to reduce impacts during construction (e.g., noise, vibrations, turbid water, dust, exhaust gases, and wastes)? (b) If construction activities adversely affect the natural environment (ecosystem), are adequate measures considered to reduce impacts? (c) If construction activities adversely affect the social environment, are adequate measures considered to reduce impacts?	(a) (b) (c)	
	(2) Monitoring	(a) Does the proponent develop and implement monitoring program for the environmental items that are considered to have potential impacts? (b) What are the items, methods and frequencies of the monitoring program? (c) Does the proponent establish an adequate monitoring framework (organization, personnel, equipment, and adequate budget to sustain the monitoring framework)? (d) Are any regulatory requirements pertaining to the monitoring report system identified, such as the format and frequency of reports from the proponent to the regulatory authorities?	(a) (b) (c) (d)	
6 Note	Reference to Checklist of Other Sectors	(a) Where necessary, pertinent items described in the Forestry Projects checklist should also be checked (e.g., projects including large areas of deforestation). (b) Where necessary, pertinent items described in the Power Transmission and Distribution Lines checklist should also be checked (e.g., projects including installation of power transmission lines and/or electric distribution facilities).	(a) (b)	(a) (b)
	Note on Using Environmental Checklist	(a) If necessary, the impacts to trans boundary or global issues should be confirmed, if necessary (e.g., the project includes factors that may cause problems, such as trans boundary waste treatment, acid rain, destruction of the ozone layer, or global warming).	(a)	(a)

1) Regarding the term “Country's Standards” mentioned in the above table, in the event that environmental standards in the country where the project is located diverge significantly from international standards, appropriate environmental considerations are required to be made. In cases where local environmental regulations are yet to be established in some areas, considerations should be made based on comparisons with appropriate standards of other countries (including Japan's experience).
2) Environmental checklist provides general environmental items to be checked. It may be necessary to add or delete an item taking into account the characteristics of the project and the particular circumstances of the country and locality in which it is located.

Source: JICA guideline for environmental and social considerations (2010)

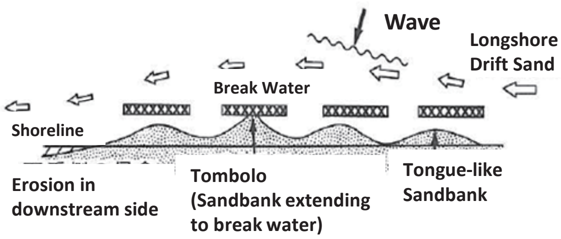
13.2 Case Study on Environmental Considerations for Coastal Protection Structures

The representative coastal protection structures from the various existing structures conducted in Mauritius were selected as the case studies on the environmental considerations for coastal protection structures. The evaluation results on the various impacts by these structures are as follows:

Case-1. Detached Break Water at A-Beach

- Main functions of detached break water are wave absorption function and sand accumulation function behind the back of break water.
- It should be noted that amounts of the longshore drift sand flowing downstream are reduced.
- Because coastal erosion in downstream side occurs by sand accumulation behind back of break water.

The coastal erosion in downstream side occurred by the construction of detached breakwater is shown in the photo on the right.



Source: JICA Expert Team

Case-2. Coastal Protection Works at B -Beach

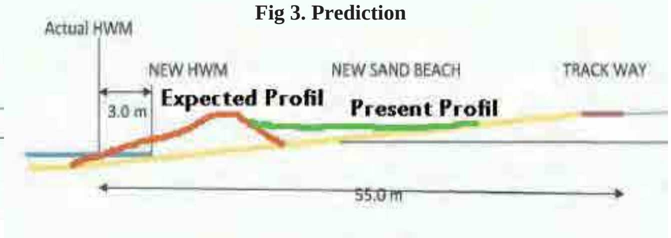
- **Beach height and beach slope are determined by the particle size of the sand and the waves basically.**
- **Therefore, even if the beach reprofiling with more gradual slope is conducted, it should be noted that it is height gradient as the surrounding beach slopes gradually.**

Fig 1. Present Condition

- At B-Beach, the removal of existing seawall and the beach reprofiling with the slope of 4% (1/25) are planned .
- It is too gentle compared to the existing beach which has a slope from 1/7 to 1/10 at the surrounding shoreline.
- It is expected that the beach slope conducted replofiling will be become steeper as existing.

Fig 2. Plan

Fig 3. Prediction



Source: JICA Expert Team

Case-3. Rock Revetment at C-Beach

The following several problems are pointed out.

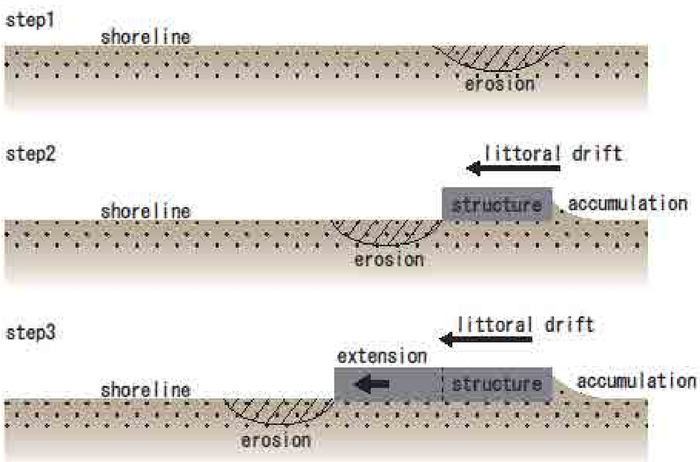
- The coastal erosion around the end of rock revetment is in progress.
- This erosion has been a problem since 2003 (Baird report). But It did not improve at all.
- Beach users is reduced because it is hard to walk on the rock revetment and not close to the water's edge.

EIA Considerations

- In the study on coastal protection measures by the coastal structures, it is necessary to evaluate the erosion impact around the end of structures.
- Regarding the assessment of coastal structure, it is necessary to either have been taken into account for the hydrophilic seen from the beach user to check.

Source: JICA Expert Team

On a natural beach if a structures is made for the temporally erosion, the structure impacted on the front and adjacent beaches and sometimes causes erosion. Especially if sediment moves alongshore the new structure causes continuous erosion as shown in the figure. The same situation will happen if the wave direction changes seasonally.



Source: JICA Expert Team

Figure 13.1.1 Continuous Erosion after the Structure Construction

Case-4. Rock Revetment at D-Beach

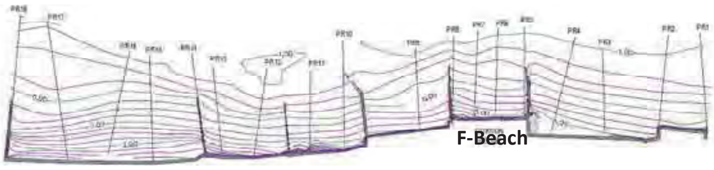
The following problem is pointed out.

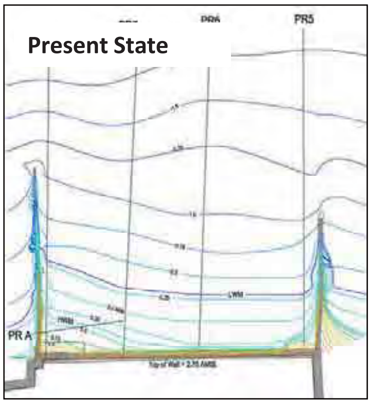
- There is no problem as the coastal erosion measure. But for the beach users, it is hard to walk on the rock revetment and not close to the water's edge
- At E-Beach on the opposite shore, the armoring rocks with bigger size were used. It is easy to close the water's edge.

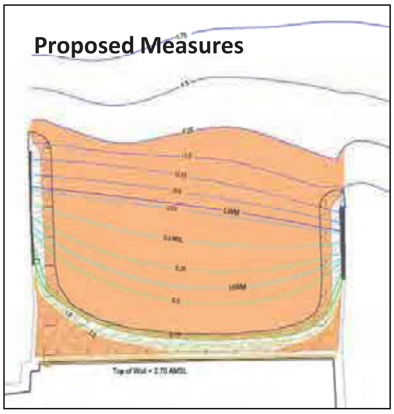
Source: JICA Expert Team

Case-5. Coastal Protection Works at F-Beach

- **A lot of jetties have been constructed personally.**
- **In this coast, the localized coastal erosions have occurred due to the cut–off of the longshore drift sand by these jetties.**
- **The measures for coastal erosion are the shortening of jetties, the construction of revetment and the sand filling.**
- **The proposed measure is the local measure for coastal erosion, but an effective measure in consideration of influence on the downstream side.**







Source: JICA Expert Team

13.3 Problem and Correspondence in EIA Study on Coastal Erosion Measures

The following are the problems in the EIA studies on measures against coastal erosion in Mauritius.

- A study area is limited to the area around a hotel concerned. Elucidation of a mechanism for coastal erosion and assessment of effects of a countermeasure on the surrounding environment require a study of an entire littoral zone which includes the study area. A littoral zone is an area of movement of sediment along a shoreline.

- Characteristics of littoral drift in the study areas have not been studied sufficiently. Factors and mechanisms causing erosion and waves, in particular, have not been analyzed sufficiently.

- Erosion control effects and environmental impacts on a surrounding coastal area of measures have not been predicted sufficiently.

A study on the characteristics of littoral drift is required in connection with “assessment of the need for erosion control measures” and the result of the study are used as basic data for predicting littoral drift and topographic changes caused by littoral drift in future. The main data required for the study of the characteristics of littoral drift are as follows:

① Aerial photographs and satellite imagery: Change in littoral drift in a littoral zone is to be studied by gathering and analyzing the image data of the past and factors causing erosion and characteristics of littoral drift (predominant direction and sediment balance) are to be deduced from changes in shorelines and structures in the surrounding area revealed by the study.

② Field survey: Current conditions on the ground are to be elucidated. Accurate knowledge of the progress of erosion and conditions of structures in the surrounding area help deduce the factors causing erosion and characteristics of littoral drift.

③ Sediment data: Longshore and cross-shore grain size distributions and the relationship between gradient in a coastal area and grain size distribution are to be elucidated. Knowledge of the relationship between the coastal gradient and grain size distribution is very important in deciding what material shall be used for beach nourishment.

④ Meteorological and oceanographic data: Frequency distributions of wind direction and wind velocity shall be deduced from the data and the distribution shall be used for prediction of waves (off the reefs) and establishment of a representative wave.

There are several models for the prediction of topographic changes in coastal areas which can be used for verification of erosion control effects and prediction of impact on shoreline around the project site. However, it is not practical to incorporate these prediction models in the guideline because the models have been used little in Mauritius. The following methods can also be used for the verification of erosion control effects and prediction of impacts of the project on the shorelines around the project site.

It is possible to predict changes in future, effects and a range of impact of countermeasures and prepare strategies for planning of countermeasures empirically from the factors causing erosion and characteristics of littoral drift deduced from the results of the image analysis and field studies mentioned above.

① The representative wave established above shall be used for the prediction of wave height distribution in the area around the project site. It is possible to determine the range in which the countermeasure will change wave height by comparing the wave height distribution at present and after the construction of countermeasure structure and estimate the effects and range of impact of the countermeasure.

② The JICA Study Team intends to add description of the method for the field surveys for the EIA studies and the methods to predict effects and impact on the surrounding coastal areas of the erosion control measures taking the problems in the EIA studies mentioned above into consideration and exchanging the views with MOESDDBM and a private EIA consultant on those methods.