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THE STUDY ON SOLID WASTE MANAGEMENT FOR MALE' CITY IN THE REPUBLIC OF MALDIVES

FINAL REPORT

Evironmental Impact Statement
(EIS)

May 1999

Pacific Consultants International
Environmental Technology Consultants Co., Ltd

Japan International Cooperation Agency (JICA)

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Definition of Technical Terms

1. Biodegradation

The destruction of organic materials to eventually to become as inorganic materials, that could be made available for a fresh cycle of plant growth, by microorganisms, soils, natural water bodies and waste treatment systems.

2. Biota

Fauna and flora of a water body.

3. Chemical Oxygen Demand (COD)

The amount of oxygen required for chemical oxidation of organic matter, principally in wastewater, using either dichromate salt, referred to as chromate COD (COD-Cr), or permanganate salt, referred to as manganese COD (COD-Mn), as the oxidizing agent. COD is essentially a measure of pollution level in water/wastewater. Basically COD-Cr is universally adopted as the COD, in particular with non-saline water/wastewater.

4. Gas vent

The piping facility installed in a solid waste landfill area to vent (convey) the gases like CO2 (carbon dioxide) and CH4 (methane) generated underground to atmosphere consequent to ongoing biodegradation of buried solid waste.

5. Leachate

Liquid wastewater percolating (passing) through a solid waste landfill/dump which in the process extracted dissolved (leached) soluble materials, such as organic salts and mineral salts, consequent to ongoing degradation of the solid waste.

6. Sanitary Landfill

A solid waste burial site operated in such a manner to minimize environmental hazards. The disposed waste is continuously compacted and covered adequately with a layer of soil to minimize blowing, odour, fire hazard and fly and rodent nuisance. Due provisions are also made to minimize environmental hazards due to leachate and bio-gas generated underground consequent to ongoing degradation of buried solid waste.

7. Solid Waste

Discarded materials consequent to human living and consumption activity, such as garbage, refuse, scrap and others, that are most commonly landfilled, but also be incinerated or recycled.

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ENVIRONMENTAL IMPACT STATEMENT (EIS)

1. Introduction

This EIS is formulated for the solid waste management improvement project for the capital region of Maldives. The Project was formed consequent to the master plan and feasibility study for the improvement of solid waste management in the capital region of Maldives, Male, and is surrounding islands conducted by JICA (Japan International Cooperation Agency) for the MCPW (Ministry of Construction and Public Works) of the Government of Maldives.

The target year of the solid waste management improvement master plan is 2010 and that of the Project subjected to this EIS, which formed the initial phase of the master plan and also the subsequent feasibility study, is 2003.

2. Need for the Project

Solid waste generation is inherent to human consumption. In particular the solid waste generation is very significant in developed areas like the capital region of Maldives with high economic activity and population density and is a potential source of environmental pollution. The present (1998) solid waste generation in Male is estimated at about 175 tons/day. Proper management of solid waste is a prerequisite to sustain the basic living environmental sanitation of an urban environment. Accordingly the project is classified as a basic human need project for sanitation.

3. Initiator of the Project

The Ministry of Construction and Public Works (MCPW), the responsible agency for the transportation and final disposal of solid waste generated in the capital region including the management of the existing final solid waste disposal site in Tilafushi serving the capital region and the surrounding islands, is the principal agency responsible for the implementation of the Project, and hence the Project Initiator.

4. Baseline Environmental Condition

4.1 Overall environment

A detailed description on existing baseline environmental condition in Tilafushi area as well as Male, including coral ecology in Tilafushi reef and the adjacent reef of Gulhifalhu and sea water and sea-bed material quality of Tilafushi and Male, groundwater quality in Male and leachate quality in the ongoing landfill area in Tilafushi (Tilafushi-1) is illustrated in Chapter

3 of the Main Report (Volume I-Master Plan). The relevant portions of the above Chapter 3 are incorporated as Annex of this EIS document.

Based on the coral ecological survey results (the survey was conducted in June 1998) the present status of coral life in and around the Tilafushi Reef was assessed as summarized below.

- The Tilafushi reef-flat coral life of channel reef and inner reef is more degraded in comparison to the outer channel reef-flat facing the Vaadoo channel.
- No significant specific areas of degraded coral life on the reef-slope of Tilafushi were noted.
- Dispersed dredged material from the Tilafushi reef consequent to the ongoing landfill operation leads to silt deposition on adjacent Gulhifalhu reef affecting its coral life.

Based on the analytical results of sea water and sea-bed material (sediment) sampling conducted in and around Tilafushi and Male both are assessed as unpolluted and representative to background levels of natural condition (refer to Table A-9, A-10 and A-11 of Annex for the analytical results of seawater and sediment quality). However the groundwater in Male is assessed as significantly polluted, since the COD level was mostly in the range of about 15-20 mg/l (refer to Table A-7 of Annex for the analytical results of Male groundwater quality). It is noted that COD level of unpolluted groundwater does not normally exceed 5 mg/l. The leachate quality in the existing solid waste landfill island of Tilafushi (Tilafushi-1) indicated active stabilization of leachate aided by exchange with surrounding sea water. Also the metallic contamination level in leachate was found to be insignificant (refer to Table A-8 of Annex for the analytical results of leachate quality in Tilafushi-1).

4.2 Baseline environment of existing Tilafushi Island

The solid waste landfill operation in the existing Tilafushi island (Tilafushi-1) was commenced in December 1992 and has been in operation for about 6 years. The ongoing landfill operation in Tilafushi could be classified as solid waste dumping in ponds created by dredging in reef-flat and raising the land level just above sea level with a final cover of dredged material from reef flat. Infrequent open burning of garbage prior to land-filling, as a crude means of processing of solid waste, was also noted. This inadequate solid waste management results in strong unpleasant odor and severe fly nuisance. Apart from these basic landfill management issues other significant environmental issues concerned to the present Tilafushi landfill management are summarized below.

(1) Dispersal of dredged material due to unconfined dredging

Unconfined and uncontrolled dredging of reef flat for the creation of pond space for filling garbage and for generating cover material for landfill results in dispersal of sediment to surrounding marine water environment. This sediment load is perceived to adversely affect the marine biota, in particular coral life. It is noted that mitigation of dispersal of dredged sediment will not only eliminate any adverse effect on marine biota but also save valuable cover material for landfill.

(2) Dispersal of garbage due to ineffective confinement

Floating garbage (solid waste) in water of a new solid waste dumping area is prevalent due to inadequate confinement of solid waste dumping area. Moreover temporary storage of solid waste too close to the shoreline may also be a cause of dispersal of garbage to surrounding marine water environment. Ineffective coastal erosion mitigation measures and the progressing coastal erosion also results in dispersal of even compacted solid waste to surrounding marine water environment. Dispersal of garbage to surrounding marine water need to be eliminated as the basic technically acceptable means of final solid waste disposal.

(3) Degradation of inner lagoon of Tilafushi

The inner lagoon located along the western face of the existing Tilafushi island is essentially a semi-enclosed water body. Insufficient dilution and dispersion of leachate from the landfill is perceived as the cause of progressing eutrophication of this inner lagoon that also resulted in coral disease and mortality. Mitigation measures against uncontrolled diffusion of leachate into inner lagoon with less assimilative capacity need to be contemplated.

(4) Improper land-use of completed landfill area

Land reclaimed with solid waste has already been earmarked for various industrial and warehouse use and some tenants have already commenced construction of relevant facilities. In this case of present Tilafushi island, solid waste is simply considered as a land reclamation material and reclaimed land is used with scant attention to the hazardous nature of leachate and other flamable gases generated consequent to the progressing degradation (stabilization) of dumped solid waste underground. This environmentally hazardous haste misuse of completed solid waste landfill area needs to be completely eliminated.

5 Project Description

5.1 General

The proposed solid waste management project will cover principally the development of a new sanitary landfill site on Tilafushi reef, referred to as Tilafushi-2, adjacent to the present site on the same reef, referred to as Tilafushi-1, from the year 2001 to the year 2003. In addition the proposed project is also comprised of solid waste collection improvement in Male including the provision of a new solid waste transfer station.

This Tilafushi-2 project in essence is comprised of two principal impacted areas of potential beneficial effects and adverse effects.

1. The solid waste generation and transportation areas of Male and the surrounding islands (beneficial areas of environmental sanitation improvement).
2. The final solid waste disposal area of Tilafushi Reef/Island (Tilafushi-2 area subjected to potential adverse environmental effects).

The transportation of generated solid waste is essential for the mitigation of environmental sanitation deterioration of the areas of Item 1 above. The relevant project components to realize this objective like the procurement of solid waste conveyance vehicles and others including the transfer station are not only minor project components with respect to their project scale but also their potential adverse environmental effects are insignificant in comparison to the sanitation improvement benefit realized by inhabitants.

Still it is noted that the existing solid waste transfer station is very unsatisfactory since it functions only as a primitive intermediate solid waste dump site and draws complaints from surrounding residents, in particular, due to its emanation of offensive odor. In fact the present transfer station is located in an area classified as residential area as per the authorized land-use plan. Accordingly, a new improved solid waste transfer station will be provided as a component of this project. The existing solid waste transfer station will be closed with the inauguration of the new transfer station by this project, leading to further environmental improvement even in the solid waste collection area of Male island.

On the other hand the final solid waste disposal area in Tilafushi Reef, Tilafushi-2, as of Item 2 of above not only has large scale of project activity resulting in land reclamation of submerged reef with solid waste but also subjected to potential adverse environmental effects requiring in-built mitigation measures. Accordingly, the components of sanitary landfill project concerned to the development of the new Tilafushi island by this project, Tilafushi-2, in between the project implementation period from the year 2001 to the year 2003 are only considered as most significant and targeted for environmental assessment by this EIS.

Still the improved new solid waste transfer station in Male and the new solid waste landfill site in Tilafushi are considered as significant projects and targeted for project description in the subsequent sections. It is further noted that it is presumed that the present landfill operation will continue until the year 2000 and the required access jetty facility for the new landfill development by this project in Tilafushi-2 will also be in place until that time. These intermediate activities until the year 2000 as well as any present or future activity concerned to Tilafushi-1 are not parts of this project and hence not targeted by this EIS.

5.2 New solid waste transfer station project for Male

The locations of the present solid waste transfer station in Male and the new improved transfer station by this project are shown in Fig. 1. The detailed plan of the facilities of the new transfer station is shown in Fig. 2.

It is noted that the new transfer station is completely surrounded by public roads and will be fenced off, an important mitigation measure against odor and aesthetic nuisance to surrounding environment. Moreover, planned segregated storage of solid waste as evident from Fig. 2 will further minimize potential odor and other nuisance. Also any leachate generated in the transfer station will be effectively drained to the sewerage system, thereby ensuring the basic sanitary condition of the transfer station. Accordingly, the new improved transfer station incorporates the required in-built mitigation measures against potential adverse environmental effects prevalent in the present transfer station and not targeted for any further assessment in this EIS.

5.3 New solid waste landfill project in Tilafushi

The proposed location of the new sanitary landfill site on the Tilafushi Reef by this project, Tilafushi-2, is located adjacent to the existing Tilafushi Island, Tilafushi-1, towards north-west. The existing Tilafushi Island, Tilafushi-1 (also the present solid waste landfill area), located on the channel reef of Tilafushi and the proposed new sanitary landfill area of this project, Tilafushi-2, located on the inner reef of Tilafushi, are shown in Fig. 3. Details of the project facilities are shown in Fig. 4 (the layout) and Fig. 5 (the sectional details). It is noted that though the construction and the operation activities of this project are distinct both activities would occur in tandem during the initial two (2) year period of the project implementation (2001-2002), the period in which all construction activities are planned to be accomplished. Hence in the year 2003 only the landfill operational activity in Tilafushi-2 would be continued.

It is noted that Tilafushi-3 area shown Fig. 3 is the proposed future sanitary landfill development area beyond the year 2003 (planned to be commenced from the year 2004) following the closure of the Tilafushi-2 area as implemented by this project. Even though Tilafushi-3 is not a component of this project, it is presumed that a similar sanitary landfill system as per the Tilafushi-2 instituted by this project would be adopted in the development of future Tilafushi-3 as well.

The basic feature of the new sanitary landfill system of Tilafushi-2 is as follows;

- Area of landfill development is 10.5ha.

- The maximum height of landfill above MSL (mean sea level) is about 3.4 m.

- A double layer landfill development system will be adopted to arrive at the final height of about 3.4 m above MSL (4 m above LLWL or lowest of low water level, the datum).

Details of the landfill structure are summarized below and its sectional details are shown in Fig. 5.

Details of Landfill Structure

Depth of Bottom layer	Layer of Waste Filling	Height of Filling	Seawall Structure of Inner Lagoon Reef (Seawall 2)	Seawall Structure of Inner Reef (Seawall 1)
E.L -2.5 m	2 Layers	E.L +4.0 m	Sheet Pile	Rock
3.2m below mean sea level	First layer up to +2.0m Second layer up to +4.0m	3.4m above mean sea level	Impermeable wall	Retention ditch between rock walls

The significant project components of the construction activity are as follows;

- Construction of seawall with leachate retention ditch (Seawall-1) along the northern reef-flat boundary of the new Tilafushi-2 facing the inner reef side (ref. Fig. 4 and 5).

- Construction of seawall with steel sheet pile (Seawall-2) along the southern reef-flat boundary of the new Tilafushi-2 facing the lagoon reef side (ref. Fig. 4 and 5).

- Excavation along the centre of the reef-flat of Tilafushi-2 with silt screen protection to generate material to form the sand-bank of the sanitary landfill system (A typical silt screen is shown in Fig. 6).

- Building of administration (operation and maintenance or O/M) facility.

The seawall protection with armour stone around the island of Tilafushi-2 is the exterior protection structure of the landfill area against tides and waves which would also mitigate over-carriage of garbage to surrounding marine environment. The steel sheet pile protection along the lagoon reef is intended at mitigating diffusion of leachate into the lagoon having limited exchange with open sea since it is a semi-enclosed water body (ref. Fig. 4 and 5).

The significant project components of landfill operational activity are as follows;

- Deposition and compaction (land-filling) of solid waste and the subsequent completion of initial (first) layer of landfill operation with cover material on a sequential area-wide basis. The landfill operational process of the initial layer is illustrated in Fig. 7.

- Dredging on reef-flat on sequential area-wide basis to create space for commencing land-filling operation as well to generate landfill cover material. The dredging (excavation) method is illustrated in Fig. 8.

- Installation of gas-vent piping facility and leachate monitoring wells. A typical gas venting pipe is shown in Fig. 9.

- Land-filling of solid waste to form the final layer and the subsequent completion of the entire landfill operation with final cover on a sequential area-wide basis. The landfill operational process of the final layer is illustrated in Fig. 10.

- Greening of completed land with final cover material using vegetation. An imagery of vegetated green area of Tilafushi-2 is shown in Fig. 11.

It is emphasized that silt-screen is adopted as the most significant mitigation measure against the dispersal of dredged material to the surrounding marine water environment. This would result in the simultaneous benefits of conservation of valuable cover material while preserving the marine biota sensitive to silt deposition like the coral life on the reef as well as deterioration of marine water quality. A typical silt screen is shown in Fig. 6 for illustrative purpose.

6. Environmental Impacts and Mitigation

6.1 General

Implementation of the proposed new sanitary landfill project in Tilafushi (Tilafushi-2) could be divided into four (4) distinct stages of pre-construction, construction, operation (post-construction) and post-operation. The anticipated environmental impacts and the relevant mitigation measures will also be distinct for each of these project stages. However as illustrated in the foregone section in the case of this sanitary landfill development project, initially the construction and operation stages will occur in tandem though the respective activities are distinct. It is further noted that post-operation stage represents the management of entirely completed and closed, for any further reception of solid waste, landfill area (Tilafushi-2). The impacts and mitigation measures for each of these four (4) project stages are illustrated in the subsequent sections.

6.2 Pre-construction stage

(1) Activity

The requirement of land acquisition for the construction of the project facilities and the resultant resettlement of population and housing compensation, if any, is identified as the most significant pre-construction activity with potential adverse effect of social nature.

(2) Impacts

The proposed project area for solid waste sanitary landfill development (Tilafushi-2 of Fig. 3) is a submerged uninhabited reef-flat located at inner reef of Tilafushi. As the area is uninhabited and belongs to the government no resettlement of population or land acquisition issue are involved. Moreover this inner reef area, in contrast to the outer reef area adjacent to the Vaadu channel, is not famous for diving and other sea water related recreation by tourism industry and also there are no marine protection areas. It is noted that the "Lion Head" area on the outer reef is a marine protected area. Accordingly, anticipated adverse social impact by the implementation of this final solid waste disposal project is evaluated as insignificant.

(3) Mitigation

No mitigation measure is contemplated as any potential adverse effect is evaluated as insignificant.

6.3 Construction stage

(1) Activity

Significant construction activities concerned to the implementation of the project (new sanitary landfill in Tilafushi-2) are as follows;

1. Construction of seawall with leachate retention ditch (Seawall-1) along the northern reef-flat boundary of the new Tilafushi-2 facing the inner reef side (ref. Fig. 4 and 5)

2. Construction of seawall with steel sheet pile (Seawall-2) along the southern reef-flat boundary of the new Tilafushi-2 facing the lagoon reef side (ref. Fig. 4 and 5)

3. Excavation along the centre of the reef-flat of Tilafushi-2 with silt screen protection (ref. Fig. 6) to generate material to form the sand-bank of the sanitary land fill system

4. Building of administration (operation and maintenance or O/M) facility

(2) Impacts

Potential adverse effects associated with the construction activities delineated above are illustrated below.

All significant construction activities delineated above result in the destruction of immobile marine biota, in particular coral life, on the targeted reef-flat area of Tilafushi-2. This inevitable loss of marine biota is in fact the first step in the conversion of the very ecosystem of the reef-flat from the saline aquatic ecosystem to land based terrestrial ecosystem with irreversible long term consequence.

Still the live coral cover on this reef-flat area is low of only about 2% as per the baseline coral ecological survey (ref. Section 4.1 and also Section A.2 of Annex for details). Moreover a minimum reef-flat set-back distance of 10m along the face of the northern inner reef boundary of the seawall (Seawall-1 of Fig. 4 and 5) with relatively high coral cover on the reef-slope will be provided. This set-back distance though primarily intended at protecting the seawall (Seawall-1) coastal protection structure of Tilafushi-2 and hence the landfill system against high waves, it would also result in the conservation of coral life at least along the edge of the (northern) inner reef-flat area.

Other potential temporary short-term adverse effects concerned to the installation of steel sheet pile for Seawall-2 (activity 2 of above) is the inherent noise and vibration. Moreover the dredging in reef-flat as per activity 3 of above would have the potential to affect the coral life on surrounding reef with silt deposition as well as short term and temporary deterioration of surrounding marine water quality. Potential adverse effect due to the construction of administration building is considered as insignificant in consideration to the small scale of this project activity.

(3) Mitigation

The mitigation measures as incorporated in the form of in-built mitigation in the project construction plan as required are illustrated below.

The long term and irreversible loss of immobile marine biota, in particular coral life, on the reef-flat due to the conversion of the very ecosystem to a land based terrestrial environment as delineated above is inevitable. The selection of inner-reef flat area with low live coral cover for the project is still is an in-built mitigation measure of loss minimization.

Concerning the temporary effect of noise and vibration due to the installation of steel sheet pile potential adverse effect is evaluated as insignificant since the project area is an uninhabited submerged reef away from residential areas and hence no specific mitigation measure is contemplated.

As the in-built mitigation measure against the dispersion of dredged material silt screen protection is adopted which would also save valuable landfill cover material (ref. Fig. 6).

6.4 Operation stage

(1) Activity

Significant operational activities of the project (landfill operation in Tilafushi-2) are as follows;

1. Deposition and compaction (land-filling) of solid waste and the subsequent completion of initial layer of landfill operation with cover material on a sequential area-wide basis (ref. Fig. 7)

2. Dredging on reef-flat on sequential area-wide basis (ref. Fig. 8) (ref. Fig. 6) to create space for commencing land-filling operation as well to generate landfill cover material

3. Installation of gas-vent piping facility (ref. Fig. 9) and leachate monitoring wells

4. Land-filling of solid waste to form the final layer and the subsequent completion of the entire landfill operation with final cover on a sequential area-wide basis (ref. Fig. 10)

5. Greening of completed land with final cover material using vegetation (ref. Fig. 11)

(2) Impacts

Potential adverse effects associated with the operational activities delineated above are illustrated below.

Land-filling activity would lead to potential odor and fly nuisance associated with biodegradable solid waste matter. Moreover dispersion of garbage to surrounding marine water environment may occur. Progressing biodegradation of land-filled solid waste would lead to generation of leachate, a source of potential marine water pollution. Moreover spontaneous fire due to emission of bio-gas like methane from landfill and uneven land subsidence in compacted landfill area may occur. All of the above potential adverse effects are essentially inherent to landfill development system and need to be given due consideration in the design of the project. Moreover, similar to effects described under the impacts on construction stage of foregone section, dredging may lead to dispersion and deposition of silt material on to surrounding coral life as well temporarily affecting the surrounding marine water quality.

(3) Mitigation

The mitigation measures as incorporated in the form of in-built mitigation in the operational plan of the project as required are illustrated below.

The basic in-built mitigation measure against odour and fly nuisance is the soil cover of the landfill system. Moreover selective application of insecticide and deodorant to office space and other landfill operation related machinery and equipment having intense human interaction will be conducted. The seawalls provided around the landfill area, in addition to serve principally as a coastal erosion mitigation structure, would mitigate the dispersal of solid waste (garbage) and other debris to the surrounding marine environment. Provision of gas vent as a project component is directly intended at mitigating spontaneous fire hazard due to emission of bio-gas from underground (ref. Fig. 9). The mitigation measure against uneven land subsidence is the controlled land use of any portion of completed landfill area as a green area with vegetation (ref. Fig. 11). This measure also needs to be continued during the post-operation stage as illustrated in the subsequent section.

As the mitigation measures concerned to the adverse effects due to dispersion of leachate on to the surrounding marine water environment the following are adopted;

The dispersion of leachate to the inner lagoon of the reef is mitigated with the provision of steel sheet pile along the lagoon face of the seawall (Seawall-2 of Fig. 4 and 5). This is in consideration to the progressing eutrophication of this inner lagoon due to the ongoing landfill operation in Tilafushi-1, which is attributed to insufficient exchange of water in the lagoon due to its semi-enclosed nature (ref. Section 4.2).

The dispersion of leachate to the surrounding marine environment will be along the inner reef side toward north of the Tilafushi-2 facing the open sea with active sea current and wave action (the Seawall-1 face of Fig. 4 and 5). As the means of provision of primary treatment of leachate prior to its dispersal into surrounding marine water environment leachate retention ditch is provided as a structural component of Seawall-1.

This leachate retention ditch will function as a stabilization pond to provide primary treatment for the eluted leachate prior to its dispersion to the sea through porous armour stone embankment of the seawall (Seawall 1 of Fig. 4 and 5) including initial dilution and mixing of the eluted leachate with seawater retained within the retention ditch area. This stabilization pond system will also lead to uniform dispersion of leachate through the seawall embankment. Moreover the attached microorganisms that would inherently develop in the pores of the armour stones would provide additional treatment for the dispersing leachate to the surrounding marine water environment.

This pre-treatment provided to the leachate is expected to be adequate to mitigate any leachate induced adverse effect to the marine ecosystem. This assessment is also based on the present seawater quality in the vicinity of Tilafushi-1 which remains virtually unaffected even with the ongoing inadequate landfill operation as delineated in Section 4.2.

As the mitigation measure against dispersal of dredged material, similar to the mitigation measure of construction stage, silt screen protection (ref. Fig. 6) could be adopted. Still, it is noted that with proper planning and execution of dredging operation to create space for solid waste land filling, dispersion of dredged material to the surrounding marine environment could be mitigated by effectively utilizing the seawall protection structure of the landfill system.

6.5 Post-operation stage

The post-operational stage is basically the management of completed sanitary landfill area, Tilafushi-2, (the land just reclaimed from sea with solid waste land filling) in an environmentally acceptable manner, with due consideration to the hazardous nature of the leachate and other flammable bio-gas like methane generated underground (and vented as per the project design) consequent to the ongoing biodegradation of solid waste (ref. Fig. 9) and the resultant potential uneven land settlement.

It is strongly recommended to manage the reclaimed land (Tilafushi-2) as a green area (wooded area) with intense tree plantation not only to enhance the ecological value of the newly created terrestrial environment but also to expedite the on-going biodegradation underground and hence to optimize the time frame of leachate and gas generation. In order to integrate both the ecological and economic benefits, development of the green area as an animal and bird park (similar to a zoo) may be considered as a long-term land-use option.

The management of this completed landfill area as a green area (park) is recommended to be undertaken by the Ministry of Fisheries and Agriculture (MOFA) which is not only responsible for the management of uninhabited wooded islands but also has the required capability to develop green areas with intense tree plantation since it has a plant nursery.

Finally ensuring the land-use of the "post-operation project area" as a green area (wooded area) is the only conceived mitigation measure against adverse environmental effect in the post-operation stage of the project (reclaimed Tilafushi-2 island). An imagery of typical green area of Tilafushi-2 is shown in Fig. 11.

7. Environmental Management and Monitoring

7.1 Environmental management

The operational management of the sanitary landfill system is basically a technical requirement, which could also be considered as the environmental management requirement since the project in itself is an environmentally oriented project.

The environmental management or the operational management is the responsibility of the operator of the landfill system, the MCPW, also the Project Initiator. This is elaborated in the Main Report (Volume 2 on Feasibility Study).

7.2 Environmental monitoring

The basic aim of the environmental monitoring program is to monitor the potential long-term effect due to the operation (and as well post-operation) of the sanitary landfill system in Tilafushi-2 on selected, representative and important surrounding environmental components.

Such a selective monitoring on a regular basis is to ensure that any potential adverse effect is in fact insignificant and also to contemplate additional environmental mitigation measures as appropriate on a timely manner in case the results of monitoring indicates the contrary.

Essentially environmental monitoring should be an integral activity of overall operational management of the landfill system to ensure the system is in fact a "sanitary landfill system", even though the monitoring program would differ from the day to day solid waste land-filling and other directly related activities.

The proposed environmental monitoring program would cover three (3) most representative components of landfill leachate quality, surrounding marine water quality and ecological status of coral life. In principle the monitoring program would be commenced within one (1) year following the start of construction works in Tilafushi-2. The basic monitoring requirement for each of these 3 components is delineated below. It is noted that the Public Health Laboratory (PHL) of the Ministry of Health (MOH) and Marine Research Section (MRS) of the Ministry of Fisheries and Agriculture (MOFA) shall be the responsible monitoring agencies, respectively for the leachate cum (marine) seawater quality monitoring and coral ecological status monitoring. The proposed tentative leachate and sea water quality monitoring locations are shown in Fig. 12.

(1) Landfill leachate quality monitoring programme

(i) Monitoring locations

The leachate quality will be monitored using leachate samples obtained from the leachate monitoring wells that would be instituted in Tilafushi-2 island, specifically for this leachate quality monitoring purpose, in tandem with progressing completion of landfill operation. Also the leachate in the retention ditch provided along Seawall-1 (ref. Fig. 4 and 5) to impart primary treatment of leachate prior to its dispersion into surrounding marine water environment be monitored. Moreover, the only remaining non-demolished leachate monitoring well in Tilafushi-1, near the present jetty, will also be monitored (ref. Fig. 12).

The proposed locations of leachate quality monitoring are seven (7) as follows (ref. Fig. 12);

- LM_0, the existing leachate monitoring well in present Tilafushi (Tilafushi-1)
- LM_1-LM_4, four (4) leachate monitoring wells to be provided in the project area (Tilafushi-2)
- LM_5-LM_6, two (2) leachate monitoring locations within the retention ditch (stabilization pond) of Seawall-1

(ii) **Monitoring frequency and parameters**

The frequency of monitoring shall be at least twice times a year, once during the relatively high wave and rainy season of July-August (within this 2 month period) and the other during the relatively calmer wave and dry season of January-February (within this 2 month period).

The leachate water quality parameters of measurement shall be as follows;

Direct measurement at field: Temperature, pH, EC (electric conductivity), DO (dissolved oxygen) and H2S (hydrogen sulfide)

Measurement at laboratory: Chloride, COD-Cr (chromate chemical oxygen demand), NH4-N (ammonia nitrogen), PO4-P (phosphate/ortho-phosphorus) and Sulfide shall be the minimum number of parameters to be measured at all times, with the last four (4) parameters being the principal pollution indicators.

Still in consideration to the insignificant level of metallic parameters measured in the leachate of Tilafushi-1 during the baseline survey of this project (ref. Table A-8 of Annex for details) and also in due consideration to the analytical complexity and limited analytical capacity of PHL, only one time measurement of the following metallic parameters is recommended to be carried out as a component of the similar baseline environment survey for the future Tilafushi-3 development project. The proposed metallic parameters of measurement are copper (Cu), iron (total Fe), cadmium (Cd), chromium (total Cr), Zinc (Zn), lead (Pb) and mercury (total Hg).

(iii) **Monitoring agency**

The Public Health Laboratory (PHL) of the Ministry of Health (MOH) shall be the responsible agency for monitoring and be allocated independent budget to undertake this monitoring on its own conforming the frequency of monitoring delineated above.

(2) **Seawater quality monitoring program around Tilafushi-2**

(i) **Monitoring locations**

The sea water quality, principally in the vicinity of Tilafushi-2, will be monitored using samples obtained both from the northern inner reef-slope area adjacent to Seawall-1 and the opposite southern reef-slope area adjacent to Seawall-2, the Tilafushi lagoon (ref. Fig. 3 and 4). The proposed locations of leachate cum sea water quality monitoring are shown in Fig. 12. It is noted that the proposed sea water quality monitoring locations include the new (south-west) harbour area of Male island as well.

The proposed locations of leachate quality monitoring are six (6) as follows (ref. Fig. 12);

- SM_0, the new (south-west) harbour area in Male, the solid waste barge loading area for Tilafushi
- SM_1, the existing jetty area of present Tilafushi (Tilafushi-1)
- SM_2, the inner-reef sea area at the centre of the proposed project area (Tilafushi-2)
- SM_3, the "Shark Point" area of Tilafushi reef at the outer-reef facing the Vaadhu channel
- SM_4-SM_5, two (2) locations within the Tilafushi lagoon facing both Tilafushi-1 and Tilafushi-2

(ii) Monitoring frequency and parameters

The frequency of monitoring shall be at least twice times a year, same as that of leachate monitoring, once during the relatively high wave and rainy season of July-August (within this 2 month period) and the other during the relatively calmer wave and dry season of January-February (within this 2 month period). Hence both the leachate and sea water quality monitoring will be conducted in tandem with each other in the same week of monitoring.

The sea water quality parameters of measurement shall be as follows;

Direct measurement at field: Temperature, pH, EC (electric conductivity) and DO (dissolved oxygen).

Measurement at laboratory: COD-Mn (manganese chemical oxygen demand), NH4-N (ammonia nitrogen), PO4-P (phosphate/ortho-phosphorus) and Sulfide shall be the minimum number of parameters to be measured at all times as the principal pollution indicator parameters. It is noted that COD-Mn is proposed instead of COD-Cr due to the difficulty in overcoming chloride interference in determining COD-Cr for clean (low COD) seawater.

Also in consideration to the insignificant level of metallic parameters measured in the seawater around Tilafushi-1 during the baseline survey of this project (ref. Table A-9 and A-10 of Annex for details), similar to that of leachate monitoring as of above, only one time measurement of the same metallic parameters as the leachate, namely, copper (Cu), iron (total Fe), cadmium (Cd), chromium (total Cr), Zinc (Zn), lead (Pb) and mercury (total Hg), is recommended to be carried out as a component of the similar baseline environment survey for the future Tilafushi-3 development project.

(iii) Monitoring agency

The Public Health Laboratory (PHL) of the Ministry of Health (MOH) shall be the responsible agency for monitoring, same as that of leachate monitoring. PHL be allocated independent budget to undertake both of these leachate cum seawater monitoring on its own conforming the frequency of monitoring (twice a year) delineated above.

(3) Coral status monitoring program around Tilafushi-2

(i) Monitoring locations

The ecological status of coral life principally both along the reef-slopes of northern inner reef adjacent to the Seawall-1 and that of the opposite southern lagoon reef adjacent to the Seawall-2 (ref. Fig. 4 and 5), forming the exterior Tilafushi reef-slopes of the landfill confinement of project area, Tilafushi-2 island, would be the principal monitoring locations.

(ii) Monitoring frequency and method

The frequency of monitoring shall be on an annual basis during the relatively calmer wave and dry season of January-February (within this 2 month period).

The Manta Tow Technique shall be used to identify and define the overall ecological status of coral life.

Still, similar to the baseline LIT (Line Intercept Transect) survey conducted for this project (ref. Section A2 ofAnnex for details), as a component of the baseline environmental survey for the future project design of Tilafushi-3, a detailed LIT survey is recommended to define clearly the status of coral life.

(iii) Monitoring agency

The Marine Research Section (MRS) of the Ministry of Fisheries and Agriculture (MOFA) shall be the responsible agency for monitoring and be allocated independent budget to undertake this monitoring on its own on an annual basis.

8. Conclusion and Recommendation

1. The most significant irreversible long term environmental effect as the direct consequence to the implementation of the project is identified as the very alteration of the ecosystem of the project area (Tilafushi-2) from a saline aquatic ecosystem to a land based terrestrial ecosystem and the resultant elimination of immobile marine biota, in particular coral life, and their habitat in the reef-flat area subjected to this ecological alteration (Tilafushi-2). Still the effect is minimized, if not entirely eliminated, with the selection of ecologically most degraded reef-flat area as the project area. It is further emphasized that the ecological value of the terrestrial ecosystem developed with solid waste landfill reclamation will be enhanced with the proposed management of the area as a green (wooded) area with active tree plantation. In this respect it is recommended that the management of completed (reclaimed) landfill area be entrusted to MOFA (Ministry of Fisheries and Agriculture).

2. Silt screen (ref. Fig. 6) is adopted as the most significant direct mitigation system of the project. This is both intended at mitigating the dispersal of dredged material to the surrounding reefs thereby potentially affecting the coral life and as well the marine water quality and also at conserving valuable landfill cover material. Its proper and continued use is essential and be ensured by the implementing agency (Project Initiator), the MCPW (Ministry of Construction and Public Works). Other significant in-built structural mitigation measures, concerned to dispersion of landfill leachate to surrounding marine environment, adopted are the steel sheet pile seawall (Seawall-2 of Fig. 4 and 5) to mitigate dispersion of leachate into Tilafushi lagoon and the stabilization pond along northern inner reef face to impart primary treatment to dispersed leachate (Seawall-1 of Fig. 4 and 5). All other potential adverse effects concerned to the implementation of the project are evaluated as insignificant.

3. Monitoring of leachate cum seawater quality and overall ecological status of the coral life in and around the project area (Tilafushi-2) on a regular basis is identified as the basic environmental monitoring requirement. The responsible agency for the monitoring of leachate cum seawater quality, twice times a year, be the PHL (Public Health Laboratory) of the MOH (Ministry of Health). The corresponding responsible agency for monitoring the status of coral life on an annual basis be the MRS (Marine Research Section) of the MOFA (Ministry of Fisheries and Agriculture). These agencies shall earmark their own budget to conduct their monitoring work independently.

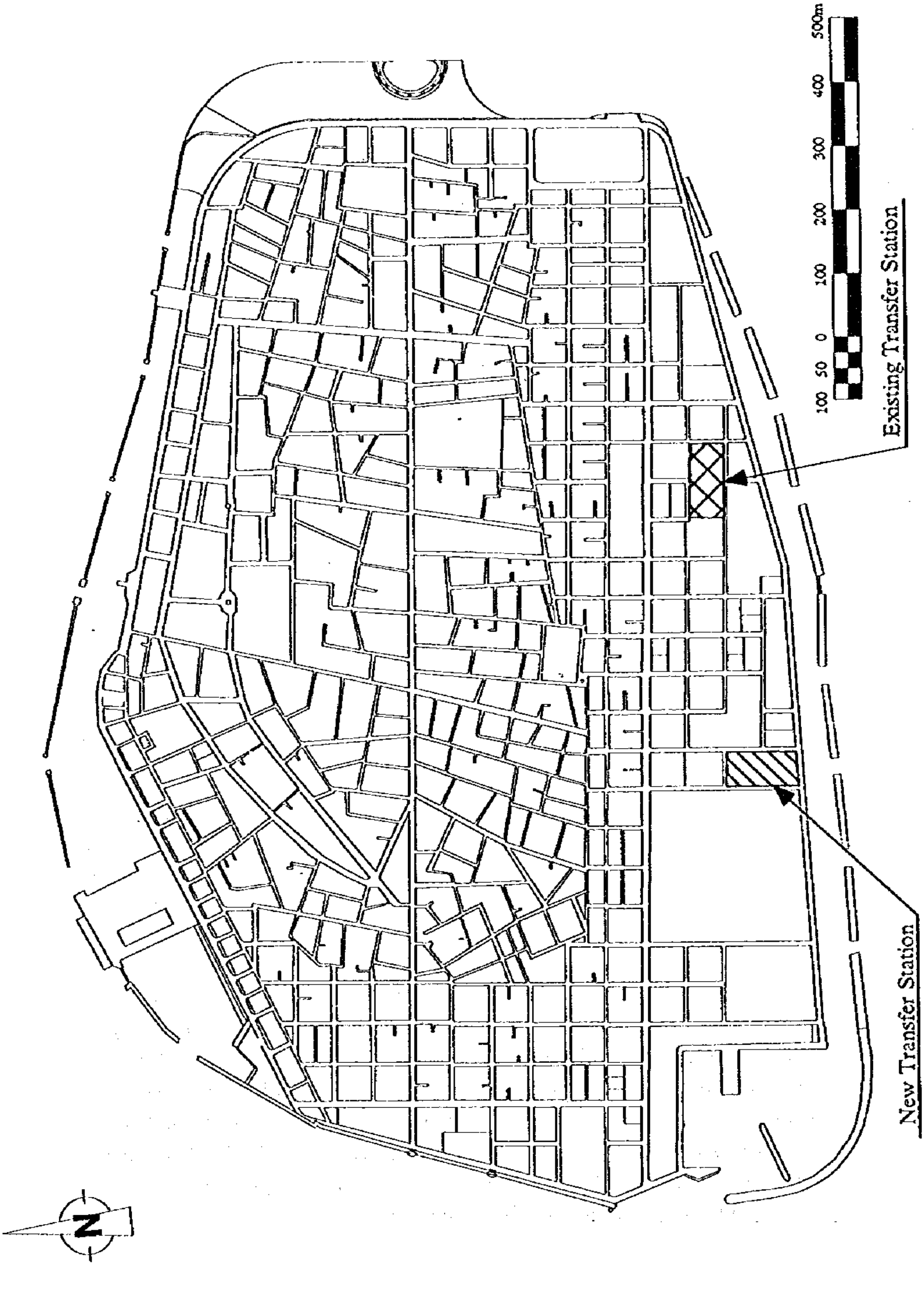


Fig. 1 Location Map of Transfer Station (Male)

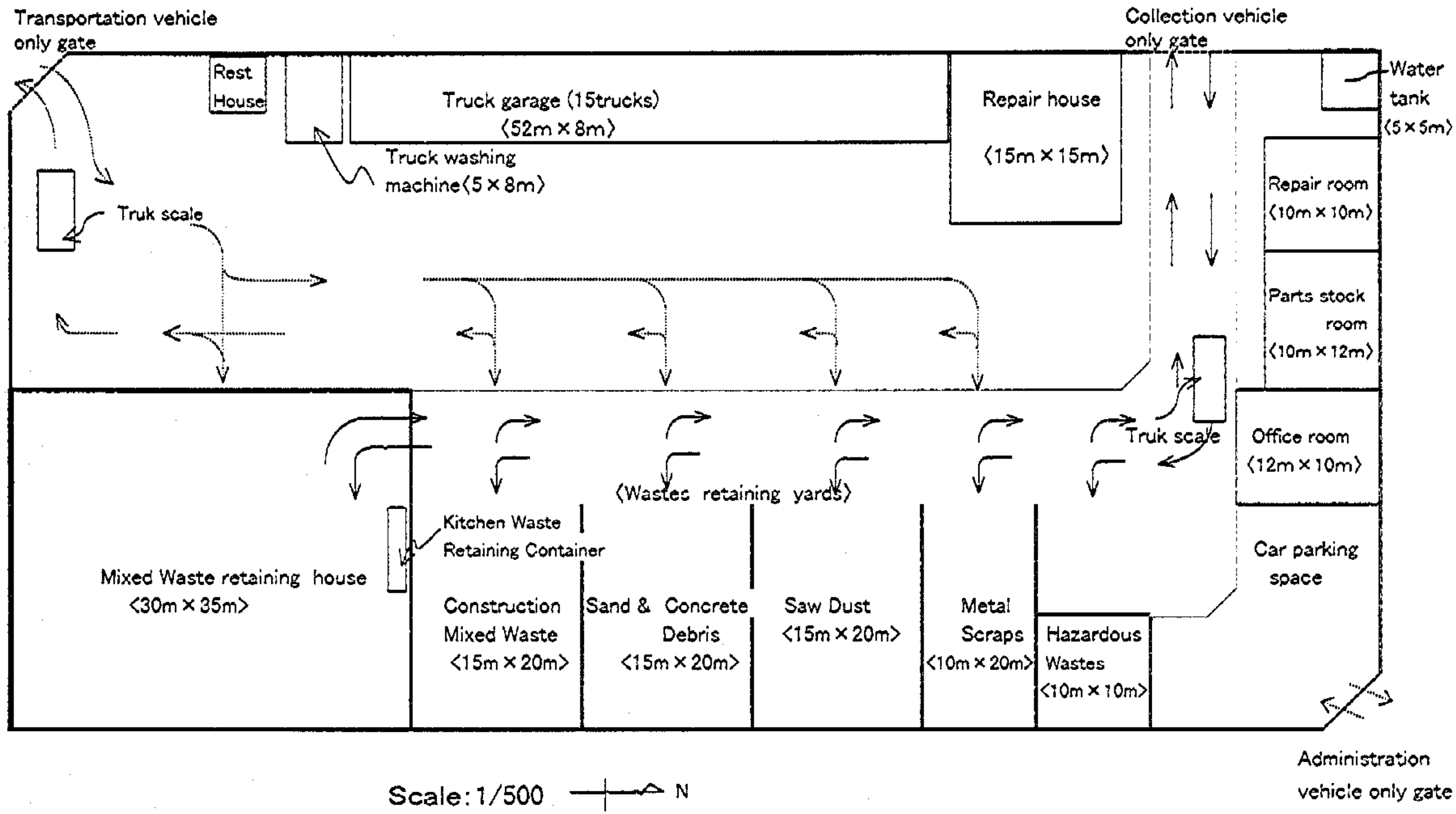


Fig 2. Transfer Station Plan (200ft×400 f t)

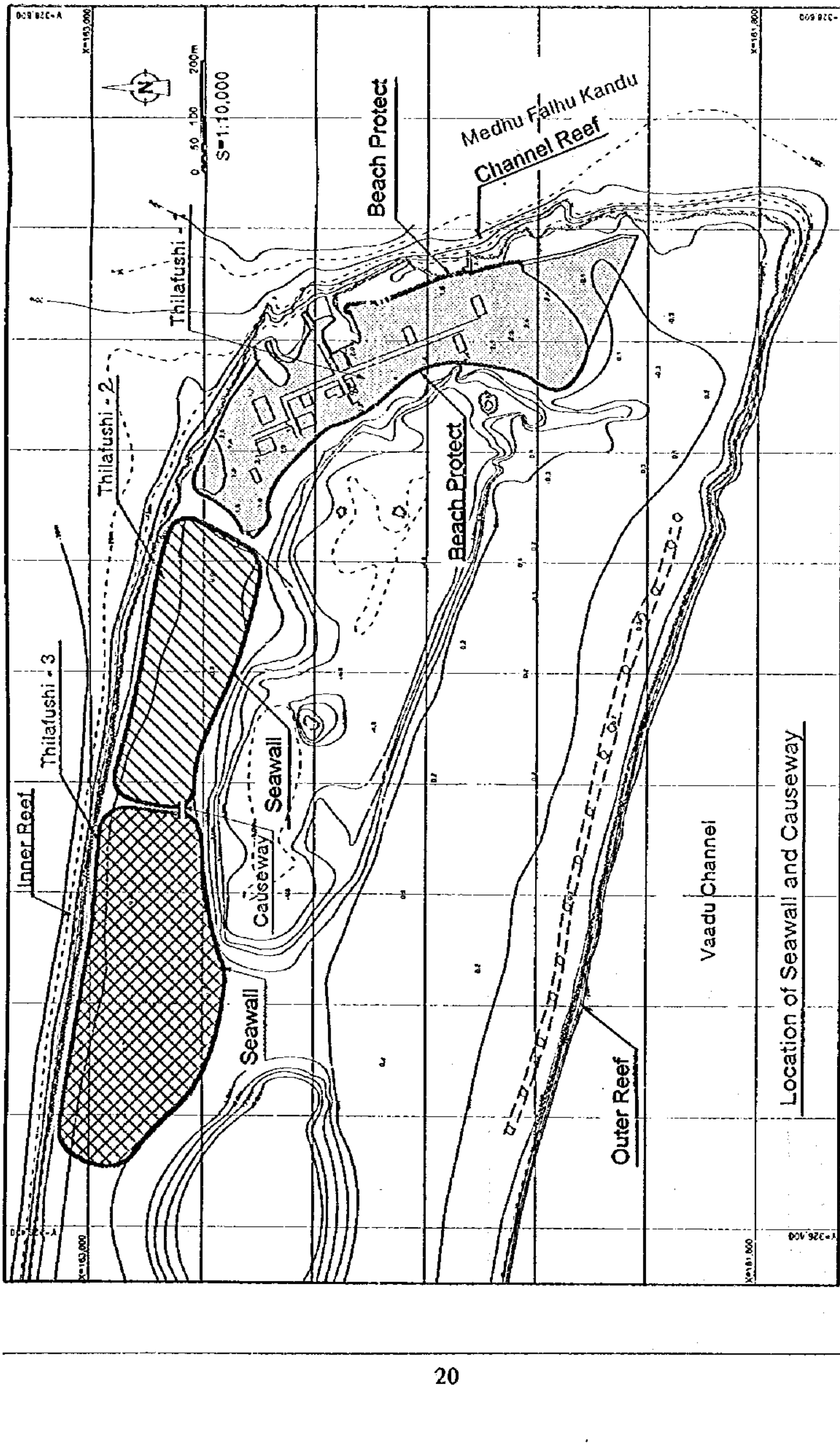


Fig. 3 Project Site in Thilafushi

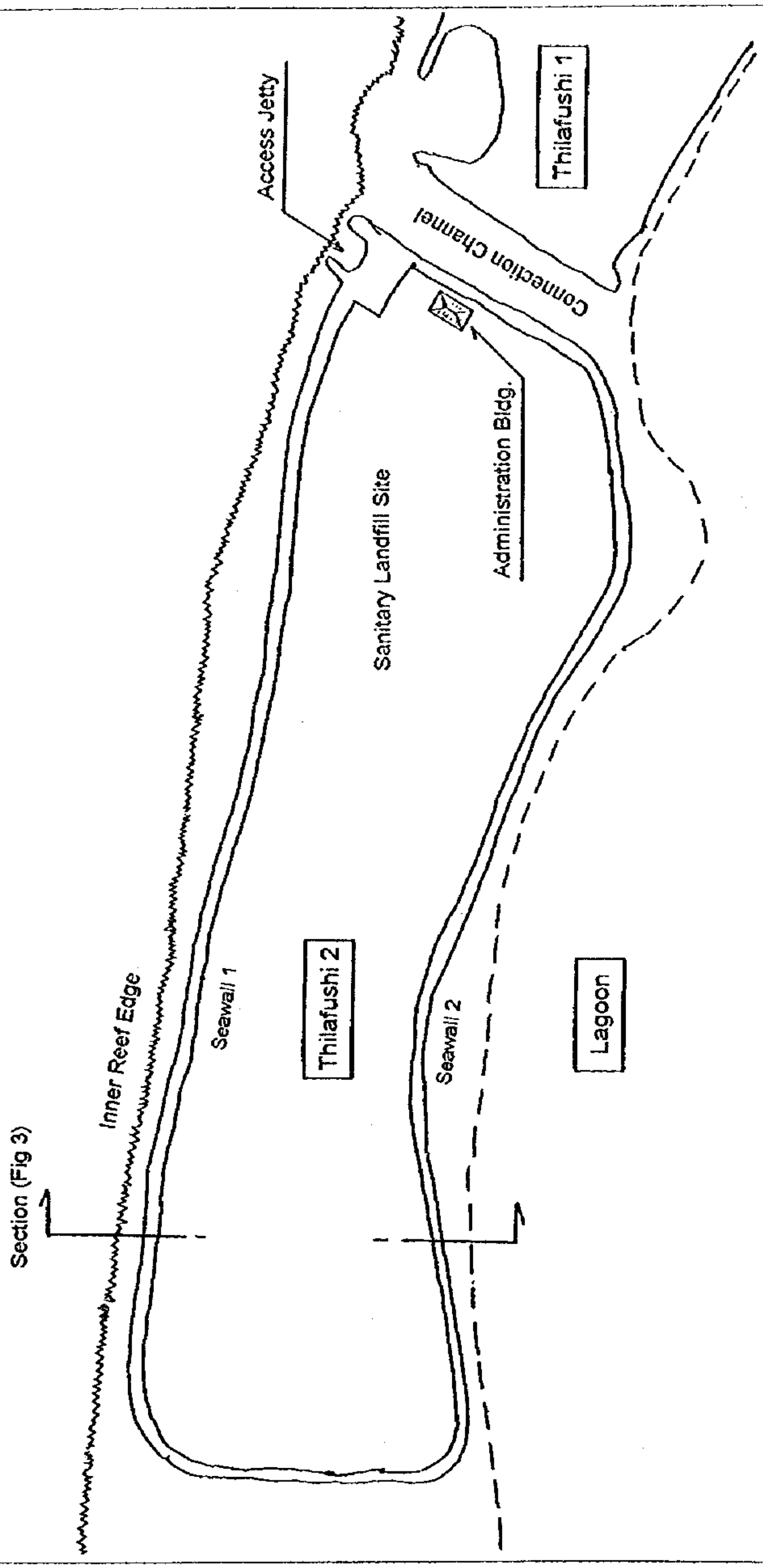


Fig. 4 Plan of Thisafushi 2

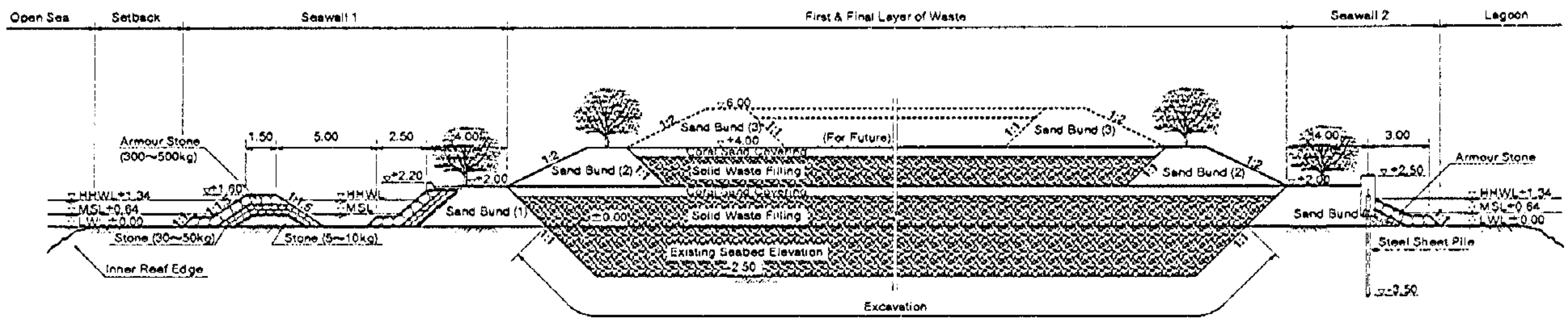
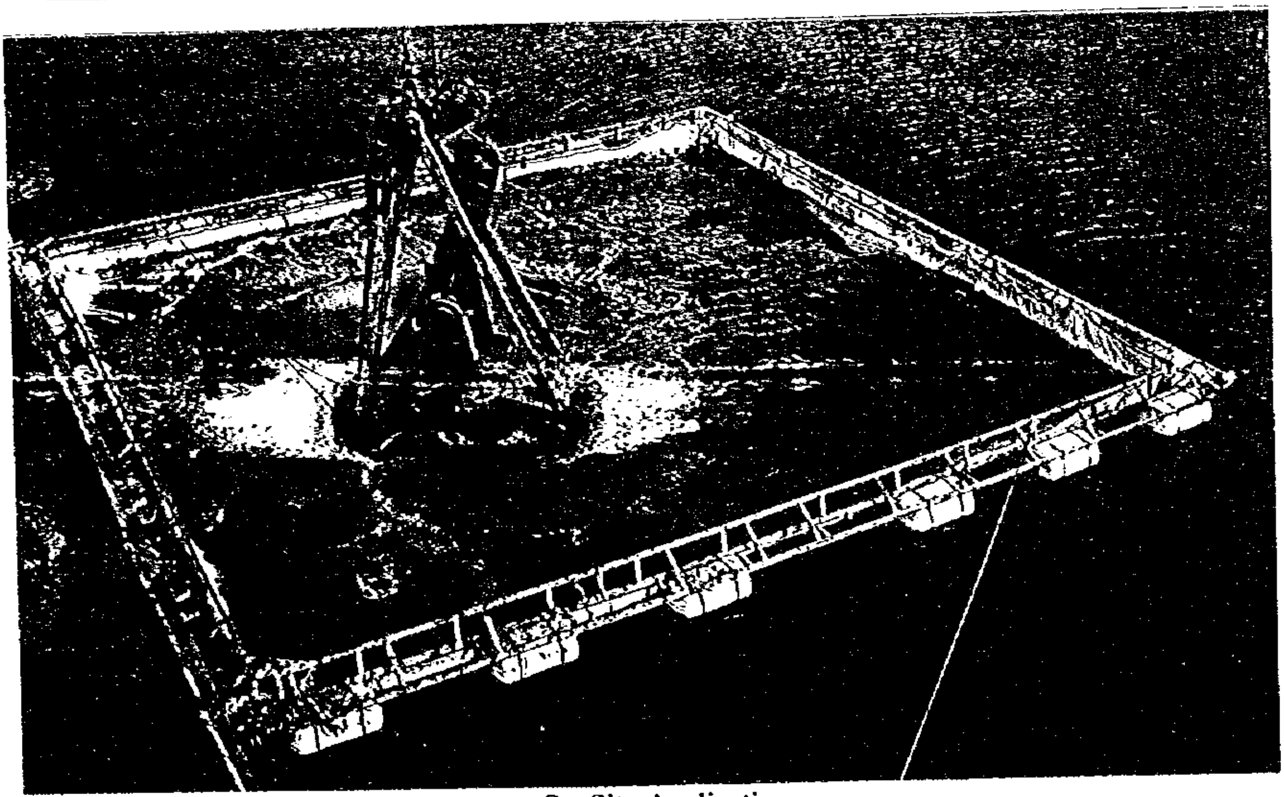
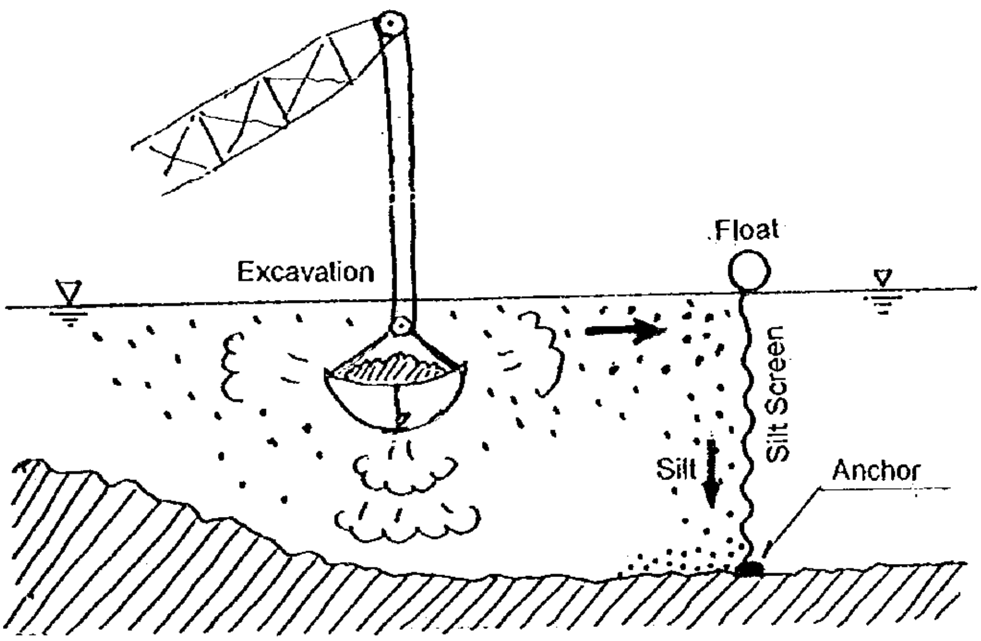


Fig. 5 Section of New Landfill Site in Thilafushi 2



a. On-Site Application



b. Function of Silt Screen

Fig. 6 Silt Screen

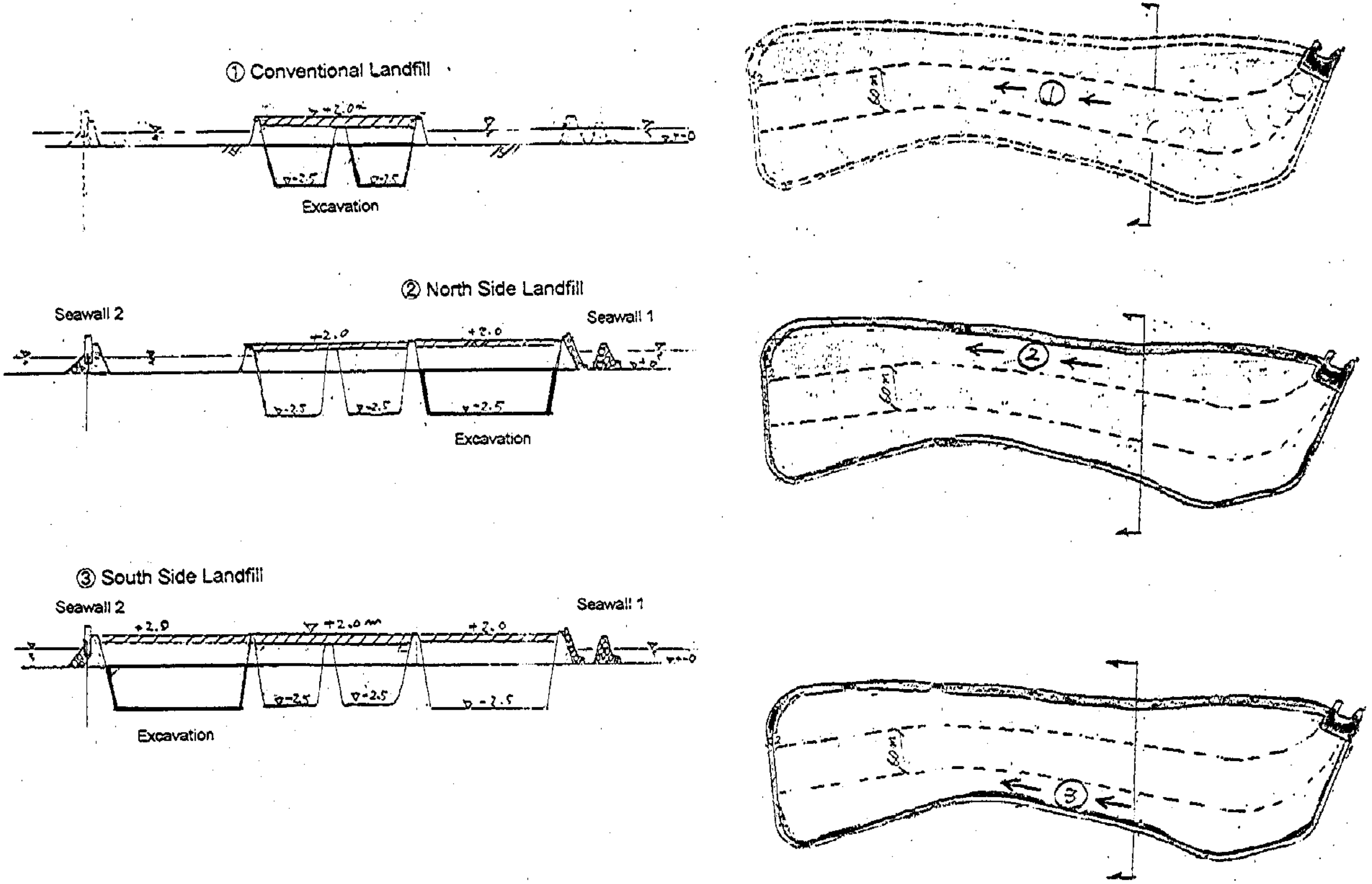
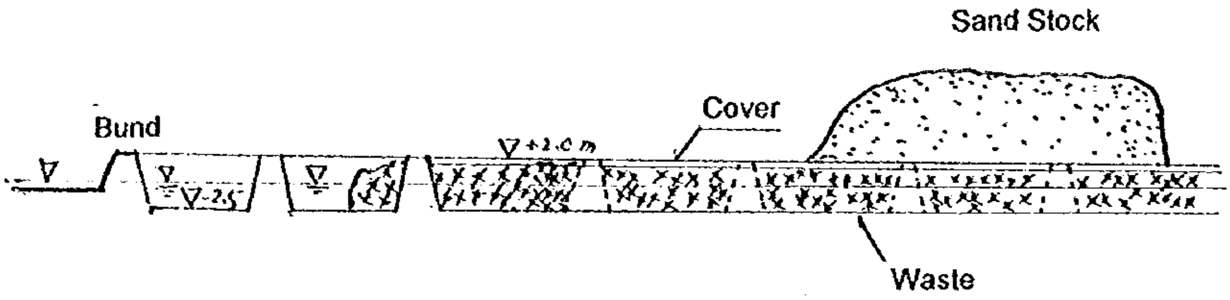
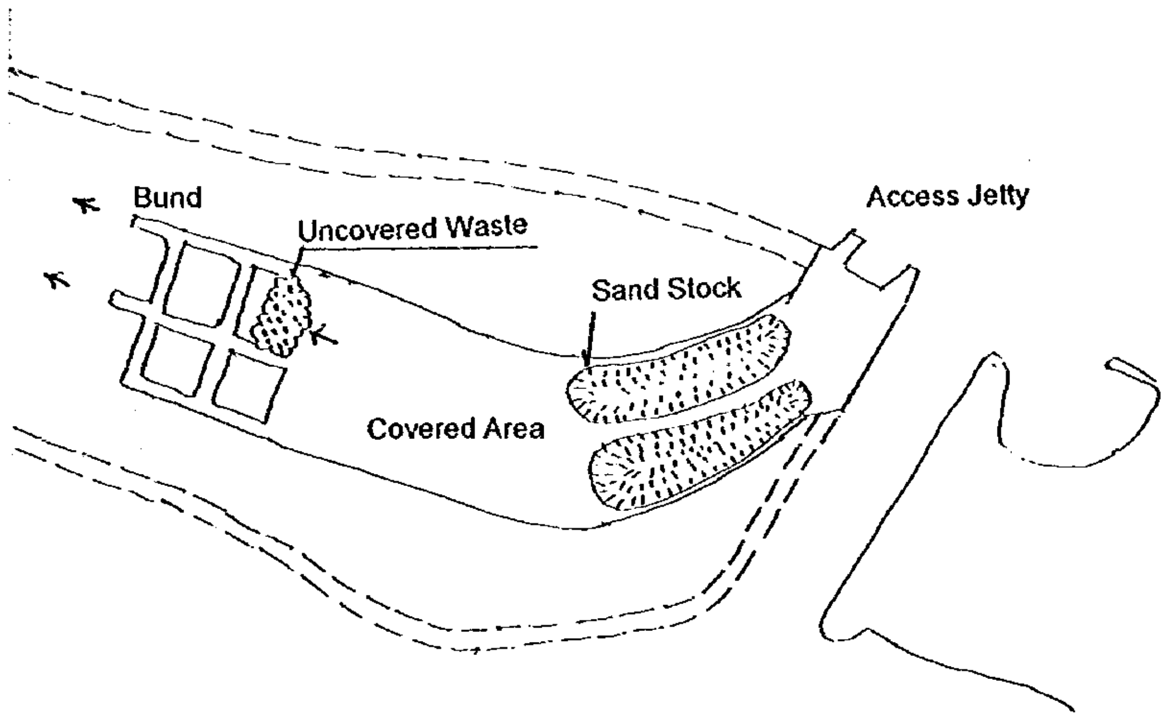


Fig. 7 Landfill Process of First Layer



b. Profile



a. Plan

Fig. 8 Excavation Method

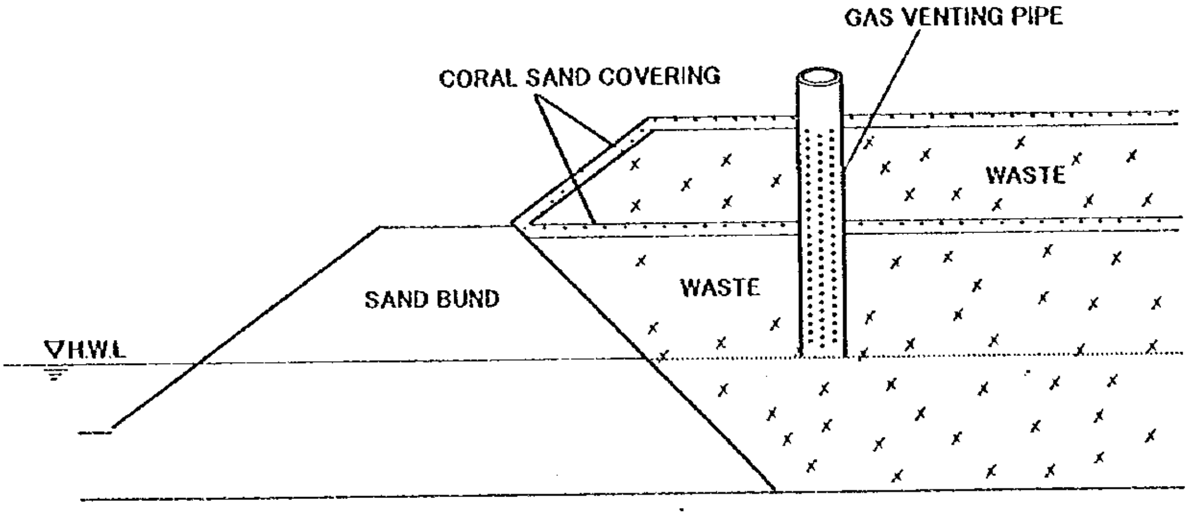


Fig. 9 GAS Venting Pipe

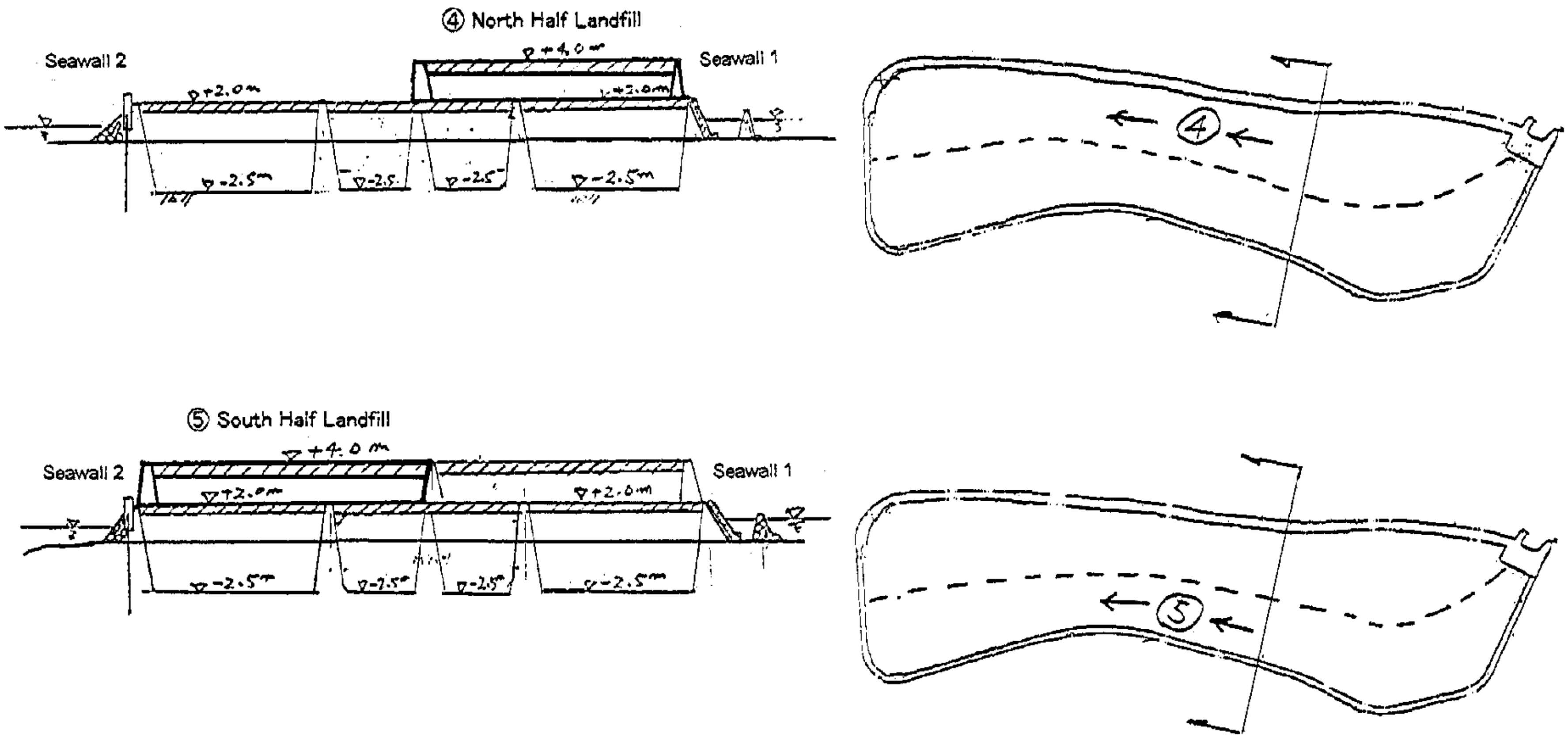


Fig. 10 Landfill Process of Final Layer

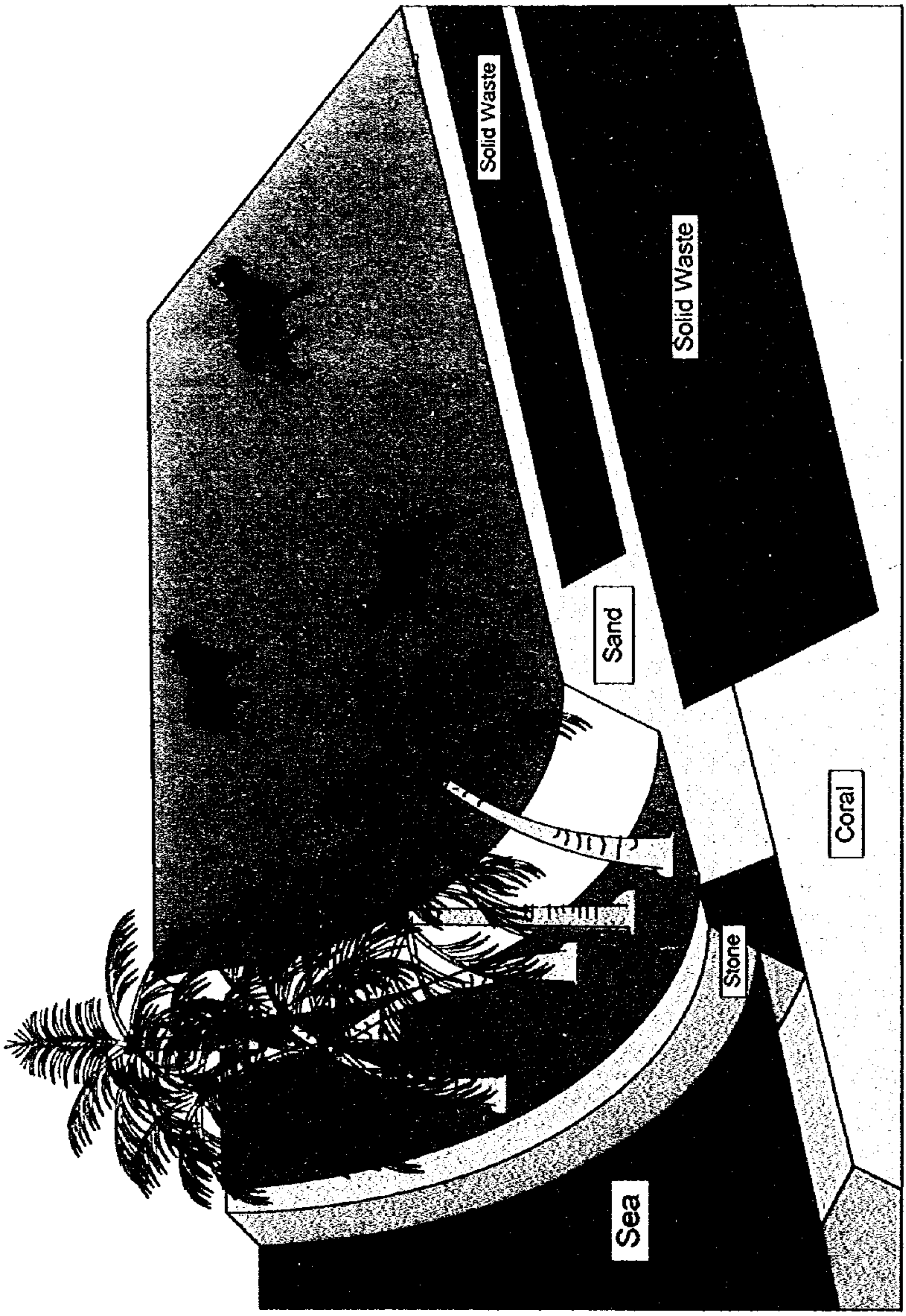


Fig. 11 Imagery of Completed Landfill

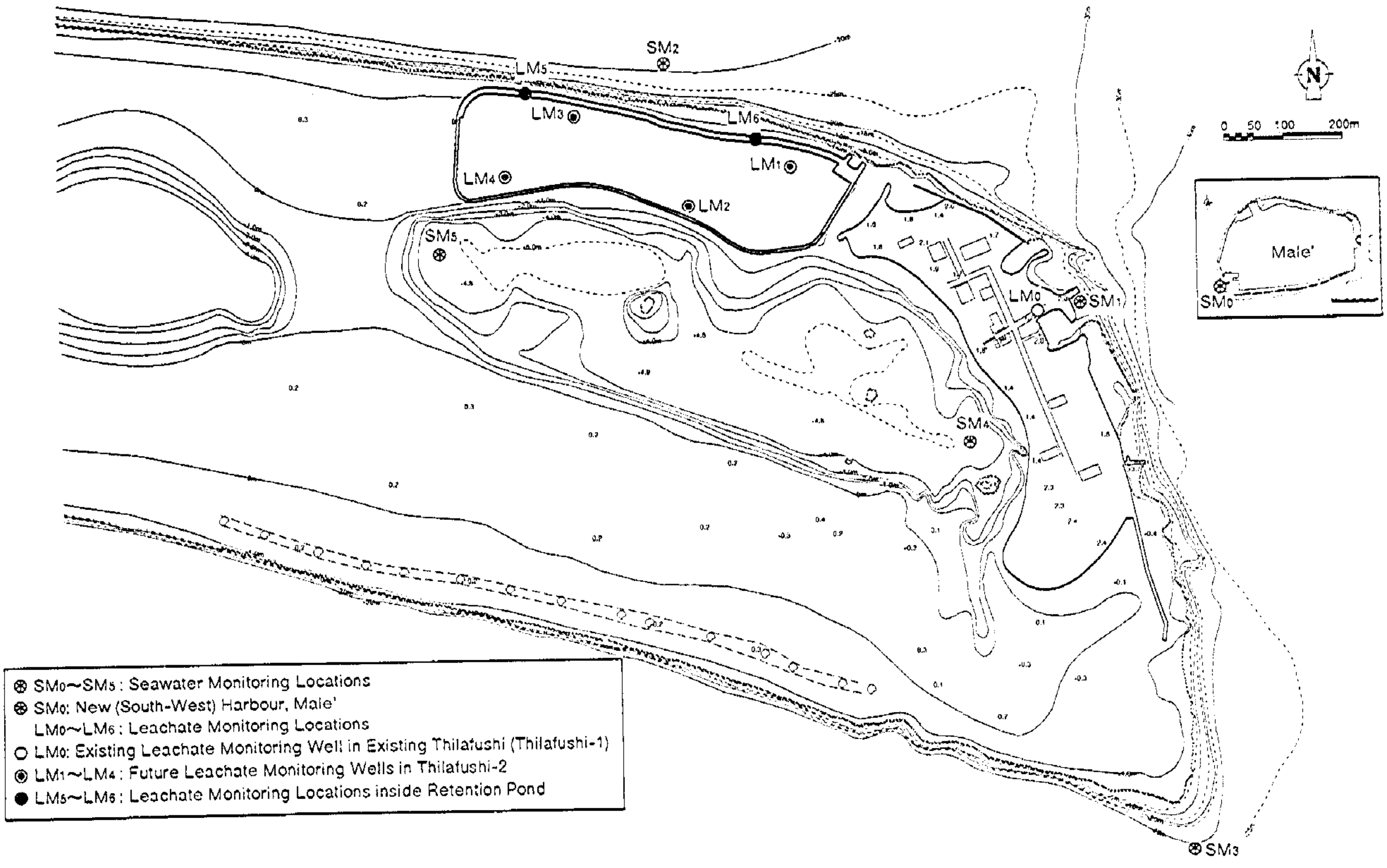


Fig. 12 Landfill Leachate and Seawater Quality Monitoring Locations

ANNEX
BASELINE ENVIRONMENTAL CONDITION

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ANNEX

BASELINE ENVIRONMENTAL CONDITION

A.1 Natural Condition on Thilafushi Island

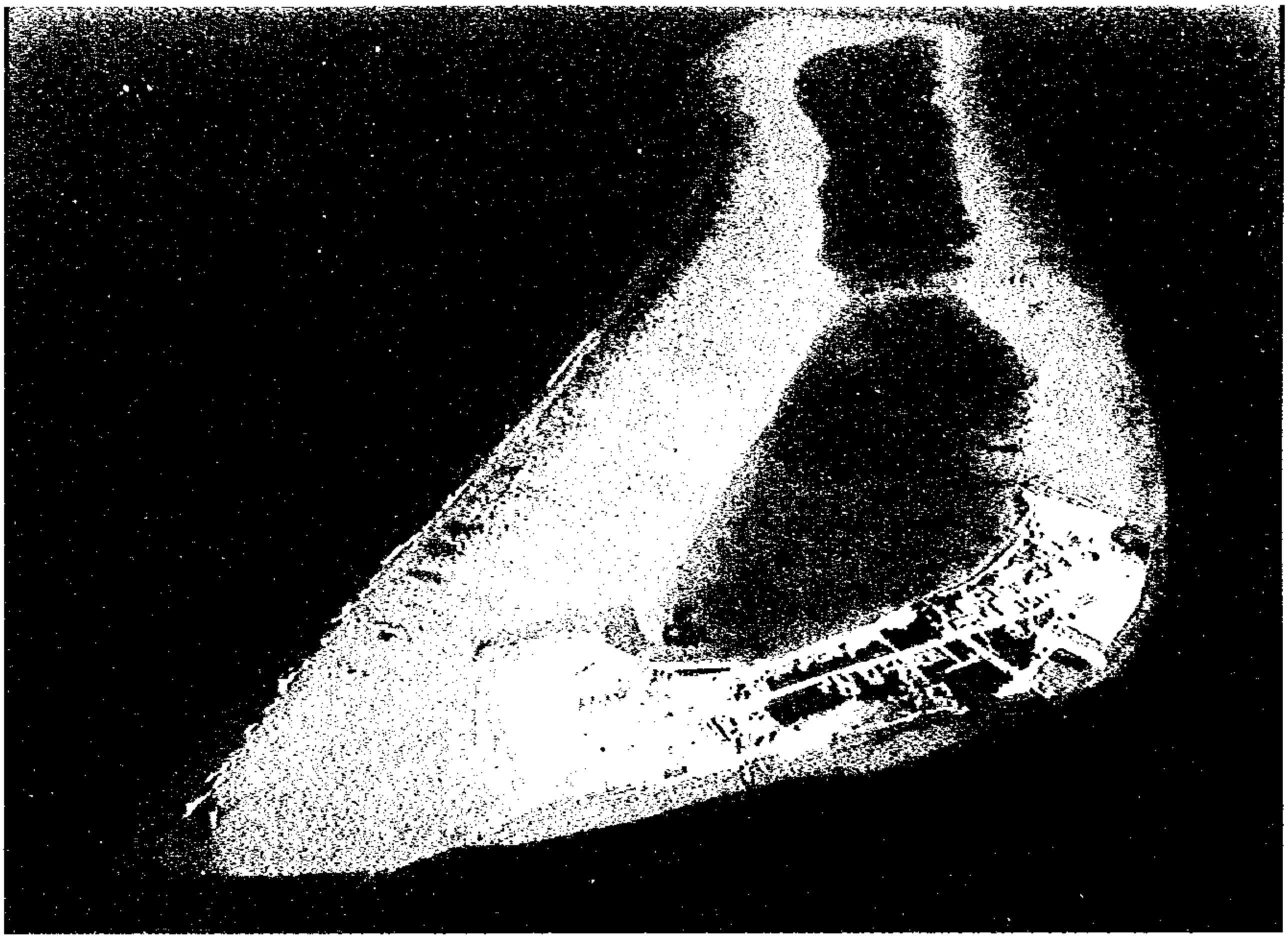
A.1.1 Topographic / Hydrographic Survey

Topographic and hydrographic survey for Thilafushi were conducted by the Study Team from July 19 to August 30, 1998. The results were drawn up in scale of 1:6000 for Thilafushi Island and its surrounding as shown in Figure A-1. However the configuration of the island has been changing day by day due to rapid sand reclamation by a suction dredger and solid waste filling. In addition to above survey, various information have been obtained from aerial photographs as shown in Photo A-1. Thilafushi reef lies on the south west fringe of North Male' Atoll and stretches from west to east in length of about 5,000 m and in width of 800 to 1,000 m. The northern reef flat (water depth :.0.5 ~ 1.5 m) facing to inner atoll is in width of 150 to 200 m and the southern reef flat facing to Vadhoo channel is in width of 250 to 350 m. Inner lagoon having water depth of about 6 m is in width of 300 to 400 m.

A.1.2 Geology and Subsoil Condition

Thilafushi reef consists of live coral, coral fragments and coral fine sand. Thila is a coral reef usually a few meters below the water surface, while fushi is a big island usually on the outside reef of the atoll. Coral growth occurs in the warm shallow waters as the volcanic base rock subsides. In due course this coral dies and forms coral rock, with new corals growing from this dead coral mass. Wave and current action produces coral sand from the coral rock formation. This sand is deposited in calmer locations, either in deep water, or, in the case of sufficiently large coral masses, at the center of the formation to produce coral islands. Where rock formations are not exposed to mechanical weathering such as in deeper water, or where coral rock is overlain by coral sand, disintegration by chemical weathering can occur, forming softer silt/clay layers. Coral atolls are one of the most complex and variable environments in which carbonate material is encountered. Coral line deposits can contain materials of vastly differing properties, from loose sand, weathered clay/silt lenses, soft and hard coral rock to large cavities in the formations. Boreholes, only meters apart, can indicate vastly different properties. Several borings were conducted in Thilafushi Island for the STO Cement Import Terminal Project, the characteristics of subsoil conditions can be classified in Table A-1.

Photo A-1 Aerial Photo of Thilafushi Island and Reef (April 15, 1998)



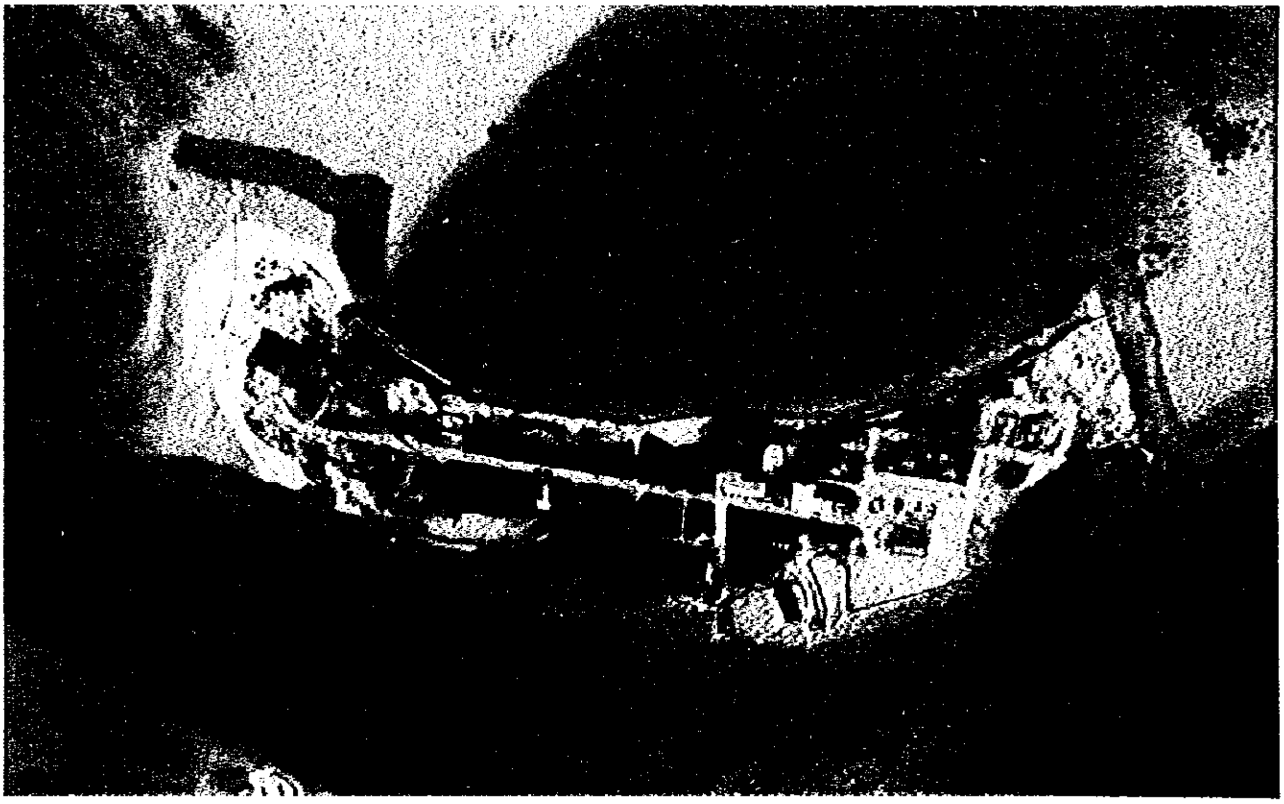


Photo A-2. Aerial photo of Thilafushi (July 23, 1998)

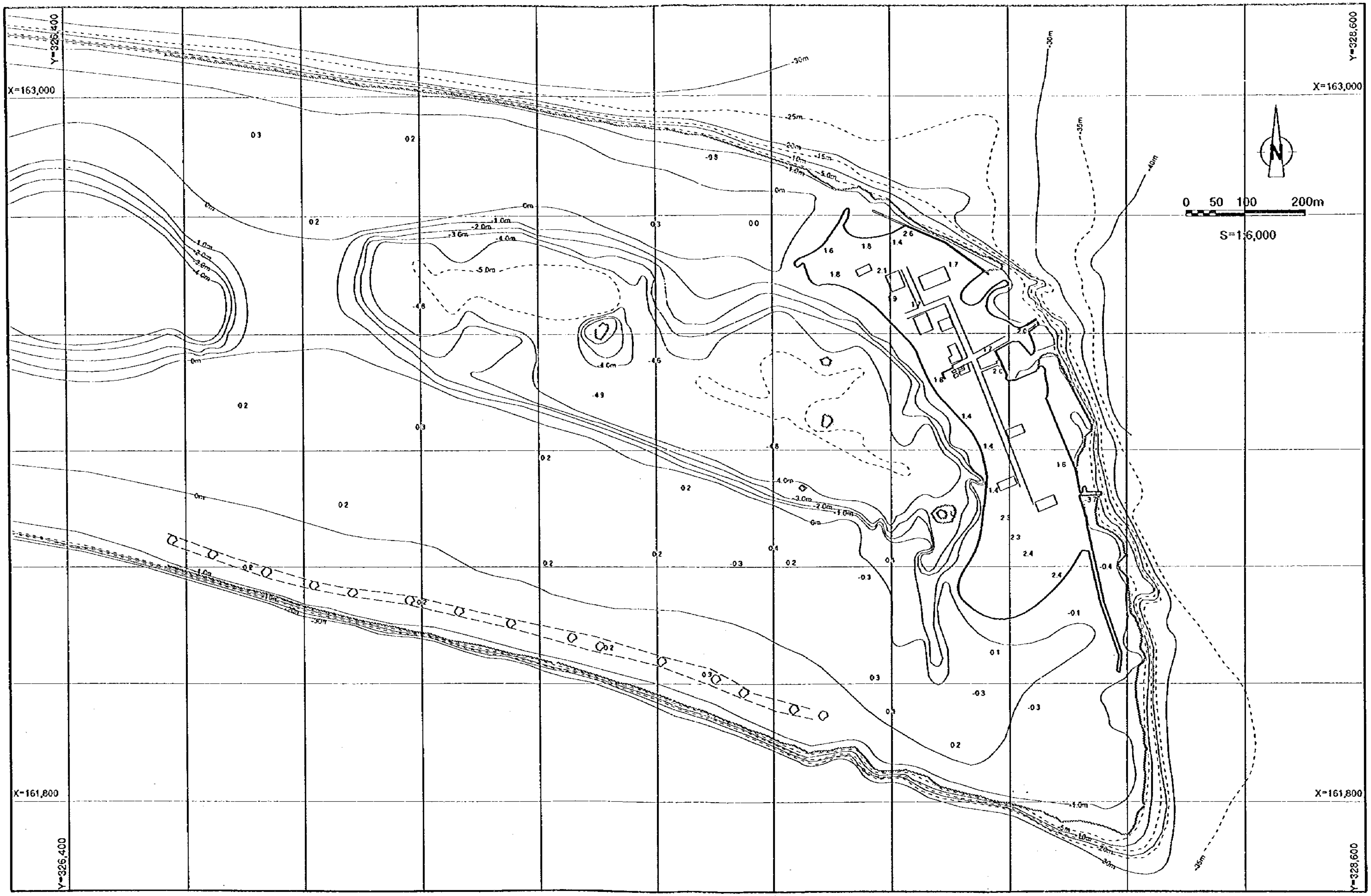


Figure A-1 Topographic Survey Map (July – August, 1998)

Table A-1 Subsoil Condition on Thilafushi Island

Boring No.1			Boring No.2			Boring No.3			Boring No.4 (a)			Boring No.5 (a)		
Depth	Description	SPT	Depth	Description	SPT	Depth	Description	SPT	Depth	Description	SPT	Depth	Description	SPT
0 - 0.2m	Rubbish & Fill Material		0 - 1 m	Fill Material with plastic & coral debris & sand	10	0 - 1 m	Rubbish / Fill Material	16	0 - 1 m	Coral Debris / Sand	10	0 - 1 m	Hardfill / Rubbish / Concrete etc.	
0.2 -1m	Sand & Fill Material	1	1 - 2 m	Sand Material (Fill)	20	1 - 2 m	Fill & Rubbish	3	1 - 2 m	Sand & Coral Debris	17	1 - 2 m	Hardfill / Rubbish / Concrete etc.	21
1 - 2 m	Sand	14	2 - 3 m	Sandy Fill Material	17	2 - 2.6 m	Fill & Rubbish		2 - 3 m	Sand & Coral Debris	25	2 - 3 m	Sand Rock @ 2.8 m	22
2 - 3m	Sand	13	3 - 4 m	Sand & Coral Fragments	14	2.6 - 3 m	Sand	8	3 - 4 m	Sand & Coral Debris	13	3 - 4 m	Coral Debris & Sand	7
3 - 4 m	Fine Sand	11	4 - 5 m	Sand & Coral Fragments	7	3 -4 m	Sand	7	4 - 5 m	Coral Debris	16	4 - 5 m	Sand & Shell Fragments	8
4 - 5 m	Fine Sand	10	5 - 6 m	Sand & Coral Fragments	5	4 - 5 m	Sand & Shell Fragments	9	5 - 6.5 m	Coral Debris & Sand	4	5 - 6 m	Sand & Shell Fragments	3
5 - 6 m	Fine Sand	14	6 - 7 m	Sand & Coral Fragments	7	5 - 6 m	Sand & Some Coral Debris	1	6.5 - 7 m	Sand & Coral Debris	29	6 - 7 m	Sand & Shell Fragments	5
6 - 7.3 m	Casing dropped under own weight while SPT rods were being with drawn from 6 m ~~level~~	4	7 - 8 m	Sand & Coral Fragments	12	6 - 7 m	Coral Debris & Shell Fragments Rock @ 6.5m	16	7 - 8 m	Coral Debris	4	7 - 8 m	Shell & Sand	1/45cm
7.3 - 8.3m	Sand	9	8 - 9.5 m	Sand & Coral Debris		7 - 8 m	Sand Coral Debris Rock @ 7.5 m	1/43 cm	8 - 9.5 m	Sand	2	8 - 9.5 m	Sand & Shell Fragments	
8.3 - 9.5m	Sand	9	9.5 - 12.4 m	Sand & Coral Debris		8 - 9.5 m	Fine Sand	1/30cm	9.5 - 12.4 m	Coral Debris & Sand		9.5 - 12.8 m	Sand with occasional lumps of Coral Debris	
9.5 - 12.8 m	Sand & Fragments shell material - strong odour with return water		12.4 m	Hard Lump of Coral Debris		9.5 - 11.8 m	Sand & Coral Debris		12.4 - 12.8 m	Sand		12.8- 17 m	Color change @14.4 m to dark brawn ,return back to light brawn @16 m	
12.8 - 15.4 m	Sand & Fragment shell		12.5 - 15.4 m	Coral Debris & Sand		11.8 - 12.8 m	Sand & Some Coral Debris		12.8 - 14.4 m	Hard Layer Coral Debris		17 - 19 m	Sand & Coral Debris	
15.4 - 15.6m	Sand & Coral Debris		15.4 - 17 m	Sand & Coral Debris		12.8 - 15.4 m	Sand & Coral Debris		14.4 - 15.4 m	Coral Debris Minor Sand		19 - 22 m	Hard Coral Debris & Sand	
15.6 - 15.7m	Fragment shell & coral boulder		17 - 21.6 m	Sand & a few Coral fragments		15.4 - 17 m	Coral Debris & Shell		15.4 - 17 m	Coral Debris Minor Sand				
15.7 - 16.4 m	Sand & Coral Debris					17 - 21 m	Sand with Coral Debris		17 - 19 m	Coral Debris Minor Sand				
16.4 - 17.4 m	Hard Coral Rock					21 - 22 m	Hard layer Coral Debris		19 - 19.2 m	Coral Rock				
17.4 - 20 m	Sand & Shell fragments/coral debris								19.2 - 20 m	Coral Debris				
20 - 21 m	Sand & Shell fragments								20 - 20.6 m	Coral Rock				
21 - 21.2 m	Coral Boulder								20.6 - 22 m	Coral Debris				
21.2 - 21. 6m	Hard Coral Rock													
21.6 -22 m	Sand & coral fragments													

Source : STO Bulk Cement Import Terminal Project, conducted by Mc CONNEL DOWELL in October 1997

A.1.3 Meteorological Condition

(1) Wind

Maldives is in the Monsoon Belt in the north Indian Ocean and the climate of the Maldives is divided into two periods, northeast monsoon season from December to March and south west monsoon season from May to October. Wind data recorded at Hulhule airport during the period between 1993 and 1997 is summarized in Table A-2.

Slightly stronger winds are associated with winds from the west typical of the southwest monsoon season. Strong winds and gales are relatively uncommon, and cyclones (hurricanes) are absent in the low latitudes occupied by the archipelago. During the SW monsoon, winds speed are typically below 12 knots for 75 % of the time, and less than 28 knots for over 99 % of the time. During the NE monsoon, 88 % of wind speeds are below 12 knots, and over 99 % are less than 22 knots. The stormiest months are typically May, June and July. Storms and squalls producing wind gusts of 50 ~ 60 knots have been recorded at Male'.

(2) Rainfall

Rainfall record during the period of 1993 to 1997 obtained at the Hulhule airport is summarized in Table A-3. Average yearly rainfall was 1969 mm in ranging between 1407 mm and 2397 mm. Maximum monthly record was 588 mm in October 1994 and minimum monthly record was 0.4 mm in February 1993. Average monthly rainfall more than 200 mm was recorded in May, September, October and November and average monthly rainfall less than 100 mm were recorded in January, February and March.

(3) Temperature, Sunshine and Humidity

Temperature, Sunshine and Humidity record during the period of 1993 to 1997 obtained at the Hulhule airport are summarized in Table A-4, A-5 and A-6 respectively.

A.1.4 Oceanographic Condition

(1) Tide and Datum Line

Tides are twice daily (semidiurnal), and typical spring and neap tidal ranges are approximately 1.0 m and 0.3 m respectively. Tidal condition on Thilafushi island can be considered the same as the one of Male' island. Therefore, the following tidal conditions can be adopted for the design of coastal facilities of the Thilafushi project in accordance with the Report of the Development Study on the Seawall Construction Project for Male' island prepared by JICA in 1992.

Design High Water Level for Outer Reef:	+1.64 m (considering wave set-up)
Design High Water Level for Inner Reef:	+1.34 m
Mean High Water Level at Spring Tide:	+1.34 m
Mean Sea Level:	+0.64 m
Lowest Astronomical Tide (LAT):	+0.00 m

(2) Wave Condition

There are two kinds of waves approaching to Thilafushi. One is swells propagated from south Indian Ocean in SW monsoon season, another is wind-waves generated by northern and eastern winds blowing in the waters in North Male' Atoll in NE monsoon. In considering the design waves adopted for the Seawall Construction Project for Male' Island, the following significant wave conditions will be employed for the design of coastal facilities for Thilafushi as indicated in Figure A-2.

	Height	Period
South Outer Reef:	3.0 m	16 sec.
North Inner Reef:	0.7 m	6 sec.
North Outer Reef:	1.2 m	4.6 sec.

(3) Current Condition

Several currents affect the Maldives islands. These currents are divided mainly into ocean currents and tidal currents, with the ocean currents being stronger than tidal currents.

The ocean currents flowing by the Maldives islands are driven by the monsoon winds. In the northern part of the Maldives, constant currents flow westward during the northeast monsoon period from December to April and eastward during the southwest monsoon period from May to August.

Generally, the tidal currents are eastward in flood, and westward in ebb. The velocity, however, varies by island area. The current patterns result from reef forms.

The study team conducted 12 hours current observation at 8 points around Thilafushi. Observations were made in every 2 meters water depth up to -20 m and every hour. The predominant currents are indicated in Figure A-3. Since observations were conducted in August of Southwest Monsoon Period, observed currents may be much influenced by the ocean currents.

Table A-2. Wind (1993-97)

	1993		1994		1995		1996		1997	Average		
	Dir	Kts	Dir	Kts	Dir	Kts	Dir	Kts	Dir	Kts	Dir	Kts
Jan	ENE	13.0	ENE	12.7	ENE	10.3	ENE	13.8	ENE	12.3		12.4
Feb	ENE	10.4	NE	8.9	ENE	9.1	NE	12.0	NE	8.9		9.9
Mar	NNW	7.3	ENE	8.0	ENE	7.5	NE	8.8	VRB	7.6		7.8
Apr	VRB	5.8	WNW	6.7	VRB	5.8	W	9.3	WNW	5.4		6.6
May	W	11.9	W	10.8	W	13.2	WNW	8.9	W	10.6		11.1
Jun	W	12.4	W	11.1	W	14.9	W	11.7	W	8.0		11.6
Jul	WNW	14.3	VRB	7.5	W	11.9	W	11.4	W	10.0		11.0
Aug	WNW	11.5	VRB	7.9	WNW	11.3	WNW	11.3	W	8.6		10.1
Sep	WNW	11.1	NW	8.9	WNW	12.3	WNW	12.6	W	9.0		10.8
Oct	WNW	11.5	VRB	8.1	W	12.4	WNW	13.0	VRB	7.0		10.4
Nov	W	12.0	VRB	7.2	WNW	11.0	WNW	8.2	VRB	8.0		9.3
Dec	ENE	7.4	ENE	11.9	ENE	14.3	VRB	10.3	E	9.3		10.6
Average		10.7		9.1		11.2		10.9		8.7		10.1

Table A-3. Rainfall (1993-97)

	1993		1994		1995		1996		1997		Average	
	mm	days	mm	days	mm	days	mm	days	mm	days	mm	days
Jan	23.6	6	70.9	7	32.3	8	158.0	6	3.2	1	57.6	6
Feb	0.4	1	1.2	2	65.4	8	47.0	6	35.3	6	29.9	5
Mar	36.1	5	99.7	6	10.8	2	51.0	5	30.2	6	45.6	5
Apr	88.7	6	78.2	14	73.9	13	324.2	15	96.2	11	132.2	12
May	453.0	18	306.4	23	240.7	21	172.8	13	227.4	20	280.1	19
Jun	138.1	14	120.8	17	69.9	14	258.5	17	76.1	14	132.7	15
Jul	358.6	20	84.4	13	162.7	11	173.0	20	178.4	15	191.4	16
Aug	145.8	13	167.8	15	171.9	18	154.1	12	226.3	15	173.2	15
Sep	322.3	21	213.3	15	126.4	13	250.4	15	194.1	17	221.3	16
Oct	196.9	16	587.6	22	271.4	21	135.1	18	147.0	18	267.6	19
Nov	428.9	21	353.0	20	107.7	8	161.3	15	316.0	22	273.4	17
Dec	204.5	14	57.8	12	73.9	11	65.1	8	419.9	27	164.2	14
Total	2396.9	155	2141.1	166	1407.0	148	1950.5	150	1950.1	172	1969.1	158

(Days with 0.3 mm or more)

Table A-4 Temperature (1993-97)

	1993		1994		1995		1996		1997		Average	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Jan	30.1	25.4	30.3	25.7	30.9	26.3	30.2	25.7	30.6	26.3	30.4	25.9
Feb	30.5	25.7	30.9	26.4	30.2	25.9	30.7	26.1	31.0	26.1	30.7	26.0
Mar	31.0	26.1	31.2	26.3	31.7	27.1	31.0	26.4	31.8	26.5	31.3	26.5
Apr	31.8	26.9	32.0	26.7	31.9	26.7	31.0	26.1	31.9	27.1	31.7	26.7
May	30.8	25.6	31.0	25.6	31.0	26.4	31.3	27.1	30.8	26.1	31.0	26.2
Jun	30.7	26.1	31.0	25.9	30.5	26.6	30.4	26.0	31.6	26.8	30.8	26.3
Jul	29.9	24.7	31.3	26.2	30.7	26.4	30.2	25.2	30.8	26.0	30.6	25.7
Aug	30.2	25.3	30.7	25.6	30.3	25.6	30.1	25.9	31.0	26.0	30.5	25.7
Sep	29.8	24.2	30.6	25.6	30.2	26.1	30.0	25.8	30.4	25.4	30.2	25.4
Oct	30.2	24.9	30.0	24.8	29.8	25.3	29.3	25.2	30.7	25.5	30.0	25.1
Nov	29.3	24.4	30.0	25.1	29.9	26.0	29.9	25.4	30.7	25.7	30.0	25.3
Dec	29.7	25.0	30.5	26.0	30.3	25.7	30.3	25.9	30.6	25.2	30.3	25.6
Ave.	30.3	25.3	30.8	25.8	30.6	26.2	30.4	25.9	31.0	26.1	30.6	25.9

Table A-5 Sunshine (1993-97)

Hours

	1993	1994	1995	1996	1997	Ave.
Jan	223	266	245	252	297	257
Feb	288	253	233	269	245	258
Mar	283	257	301	289	303	286
Apr	279	257	252	227	277	258
May	209	139	204	263	207	204
Jun	218	189	186	160	247	200
Jul	195	232	230	172	191	204
Aug	283	199	220	259	259	244
Sep	216	196	242	211	194	212
Oct	269	167	232	231	222	224
Nov	158	174	244	240	202	204
Dec	205	209	246	287	175	224
Total	2826	2537	2834	2858	2820	2775
Ave.	7.7	7.0	7.8	7.8	7.7	7.6

Table A-6 Humidity (1993-97)

%

	1993	1994	1995	1996	1997	
Jan	74	75	76	79	78	76
Feb	70	75	77	78	77	75
Mar	74	74	73	75	76	74
Apr	74	75	79	81	78	77
May	81	78	83	78	82	80
Jun	78	79	81	82	81	80
Jul	80	76	80	80	79	79
Aug	77	76	80	79	79	78
Sep	79	76	78	81	82	79
Oct	78	79	82	83	81	81
Nov	82	80	79	79	82	80
Dec	79	77	78	77	83	79
Ave.	77	77	79	79	80	78

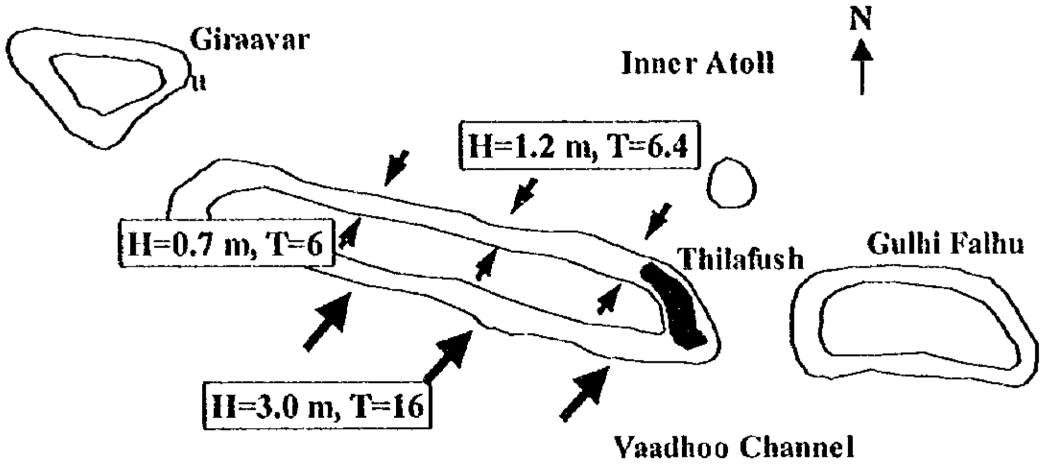


Figure A-2. Waves approaching to Thilafushi

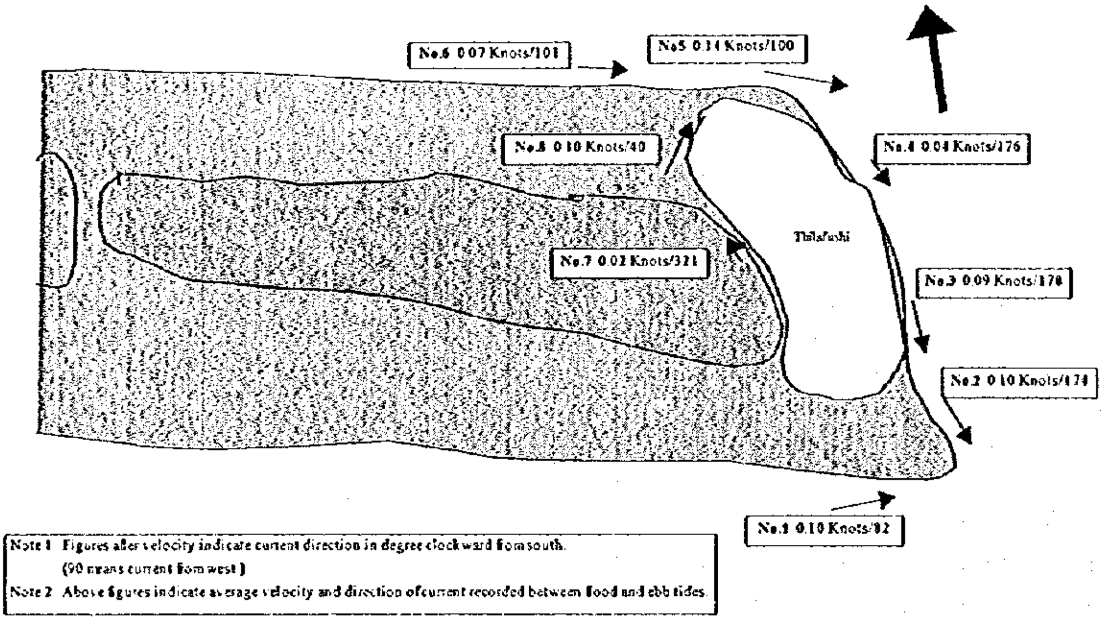


Figure A-3. Current Records (August 1998)

A.2 Coral Ecology

A.2.1 Introduction

The ecological status of coral life in Thilafushi reef, including the Marine Protected Area (MPA)-Lions Head, and Gulhifalhu, including the MPA - Hans Hass Place (Kiki Reef),.were studied using both Manta Tow Survey and detailed Line Intercept Transect (LIT) survey.

Thilafushi comprises a submerged ring reef known locally as a *Faro*. This type of reef structure is unique to the Maldives. It is located in North Malé Atoll to the west of the capital island Malé on the southern perimeter of the atoll barrier reef, facing the 4.5 km width Vaadu channel which separates North Male and South Male Atolls. To the east of Thilafushi is another faro - Gulhifalhu which is separated by a narrow channel called Medhu Falhu Kandu (refer to Figure A-4).

The coral reef community structure is strongly influenced by the physical environment such as wave energy, exposure, currents, sea-water temperature, salinity and tidal influence. In the Maldives, sites situated on the outer atoll reef have different community structure to those on the inner atoll reef and those lining the channels. The survey design concentrated on a limited number of sites near the landfill area at Thilafushi and Gulhifalhu with appropriate reference locations.

A.2.2 Survey Methodology

(1) Manta Tow Survey

The observer was towed using a manta board and rope behind a Dhoni (traditional boat). The tows were carried out parallel to the reef crest for 2 minutes at a constant speed, the boat stopped to allow the observer to record the data. GPS (global positioning system) was used to determine the locations of survey points.

Purpose: The Manta Tow technique was used to conduct a broad-scale assessment of large areas of the reef system at Thilafushi and Gulhifalhu. This technique provided information on the following:

a) the spread of garbage from the landfill site

b) percent cover of live, dead and soft coral

c) selection of representative sites for the Line Intercept Transect (LIT) survey

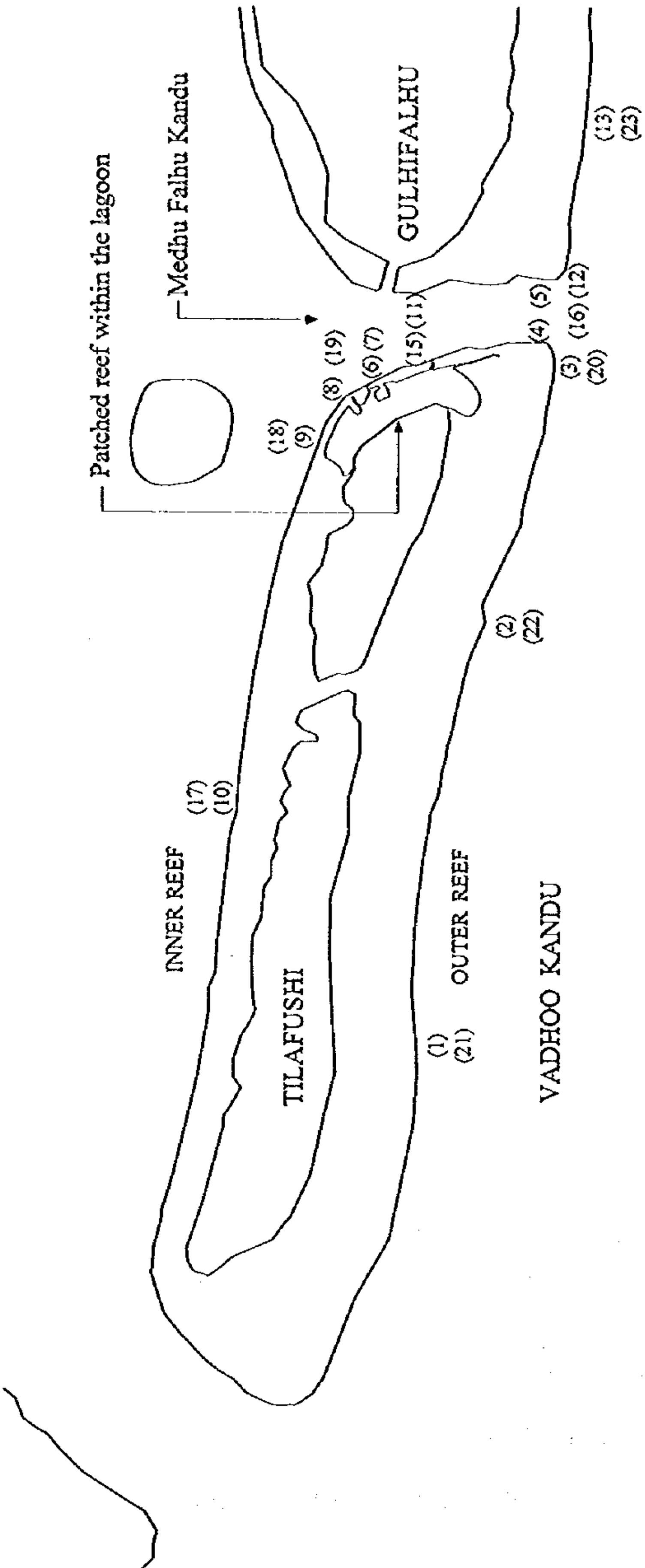


Fig. A-4. Locations of Line Transect Coral Survey - Tilafushi and Gulhifalhu (JICA)

(2) Line Intercept Transect (LIT)

The selected representative locations of LIT survey are shown in Figure A-4, which basically targeted the existing solid waste reclaimed Thilafushi Island and its vicinity. These stations are classified according to their reef locations as shown below (RF-Reef-flat, RS-Reef-slope, MPA-Marine Protected Area).

Outer atoll reefs		Inner atoll reefs		Channel reefs	
Site Ref.	Reef location/name	Site Ref.	Reef location/name	Site Ref.	Reef location/name
1=RF 21=RS	Thilafushi - south Lions Head (MPA)	9=RF 18=RS	Thilafushi - north	4=RF 5=RS	Thilafushi - east face (south)
2=RF 22=RS	Thilafushi - south	10=RF 17=RS	Thilafushi - north	6=RF 7=RS	Thilafushi - east face (north)
3=RF 20=RS	Thilafushi - south-west point	8=RF 19=RS	Thilafushi - north-east point	11=RF 15=RS	Gulhifalhu - west face (north)
13=RF 23=RS	Gulhifalhu - south Kiki reef (MPA)			12=RF 16=RS	Gulhifalhu - west (south)

A 20 m transect line was laid along the specified contour by the dive buddy pair. For the shallow reef-flat station the transect was positioned approximately 5 m from the reef crest. The depth varied between 1-3 m and was generally deeper on the outer atoll reefs. The reef-slope transect was located at 10 m at all stations.

Purpose: The Line Transect was used to assess the condition and health of reefs at the selected stations. The method provides information on the following key community parameters:

a) Species number per transect

b) Number of coral colonies per transect

c) Live/Dead coral coverage per transect

d) Coral health (i.e. bleaching)

(3) Fish Census - Belt Transect Method

The fish belt transect was the first survey completed after the transect line was deployed. The census was started after a minimum 5 minute period during which no divers were allowed to disturb the area. The recorder swam slowly along the transect counting all fish encountered within a belt 2.5 m of each side of the transect line.

Purpose: The fish census was used to collect information on the reef fish community including:

a) Coral reef fish abundance

b) Coral fish diversity

A.2.3 Findings of the Survey

(1) Manta Tow Survey

a. Thilafushi reef

i) Coral reef assessment

Live coral cover varied between 10-40 % for the inner atoll reef, 0-20 % for eastern (channel) reef and 15-20 % for the outer atoll reef. Generally, live coral cover was low adjacent to the landfill, channels and harbour areas as a result of physical coastal alteration.

A manta tows was also conducted at the west side of Thilafushi to act as a reference area. Live coral cover varied between 20-60 % at the reef-slope.

ii) Garbage

The highest density of general domestic garbage was observed along the east face of the reef-flat from the main harbour to the small jetty towards the south. This comprised cans, glass bottles and plastics. Construction waste was generally associated with areas which had been modified for channels and harbours. The reef area at the north-east point towards the inner atoll reef also had a large volume of construction waste, which was probably associated with the construction of the sea wall. There was less garbage at the outer atoll reef.

b. Gulhifalhu

i) Coral reef assessment

Live coral cover on the outer atoll reef-slope varied from 20-60 %. However, bleaching was highly uniform at around 80 %. Moving along the south reef towards the entrance of the channel live coral cover was reduced to 10-15 %. Visibility at the south-west point was reduced due to sediment plumes that originated at the south-east point of Thila Fushi. Along the west face of the reef the amount of live coral cover was patchy, generally between 10-20 %. In the vicinity of the boat channel to the lagoon, coral cover had been reduced to zero by dynamite blasting and dredging. Coral bleaching was around 60 %, being lower than that estimated for the outer atoll reef.

A manta tow was also conducted at the east side of Gulhi Falhu. Live coral cover was low (between 2-15 %) and large amounts of coral rubble and sand shutes indicated that this area had been impacted in the past.

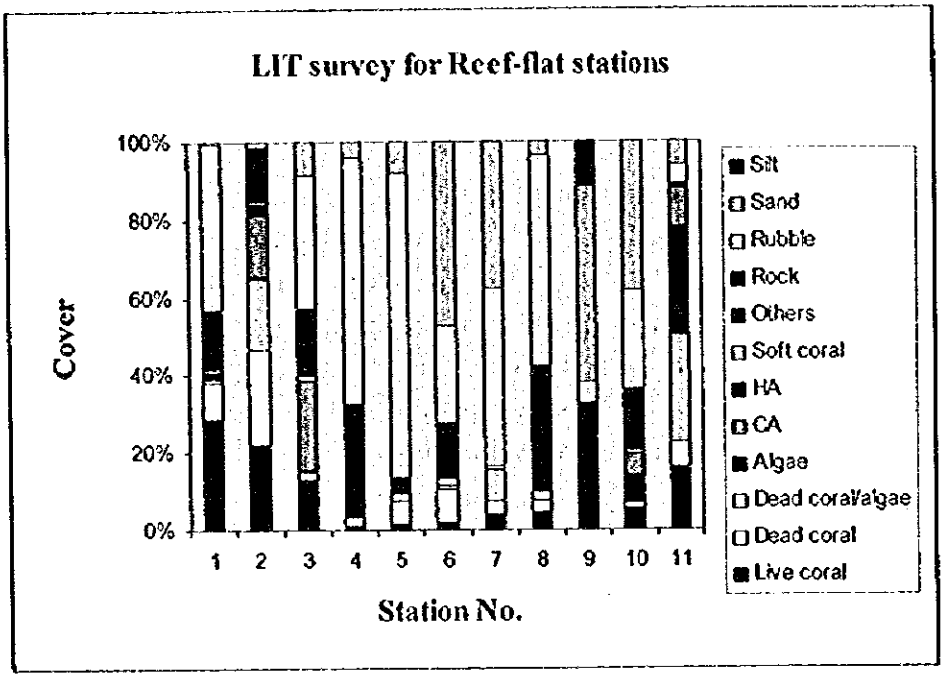
ii) Garbage

Both domestic and construction waste was randomly distributed along the entire west face of the reef adjacent to the channel. Higher densities of construction waste were associated with reef-flat area close to the channel entrance to the lagoon. Overall there was virtually no garbage at the outer and inner atoll reefs. At the eastern side of Gulhifalhu, there were large amounts of garbage distributed randomly. It is possible that this reef area has been used as a dump site during the redevelopment of Villingili.

(2) LIT survey

The results of the line intercept transect (LIT) survey are shown in Figure A-5 distinguished between reef-flat stations and reef-slope stations. The percent live coral cover also distinguished between reef-flat and reef-slope stations is shown in Figure A-6.

All sites showed high levels of variation in the percent cover of benthic reef organisms and substrate types. Overall the ratio of non-living substrate (NLS) cover to living cover was significantly greater in the reef-flat stations with the exception of reference areas located away from the landfill site at outer atoll reefs - Kiki reef, Gulhifalhu (#13) and Thilafushi-south (#2) (refer to Figure A-4 for the location of stations).



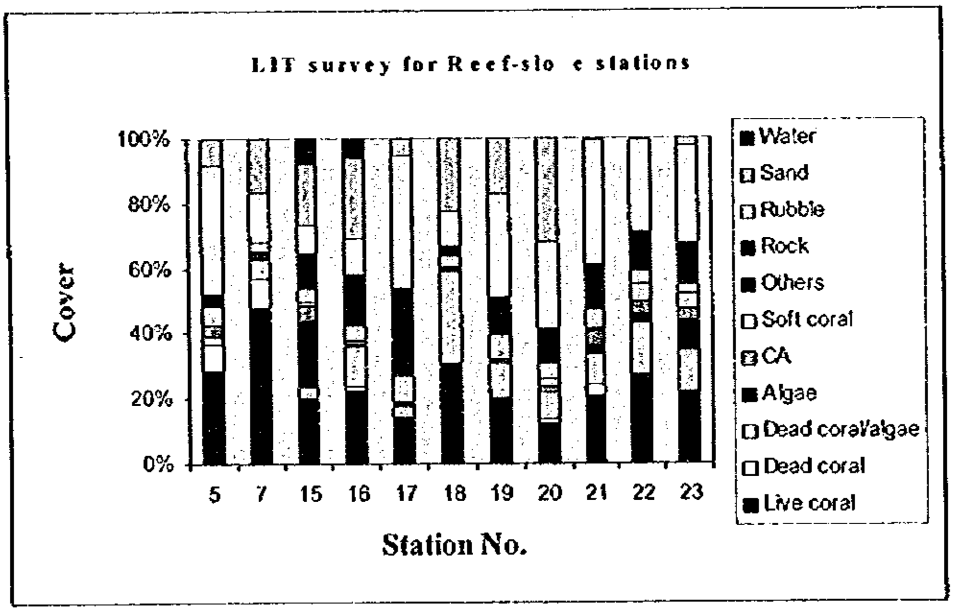
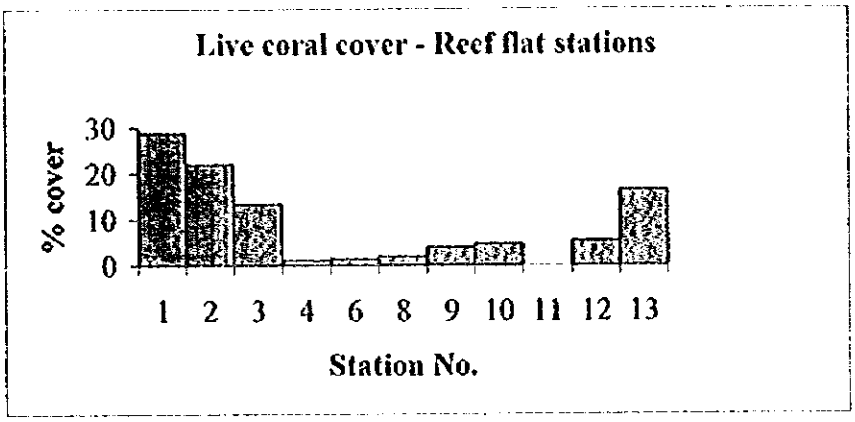


Figure A-5. Life form benthic categories and non-living substrate at reef-flat and reef-slope stations at Thilafushi and Gulhi Falhu.

Note : HA-Halimeda algae, CA-Calcareous algae



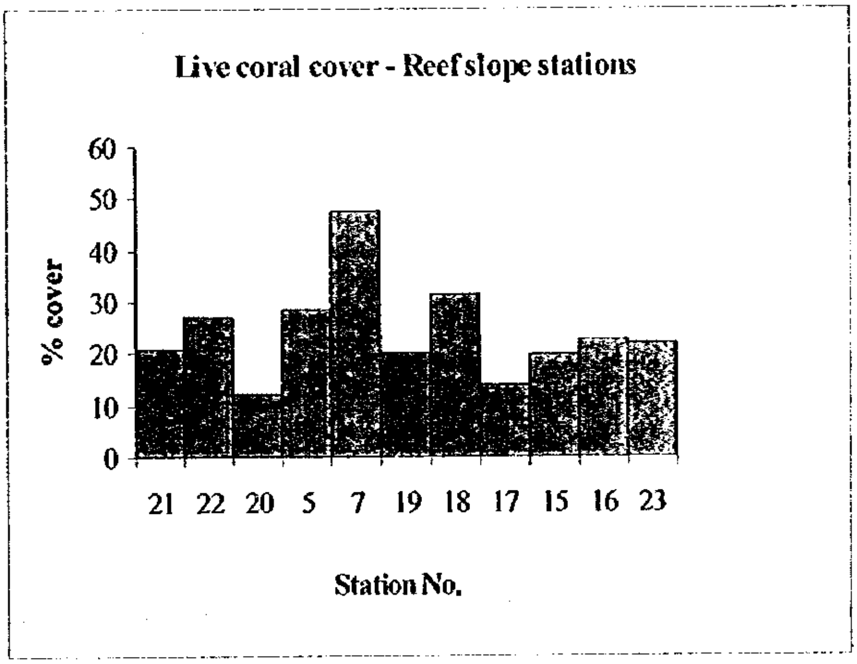


Figure A-6 Percent live coral cover for all reef- flat and reef-slope stations

i) Reef-flat

Live coral cover in the reference stations (outer atoll reefs) adjacent to the Vaadu Channel varied from 13-29 %. The Marine Protected Area (MPA) - Lions Head (#1) had the highest live coral cover. All remaining reference sites supported high calcareous and coralline algae cover (10-22 %) which is typical of wave exposed reef sites. Live coral cover at Kiki reef (#13 MPA at Gulhifalhu) was only 16 %, however, recently dead coral accounted for 28 % cover. The high value for this category was associated with the recent bleaching event.

All inner atoll reef stations supported low live coral cover (2-4 %) and had a high ratio of NLS. Similar values were recorded for the channel reef stations at Thilafushi and Gulhifalhu (0-5 % live coral cover). The non-living substrate categories in these stations varied considerably but overall coral rubble and sand were dominant at most stations.

Based on these observations, the inner reef-flat of Thilafushi would be the preferred location for future expansion of solid waste landfill development, since this choice at-least would minimise the inevitable and irreversible loss of coral life inherent to landfill development.

ii) Reef-slope

Live coral cover for the outer atoll stations varied from 12-27 % and was similar to values recorded for the corresponding reef-flat stations. In contrast, both the inner atoll and channel stations showed a considerable increase in percent live coral cover compared to their corresponding reef-flat stations. Live coral cover varied from 14-31 % for inner atoll reefs and from 20-48 % for channel reefs. The highest live coral cover (48%) was recorded at Thilafushi at the northern channel (#7) where the reef-flat cover was only 1 %. A similar situation was noted also at the station on the inner atoll reef towards the north-east point (#18), live coral cover was 31% for the reef-slope compared to 4 % for the reef-flat.

Based on these observations, it could be concluded that the existing solid waste reclaimed Thilafushi Island, though led to the rather inevitable loss of reef-flat coral life due to ecological alteration of the very reclaimed land environment from aquatic to terrestrial and other physical alterations, it virtually caused no significant adverse effect on the coral life of reef-slope in the channel (Medhu Falhu Kandu) reef.

iii) Patch reefs in Thilafushi lagoon

Due to the topography and reef contour it was not appropriate to use the LIT method for assessing cover by benthic organisms and NLS. A semi-quantitative assessment was adopted which involved making a visual estimate of % live cover and dead cover and the dominant substrate type. Visibility at the eastern area of the lagoon close to the landfill was reduced to less than 3m.

Live coral varied between 5-15 %, dead coral accounted for up to 80 % and the dominant NLS was sand (5-10 %). Large portions of the dead coral were colonised by dense growths of dark red filamentous mats of algae. This algae belongs to phylum Cyanophyta (Blue-green algae) which often form fuzzy masses of filaments. They generally prefer high temperatures and sunlit areas with elevated nutrients. These algae were not observed in patch reefs distant from the landfill areas. The conditions responsible for the dense growth of blue-green algae may involve a combination of factors such as nutrient enrichment and elevated sea water temperatures. At the same patch reef the coral diseases known as *black band disease* and *black spot disease* were observed on some coral colonies.

The elevated nutrient level and its perceived adverse effect on coral life due to progressing eutrophication in the lagoon could be attributed to insufficient dilution of dispersed leachate into the lagoon from the Thilafushi landfill site.

iv) Transfer station in Malé

The Malé transfer station is situated within the south-west harbour at the north towards the entrance. The shallow area adjacent to the transfer station was inspected by snorkelling to assess the condition and the status of garbage. The sea-bed in this area was composed of sand and fine rubble and the only coral communities were those growing on the concrete sea-walls and breakwaters. Overall the nature and level of garbage is similar to that observed in other parts of the south-west harbour. Accordingly, it is concluded that there was no significant adverse effect on the marine environment due to the activities associated with the transfer station.

v) Evaluation of Bleaching

At the beginning of the present survey, sea surface temperatures were returning to 29-31 °C from the previous high values of 32-34 °C recorded in May 1998. Evidence of bleaching was clearly visible from the surface, with large expanses of pale coloured reef communities. Over the survey period, large number of reef organisms, particularly hard and soft coral colonies regained their pigmentation. However, certain species of hard coral appeared to be more susceptible to bleaching and hence suffered high mortality and were rapidly colonised by filamentous algae.

All reef organisms may be stressed for a long period as a result of this bleaching event. It is therefore imperative to reduce other sources of stress to promote conditions that would allow natural recovery processes. In areas, such as Thilafushi, where coral reef organisms are subject to high sedimentation the ability of the organisms to remove the sediment may be reduced. Hence it is imperative to mitigate the dispersal of dredged material due to landfill management in Thilafushi to surrounding marine environment.

vi) Fish Census

All stations showed similar trends in terms of the abundance of fish in the major fish families encountered, namely, Triggerfish, Surgeonfish, Parrotfish, Wrasses, Damselfish, Butterflyfish, and Groupers. Degraded reef-flat areas tended to be dominated by wrasse and parrotfish. Damselfish were abundant at all reef-flat stations with the exception of the inner atoll sites.

Reef-slope stations were characterised by high densities of damselfish, particularly juveniles. Groupers and butterflyfish distinguished reef-slope stations from their corresponding reef-flat stations. Overall the number of species within the different reef areas was very similar, with the exception of physically degraded areas.

vii) Protected or endangered species at or close to the landfill site

A small number of protected species were observed at the outer atoll reef stations at Thilafushi and Gulhifalhu adjacent to the Vaadu Channel. These included the hawksbill turtle, the grey reef shark and black coral. In all cases observations were at 10 m depth or lower and hence not at reef-flat areas.

A.2.4 Conclusion

It is recognised that some damage to the coral reef system in the vicinity of the landfill operations is inevitable. However, this must be weighed against the benefits arising from the improvement to public health and the environmental pollution in Malé as a result of the solid waste collection and disposal system now in place. It is however, important to ensure that any damage to the coral reefs in the immediate vicinity of the landfill are minimised and that all possible control measures are adopted to protect the adjoining reefs.

High level of sedimentation and silt from dredging activities is considered as the major cause of reef degradation associated with the Thilafushi solid waste land reclamation site. The results of the LIT surveys indicate that reef-flat areas opposite the impacted site on Gulhifalhu are also affected by the high concentration of fine suspended particles. Hence it is imperative to mitigate the dispersal of dredged material (sediment) into the surrounding marine environment.

Overall the impacts from garbage are highly localised and directly associated with the Thilafushi landfill site. No significant distribution of garbage on to the adjoining reefs was noted. Despite the large volumes of loose garbage at the landfill and in the shallow back-reef areas, the amount of garbage observed underwater was fairly low. Nevertheless, from the very basic view points of aesthetics of marine environment and technically sound means of final solid waste disposal, it is imperative to prevent dispersal of garbage into surrounding marine water environment.

A.3 Water and Sediment Quality

The water and sediment (sea bed material) quality in Male Island, the major solid waste generation and transfer area, and Thilafushi Island, the area where the solid waste is transported and dumped resulting in reclamation of the very island from the submerged reef, is studied in this section.

This study is made both based on available water quality monitoring data with the Public Health Laboratory (PHL) of the Ministry of Health (MOH) and also with water and sediment sampling and analysis conducted by the Study Team, principally in and around Thilafushi Island and as well in Male Island.

Relevant waters of concern to solid waste management activity of both at present and in past are groundwater in Male, sea water both around Thilafushi and Male and leachate generated in the already reclaimed (existing) Thilafushi Island. It is noted that until recent past solid waste was used in combination with other materials for the reclamation of southern part of Male Island from sea. This is perceived as a cause of poor groundwater (well water) quality with high hydrogen sulfide (H_2S) levels, as monitored by the PHL.

Concerning sea-bed material quality either around Thilafushi Island or Male Island there is no available data, since no such sediment sampling and analysis was conducted in the past. As such analysis results by the Study Team will only be used to define the status of sea bed material and effects, if any, due to solid waste reclamation of Thilafushi Island.

A.3.1 Water quality

(1) Available data

a. Groundwater in Male

The groundwater in Male is saline with chloride level mostly exceeding 1000 mg/l and hence unfit for potable use from the view point of this very basic drinking water quality requirement. Widely reported recent range of chloride level (1996-1998 data, as available in PHL) in groundwater is from 1000 to 3000 mg/l, at times even up to 15,000 mg/l which is almost the same as that of sea water (chloride level in Male coastal sea water is around 20,000 mg/l). It is also noted that the chloride level in Male groundwater as determined by the previous JICA study for the Seawall Construction Project in 1991 also exceeded 1000 mg/l in all five (5) wells measured.

Still, the available data in PHL on groundwater quality a decade ago in Male (1988) indicated a chloride level of around 100 mg/l only, which was even less than the chloride level of around 250 mg/l in the desalinated potable water presently supplied by the Maldives Water and Sanitation Authority (MWSA). Hence the present high groundwater chloride level in Male could be attributed to salinity intrusion of sea water, which might also be aided by sea reclamation of land, due to the obvious cause of over exploitation of groundwater by recent high increase in population.

Moreover, the recent (1997-1998) groundwater quality data of PHL indicates widespread contamination with Hydrogen Sulfide (H_2S) distributed to all over the Male island, with H_2S level exceeding 3 mg/l.

This effect also could be attributed to past land reclamation of the southern part of the island with solid waste which results in lechate generation, and the over exploitation of groundwater which contributes to the dispersion of lechate to the entire underground of the island, thereby affecting the groundwater quality of even those parts of the natural (non-reclaimed) island.

Based on the above aspects it could be concluded that the groundwater in Male island is both saline and polluted and not suited for most beneficial uses, in particular potable use.

b. Leachate in Thilafushi

Monitoring of the lechate quality generated in the Thilafushi solid waste landfill (sea reclamation) site was initiated in October 1993, with the provision of four (4) leachate monitoring wells within the already reclaimed area. Simultaneously, sea water quality monitoring around the sea area of the entire Thilafushi reef, including the near-by reefs of Gulhifalhu and Bodugiri, at seven (7) monitoring stations, were also initiated (refer to the subsequent section on sea water).

However, with time not only this leachate cum sea water monitoring frequency has become infrequent, but also the leachate monitoring wells (bore-holes) were gradually demolished to only one single remaining well at present (1998). No monitoring data is available for the entire year of 1995 and also no monitoring was conducted in this year (1998).

Of the leachate quality parameters monitored, though comprised of 25 items, that could be regarded as primary pollution level indicators due to decaying solid waste represented by leachate are only three (3), namely, Ammonia, Hydrogen Sulfide and DO (dissolved oxygen).

As could be expected of leachate quality rather wide range of ammonia and H2S and consistently almost nil (0) DO were noted, typical for high strength wastewater. The most recent data of July, 1997 indicated an ammonia level around 115 mg/l and varying H2S level of about 2 and 18 mg/l measured in 2 monitoring wells remained at that time. However since COD (chemical oxygen demand), the most representative parameter to determine the pollution load of a high strength waste like leachate was never measured, due to lack of laboratory capability, no quantitative estimation of the strength of leachate is possible, based on the available data.

c. **Sea water**

There are seven (7) sea water quality monitoring stations established in October 1993, simultaneously with the above mentioned leachate monitoring programme in Thilafushi, around the entire reef of Thilafushi, including its surrounding reefs of Gulhifalhu and Bodugiri. (refer to Figure A-9 for locations). This is the only consistent long term (1993-1997) sea water quality monitoring data available in the vicinity of the Study Area including Male and Villingilli islands.

All sea water quality monitoring were conducted almost simultaneously (on the same day or in 2 days time) with the leachate quality monitoring delineated above, since this is an integrated leachate cum seawater quality monitoring programme in and around the Thilafushi reef. Also other than for the addition of Transparency (Visibility) all parameters monitored are the same as that of leachate monitoring, and hence the total parameters monitored were 26.

This integrated leachate cum seawater quality monitoring programme could be considered to be intended at monitoring the effect of dispersion of leachate from the Thilafushi landfill to the surrounding marine environmental water quality on a macro basis, since except for one (1) monitoring station located at jetty where solid waste transportation barge unload the solid waste containing vehicles on to the island, all the remaining 6 stations are located away from the immediate vicinity of Thilafushi.

Anyhow the available sea water quality monitoring results (1993-1997) indicate the marine water quality remains typical to that of sea water with no discernable effect attributable to dispersion of leachate to marine environment.

Still it should be noted that this monitoring programme does not target adequately the immediate vicinity of Thilafushi reef, in particular the inner lagoon of the reef. Moreover, marine water quality is only a broad (macro) means of assessing the health of marine water environment and it alone would not be sufficient, though necessary, to guarantee that the ongoing solid waste filling and the related activities of dredging of reef and the resultant dispersal of sediment (dredged material) and over carriage of garbage to reef surroundings of the Thilafushi Island do not in fact affect the marine ecosystem.

(2) Sampling by the Study Team

Water quality sampling by the JICA Study Team targeting ground water in Male (4 locations), leachate in Thilafushi (4 locations) and sea water around Thilafushi, including its immediate vicinity and the seven (7) established monitoring stations of PHL (19 locations), and Male (2 locations) were conducted in the beginning of September 1998.

The water quality parameters measured were basically the ones to determine the pollution effects including heavy metals and same for all three (3) types of water (groundwater, leachate and sea water). Significant parameters measured are, namely, temperature, pH, DO (dissolved oxygen), COD (chemical oxygen demand), sulfide, sulfate, ammonia, nitrite, nitrate, phosphate, total coliform (TC), fecal coliform (FC) and the metals of iron (total), copper, chromium (total), lead and mercury.

The water quality sampling locations are shown in Figure A-7 (groundwater and seawater cum sediment sampling locations of Male), Figure A-8 (leachate sampling locations in Thilafushi), Figure A-9 (seawater sampling locations in the 7 monitoring stations of the PHL around Thilafushi reef) and Figure A-10 (seawater cum sediment sampling locations in the vicinity of Thilafushi).

The following code system was used to distinguish the types of sampling locations;

- The four (4) groundwater sampling locations of Male coded as G1 to G4 (Figure A-7)
- The four (4) leachate sampling locations of Thilafushi coded as L1 to L4 (Figure A-8)
- The seven (7) seawater sampling locations of the PHL monitoring stations around Thilafushi coded as S1 to S7 (Figure A-9)
- The fourteen (14) seawater cum sediment (sea-bed material) sampling locations in vicinity of Thilafushi and Male coded as SW1 to SW14 (Figure A-10 for SW1-SW12 of Thilafushi and Figure A-7 for SW13-SW14 of Male)

It is noted that the location SW13 at south-east coast of Male was selected as a representative station for background quality, while the location SW14 at the south-west harbour of Male is selected as it is the loading area for solid waste transportation barge from Male to Thilafushi landfill island (ref. Figure A-7).

Also all the remaining 12 locations of SW1-SW12 were selected in and around the immediate vicinity of the existing solid waste reclaimed Thilafushi island, but still to encompass the possible areas of the Thilafushi reef that could be subjected to future solid waste land-filling by this master plan including the inner lagoon of the reef adjacent to the existing solid waste reclaimed Thilafushi Island (ref. Figure A-10).

The sediment (sea-bed material) sampling results of these 14 locations (SW1-SW14) is dealt with in the subsequent section on Sediment Quality.

The results of water quality analysis for groundwater in Male (G1-G4 of Figure A-7) is summarised in Table A-7, that of leachate in Thilafushi Island (L1-L4 of Figure A-8) in Table A-8, that of the 7 seawater quality monitoring stations of PHL (Public Health Laboratory of the Ministry of Health) around Thilafushi reef (S1-S7 of Fig.A-9) in Table A-9, and finally that of the 14 seawater and sediment quality sampling locations in the vicinity of Thilafushi Island (SW1-SW12 of Fig.A-10) and the south-east and south-west coast of Male (SW13 and SW14 of Fig.A-7) in Table A-10.

Based on the results of analysis the following observations are made on the quality of each type of water (groundwater, leachate and seawater).

a. **Groundwater in Male**

The all four (4) wells sampled are located in Mosques of Male. Heavy rainfall was experienced in the week prior to the sampling. Moreover the well G2 of Masjidul Furugan Mosque, located near the solid waste transfer station, is injected with rainwater collected on the roof-top of the Mosque in order to improve the well water quality. Still the other 3 wells do not have such artificial introduction of rainwater.

The COD results, that ranged from 7 to 20 mg/l (ref. Table A-7), indicates significant pollution of groundwater for all 4 locations. In fact the lowest COD of 7 mg/l is measured in well G2 with artificial rainwater introduction. Disregarding G2 all the remaining wells recorded COD level in the range of about 15-20 mg/l, clearly indicating significant organic pollution for groundwater, since COD level of unpolluted groundwater normally does not exceed 5 mg/l. The cause could be the dispersion of landfill leachate generated at the solid waste reclaimed southern part of Male, as also pointed out in the foregone section.

Still nil (0) total and fecal coliform levels recorded in all 4 wells indicate no bacterial pollution attributable to human waste contamination thereby basically ensuring the public health safety of the groundwaters. Relatively low chloride level in the range of only about 250-1000 mg/l (against the typical range of 1000-3000 mg/l as per the available monitoring data of PHL) in the wells could be attributed to dilution effect due to heavy rainfall. It is also noted the lowest chloride level of 250 mg/l was recorded at the well G2 with artificial rainwater introduction.

No significant metallic contamination, including heavy metals, is noted.

Finally considering the relatively high pollution level and chloride level of Male groundwater artificial introduction of rainwater to wells leads to inherent beneficial effect of overall groundwater quality improvement, which needs to be encouraged.

b. Leachate in Thilafushi

It is noted that of the four (4) leachate sampling locations of L1-L4, L1 is the only remaining leachate monitoring well (bore-hole) of PHL established in October 1993 as noted in the foregone section (ref. Figure A-8), hence be representative to longest age of leachate generation since the commencement of the landfill operation in Thilafushi in December 1992.

All other 3 locations (L2-L4) are leachate ponds that remained at the time of sampling. Though surface ponds, they are not directly linked to the surrounding seawater. Still L3 and L4 are located adjacent to sea coast.

The COD level measured in all 4 locations was in the range of about 200-750 mg/l (ref. Table A-8), indicating relatively low pollution load typical to leachate. Still considering the specific environmental condition of the island that reclaimed from sea with solid waste, this would simply mean dilution and dispersion of leachate to surrounding sea environment due to active exchange with seawater. Accordingly it could be presumed that seawater assists in active treatment of leachate, though inefficient dispersion of leachate may affect the surrounding marine environment.

The lowest COD level of 220 mg/l in combination with high ammonia and hydrogen sulfide levels as noted in L1, the leachate monitoring well, indicates the long age of leachate generation and effective waste stabilisation.

The concentration level of metals measured, including the heavy metals, is very low for a typical leachate. Accordingly in could be concluded that the metallic accumulation in the landfill leachate is insignificant.

c. Seawater around Thilafushi and Male

The results of analysis of sea water quality in all of the 21 locations, the seven (7) monitoring stations of PHL around Thilafushi reef (ref. Figure A-9) and the 14 seawater cum sediment sampling locations in the vicinity of solid waste reclaimed Thilafushi island as well as Male (ref. Figure A-10 and Figure A-7) clearly indicates no significant deterioration of seawater quality that could be attributed to any of the on-going waste disposal means either in Thilafushi or Male. It is noted that sewage generated in Male also disposed via sea out-falls located around Male island.

In particular near saturation DO level exceeding 7 mg/l in most locations (ref. Table A-9 and Table A-10), still exceeding 6 mg/l in all locations, typical for unpolluted water environment, points to the cleanness of seawater. Moreover mostly nil (0) total and fecal coliform level indicates no significant lingering effect that could be attributed to human waste pollution as well.

Most metallic parameters measured are also basically at near zero (0) detection limit (DL) level of analytical measurement for all the 21 sea water samples analysed.

The fine seawater quality around Thilafushi could be interpreted as effective dilution and dispersion of leachate in the surrounding marine environment to undetectable pollution level, due to sea waves, tides and current. In other words, in an overall sense, under the current rate of solid waste land-filling and subsequent leachate generation, the surrounding marine environment posses the required assimilative capacity to naturally render the pollution due to leachate insignificant, as far as the sea water quality is concerned. This is despite the fact that the on-going landfill operation in Thilafushi has many environmental concerns including the over-carriage (dispersal) of floating garbage to surrounding marine water environment.

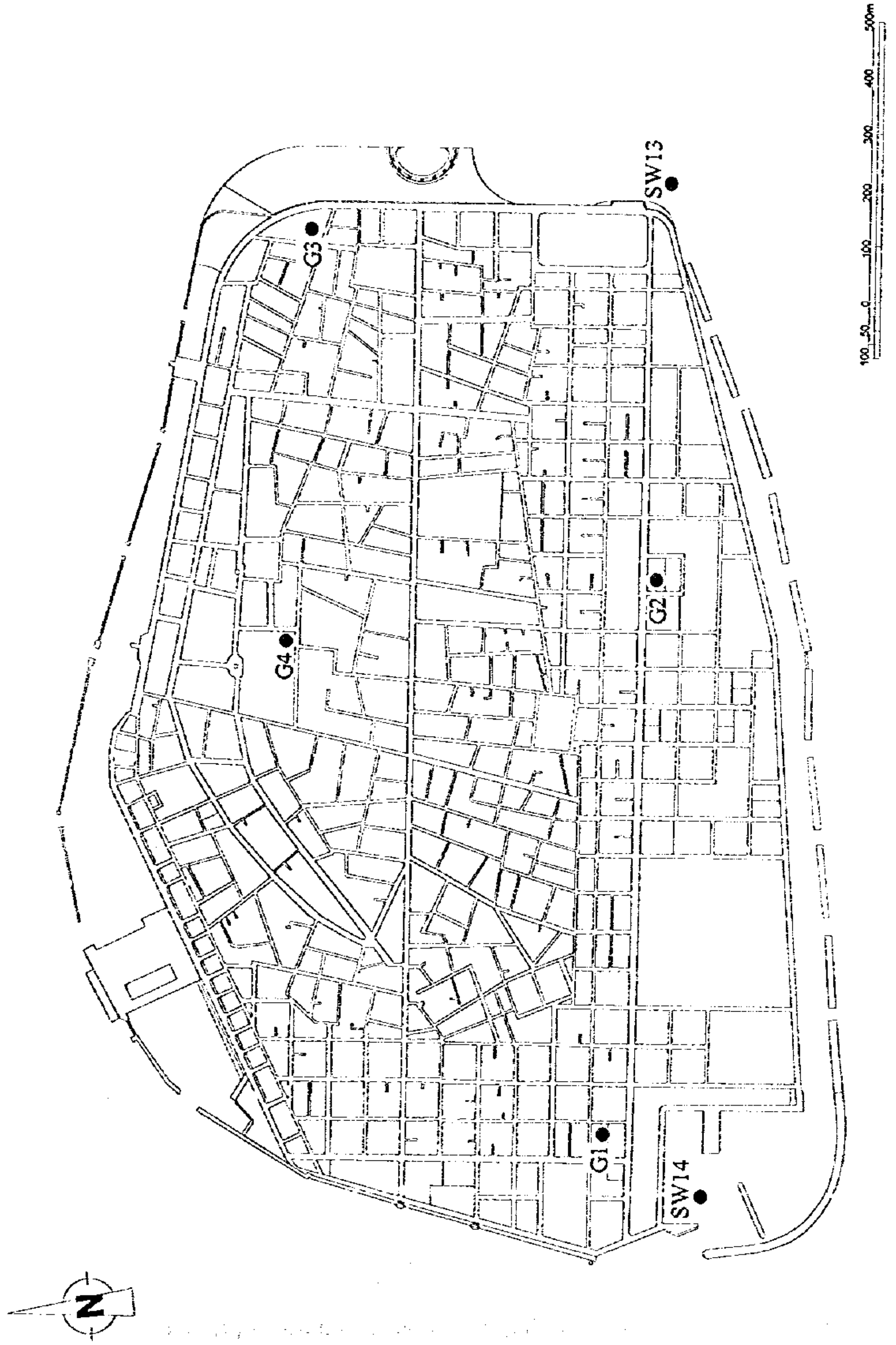


Fig. A-7. Ground Water and Sea Water cum Sediment Sampling Locations in Male (JICA)

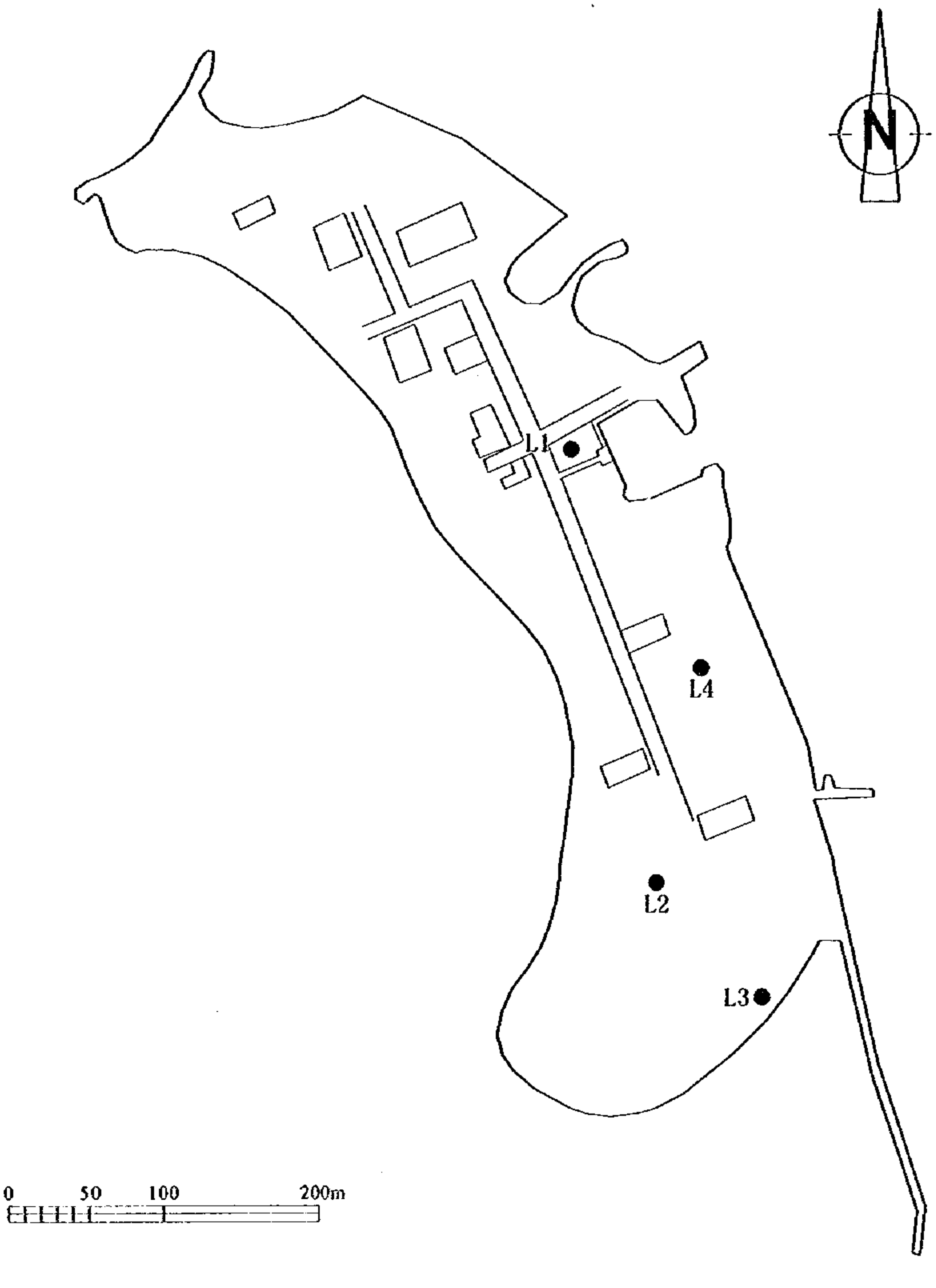


Fig. A-8. Leachate Sampling Locations in Tilafushi (JICA)

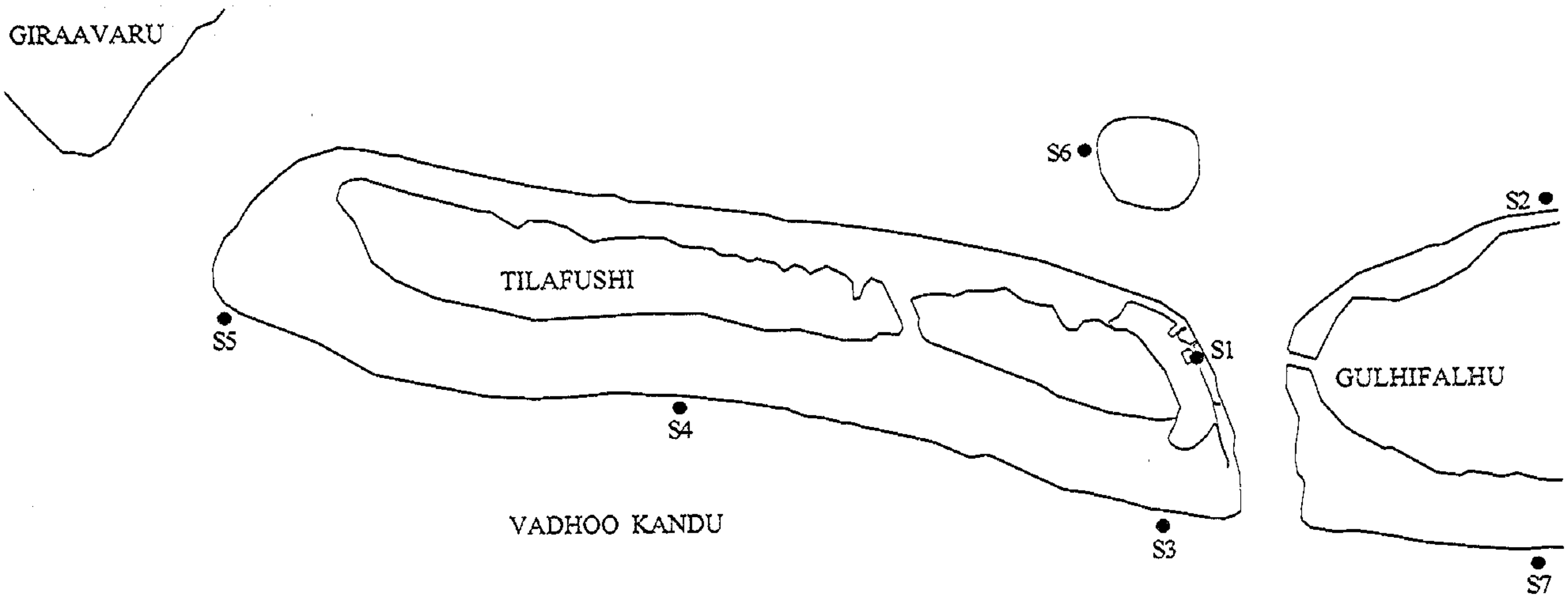


Fig. A-9. Sampling Locations around Tilafushi - Sea Water Monitoring Stations (JICA)

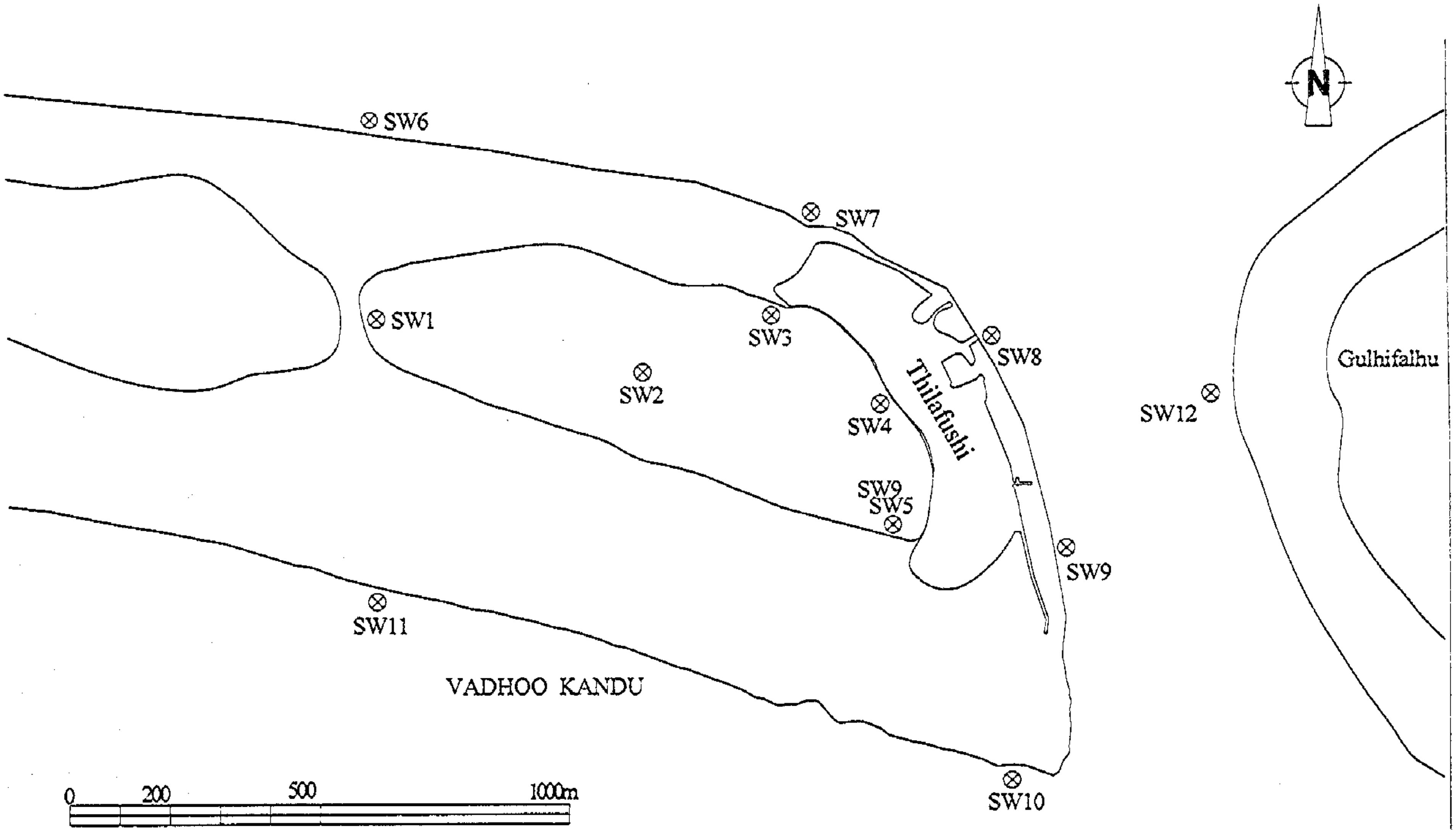


Fig.A-10 Sea Water cum Sediment Sampling Locations around Thilafushi (JICA)

Note : Refer to Fig.A.7 for the sampling locations of Male

Table A-7. Groundwater Quality Sampling Results-Male

Parameter	Unit	G_1	G_2	G_3	G_4
Physical Appearance		Clear & Colourless	Clear & Colourless	Clear & Colourless	Clear & Colourless
Temperature	°C	28.6	27.7	28.4	28.7
pH		7.7	7.6	7.6	7.3
Conductivity	ms/cm	3.000	1.061	1.460	3.870
Total Dissolved Solids	g/l	1.480	0.532	0.732	2.060
Dissolved Oxygen	mg/l	0.4	5.4	4.0	2.2
Chemical Oxygen Demand	mg/l	16.5	7.0	19.0	22.0
Hydrogen Sulphide	mg/l	0.1-0.3	0.0	0.0	0.0
Sulphide	mg/l	0.001	0.001	0.002	0.001
Ammonia	mg/l	0.54	0.23	0.06	0.01
Nitrate	mg/l	0.9	0.6	1.1	0.8
Nitrite	mg/l	0.004	0.005	0.003	0.00
Phosphate	mg/l	0.04	0.05	0.06	1.43
Sulphate	mg/l	75	32	75	75
Chloride	mg/l	777	250	262	1024
Chromium	mg/l	< 0.06	< 0.06	< 0.06	< 0.06
Lead	mg/l	< 0.10	< 0.10	< 0.10	< 0.10
Mercury	mg/l	< 0.002	< 0.002	< 0.002	< 0.002
Copper	mg/l	< 0.05	< 0.05	< 0.05	< 0.05
Iron	mg/l	< 0.06	< 0.06	0.1	< 0.06
Faecal Coliforms	/100ml	NIL	NIL	NIL	NIL
Total Coliforms	/100ml	NIL	NIL	NIL	NIL

Remarks

G_1 Masjidul Salaam (Maafannu)
G_2 Masjidul Furuqan (Galolhu)
G_3 Masjidul Noor (Henveiru)
G_4 Kalhuvakaru Miskiiy (Galolhu)

Table A-8. Leachate Quality Sampling Results-Tilafushi Island

Parameter	Unit	L_1	L_2	L_3	L_4
Physical Appearance		Pale Brown	Brown	Brown	Pale Brown
Temperature	°C	30.5	30.9	32.5	31.0
pH		7.8	7.7	8.7	8.0
Conductivity	ms/cm	17.24	29.04	58.72	58.16
Total Dissolved Solids	mg/l	9.39	14.52	29.36	29.20
Dissolved Oxygen	mg/l	0.2	0.0	-	1.9
Chemical Oxygen Demand	mg/l	220	755	520	300
Hydrogen Sulphide	mg/l	>5	1.0	2.0	4.0
Sulphide	mg/l	2.45	0.20	0.45	0.80
Ammonia	mg/l	30.0	30.0	9.5	3.0
Nitrate	mg/l	16	7	14	15
Nitrite	mg/l	0.02	0.01	0.12	0.03
Phosphate	mg/l	10.8	34.2	5.2	1.0
Sulphate	mg/l	124	120	300	300
Chloride	mg/l	8137	8292	18392	18279
Chromium	mg/l	< 0.06	0.06	0.08	0.09
Lead	mg/l	< 0.10	< 0.10	< 0.10	< 0.10
Mercury	mg/l	< 0.002	< 0.002	< 0.002	< 0.002
Copper	mg/l	< 0.05	< 0.05	< 0.05	< 0.05
Iron	mg/l	0.3	3	0.4	2
Faecal Coliforms	/100ml	NIL	NIL	NIL	NIL
Total Coliforms	/100ml	NIL	NIL	NIL	NIL

Remarks : L_1 is the only remaining leachte monitoring well (bore-hole) in Tilafushi

L_2~L_4 are leachate ponds existed at the time of sampling in Tilafushi

Table A-9. Sea Water Quality Sampling Results-PHL Monitoring Stations

Parameter	Unit	S_1	S_2	S_3	S_4	S_5	S_6	S_7
Physical Appearance		Clear & Colourless	Clear & Colourless	Clear & Colourless	Clear & Colourless	Clear & Colourless	Clear & Colourless	Clear & Colourless
Temperature	°C	29.2	28.9	29.2	29.2	28.9	28.0	28.9
Conductivity	ms/cm	64	60.0	60.9	61.05	60.85	61.6	60.7
Total Dissolved Solids	g/l	30.3	30.1	30.5	30.6	30.45	30.85	30.4
Dissolved Oxygen	mg/l	6.2	7.6	7.4	7.6	7.5	7.7	7.6
Chemical Oxygen Demand	mg/l	< 5	< 5	< 5	< 5	< 5	< 5	< 5
pH		8.2	7.3	8.2	8.1	8.3	8.2	7.7
Sulphide	mg/l	0.003	0.002	0	0.001	0.001	0.002	0.001
Ammonia	mg/l	0.24	0.00	0.00	0.00	0.00	0.03	0.01
Nitrate	mg/l	1.6	2.0	2.7	2.8	2.0	3.0	2.0
Nitrite	mg/l	0.009	0.003	0.003	0.003	0.002	0.002	0.006
Phosphate	mg/l	0.07	0.02	0.06	0.17	0.07	0.09	0.03
Sulphate	mg/l	2150	2050	1800	2300	2200	2000	2100
Chloride	mg/l	19354	18114	19419	18904	18399	19264	19312
Chromium	mg/l	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06
Lead	mg/l	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Mercury	mg/l	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Copper	mg/l	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Iron	mg/l	0.09	< 0.06	0.06	< 0.06	0.1	< 0.06	< 0.06
Faecal Coliforms	/100ml	NIL	NIL	NIL	NIL	NIL	NIL	NIL
Total Coliforms	/100ml	NIL	NIL	NIL	NIL	NIL	NIL	NIL

Remarks : $S_1 \sim S_7$ are the 7 monitoring stations around the entire Tilafushi reef and its vicinity established in October 1993.

Table A-10. Sea Water Quality Sampling Results- Tilafushi and Male

Parameter	Unit	SW_1	SW_2	SW_3	SW_4	SW_5	SW_6	SW_7	SW_8	SW_9	SW_{10}	SW_{11}	SW_{12}	SW_{13}	SW_{14}
Physical Appearance		Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear
Temperature	°C	29.2	29.4	29.6	29.7	29.5	29.2	28.6	29.3	29.0	28.9	28.9	29.2	28.1	27.0
Conductivity	ms/cm	73.90	75.45	71.75	73.40	72.45	70.05	69.40	72.25	72.30	69.75	74.50	71.50	71.40	71.80
Total Dissolved Solids	g/l	37.00	37.85	35.85	36.85	36.25	35.20	34.75	36.15	35.35	34.90	37.20	35.80	35.60	36.10
Dissolved Oxygen	mg/l	7.1	7.2	7.3	7.0	6.3	7.6	7.3	6.6	7.4	7.4	7.6	7.6	7.5	7.0
Chemical Oxygen Demand	mg/l	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
pH		8.20	8.20	8.20	8.20	8.20	7.60	9.01	7.85	8.74	7.39	7.31	8.20	8.24	8.20
Sulphide	mg/l	0.75	3.00	2.50	3.50	0.75	6.75	1.25	1.50	3.00	5.25	3.00	2.50	2.60	1.50
Ammonia	mg/l	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.600	0.000	0.001	0.000	0.000	0.010	0.000
Nitrate	mg/l	1.8	1.4	1.2	1.3	1.3	1.1	1.3	1.5	1.2	1.3	1.2	1.0	0.9	1.1
Nitrite	mg/l	0.007	0.006	0.011	0.006	0.008	0.004	0.003	0.003	0.002	0.003	0.003	0.003	0.001	0.002
Phosphate	mg/l	0.04	0.02	0.01	0.02	0.01	0.02	0.02	0.07	0.03	0.02	0.02	0.01	0.04	0.27
Sulphate	mg/l	1800	2150	2200	2200	2350	2250	2450	2300	2100	2000	2200	2250	1300	2400
Chloride	mg/l	21133	20203	18404	20156	21285	17984	20541	19309	21356	21551	19621	19836	19122	19911
Chromium	mg/l	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06
Lead	mg/l	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Mercury	mg/l	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Copper	mg/l	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Iron	mg/l	< 0.06	< 0.06	0.4	0.3	< 0.06	< 0.06	< 0.06	0.1	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06
Faecal Coliforms	/100ml	NIL	NIL	NIL	NIL	7	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	24
Total Coliforms	/100ml	NIL	NIL	NIL	NIL	13	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	37

Remarks

SW1~SW12 are sea water and sediment sampling locations in the vicinity of Tilafushi Island.
SW13~SW14 are sea water and sediment sampling locations in Male.
SW13~South -east coast of Male
SW14~Male South -west harbour (solid waste barge loading area for Tilafushi)

A.3.2 Sediment quality

No data is available on the sediment (seabed material) quality in and around Male or any other island of Maldives. This could be attributed to the very specialized nature of the analytical work involved, in particular the pre-treatment of the sample to facilitate the elution of the constituent measured. This requires elaborate laboratory facilities and technical skill that is lacking in Maldives.

The sediment (seabed material) sampling by the Study Team was also conducted in the beginning of September 1998 in tandem with the water quality sampling as mentioned in the foregone section. The sampling locations are the immediate vicinity of the Thilafushi Island (12 locations) and that of Male Island (2 locations) with a total of 14 locations, the sea-beds of the same seawater quality sampling locations of SW1-SW14 shown in Figure A-10 and Figure A-7 Nevertheless in order to distinguish the seabed sampling locations from the corresponding sea water sampling locations, the sea bed locations are referred to as SE1-SE14.

The sediment quality parameters analysed are those representative to accumulation of pollution including heavy metals to bed materials of water bodies, namely, total nitrogen, total phosphorus, total sulfur and the metals of total iron, copper, total chromium, lead and mercury.

The results of seabed material quality analysis are shown in Table A-11. Based on the results the sediment quality is assessed as clean with no significant contamination and hence representative to natural background seabed material.

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The coral ecological survey was conducted with the assistance of Dr. Susan Clark of the University of Newcastle on Tine, the United Kingdom and MRS (Mariue Research section) of MOFA (Ministry of Fisheries and Agriculture). The water and sediment sampling work was conducted with the assistance of PHL (Public Health Laboratory) of MOH (Ministry of Health) and CISIR (Ceylon Institute of Scientific and Industrial Research) of Sri Lanka. The analysis of all water quality parameters other than heavy metals was conducted at the PHL of MOH. The analysis of all the remaining parameters, including that of the entire sediment quality, was conducted by CISIR in its laboratory in Sri Lanka.

Table A-11. Sediment (sea-bed) Quality Sampling Results - Thilafushi and Male

Parameter	Unit	SE_1	SE_2	SE_3	SE_4	SE_5	SE_6	SE_7	SE_8	SE_9	SE_{10}	SE_{11}	SE_{12}	SE_{13}	SE_{14}
Total Nitrogen	mg/kg	10	<5	7	<5	16	212	82	112	95	<5	<5	5	44	64
Total Phosphorus	mg/kg	9	10	36	45	70	30	41	20	15	49	13	39	30	16
Total Sulfur	g/kg	1.0	1.0	1.0	1.0	1.0	2.0	1.0	2.0	2.0	2.0	1.0	1.0	1.0	3.0
Total Chromium	mg/kg	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12	<12
Lead	mg/kg	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20	<20
Total Mercury	mg/kg	<0.1	0.1	<0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Copper	mg/kg	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Total Iron	mg/kg	21	80	26	69	55	36	35	43	69	43	44	45	68	607

Remarks

SE_1 ~ SE_{12} are sediment sampling locations in the vicinity of Thilafushi Island.
SE_{13} ~ SE_{14} are sediment sampling locations in Male.
SE_{13} ~ South - east coast of Male
SE_{14} ~ Male South - west harbour (solid waste barge loading area for Thilafushi)

References

1. An information handbook for proponents and government agencies, MPHRE, Republic of Maldives (1997).
2. Environmental considerations for port and harbor developments, World Bank technical paper number126 (1990).
3. Fifth national development plan, Republic of Maldives (1997).
4. Guidelines for drinking water quality, Second edition, World Health Organization (1993).
5. Handbook of environmental analysis, Second edition, Roy-Keith Smith, Genium Publishing Corp. (1994).
6. Hulhumale development, Initial environmental evaluation, MPHRE, Republic of Maldives (1996).
7. Standard handbook of environmental engineering, Robert A.Corbitt, McGraw-Hill, Inc. (1990).
8. Standard methods for the examination of water and wastewater, 18-th edition, APHA, AWWA & WEF (1992).
9. The development study on the seawall construction project for Male island in the Republic of Maldives, JICA (1992).

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