Environmental Impact Assessment

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MLD: Greater Malé Waste-to-Energy Project – Waste to Energy Plant PART A

Prepared by Ministry of Environment of the Republic of Maldives for the Asian Development Bank.

Explanatory Note:

This revision to the environmental impact assessment (EIA) report, as prepared by the Government of Maldives for the Greater Malé Waste-to-Energy Project (GMWTEP), provides additional information and other minor editorial improvements that ADB identified during the review of the EIA report. These additional information and minor editing do not alter, in any way, the substantive meaning and essence of the disclosed EIA report dated December 2019 and March 2020. All impacts, mitigation measures, and recommendations remain the same.

The additional/modified information included in this revision are the following:

(i) Results of the re-run of the heat dispersion modeling for the cooling water discharge from the waste-to-energy (WTE) plant by using the appropriate discharge flow rate and pipe configuration. The modeling report is attached as Appendix 8. The outcome of this modeling shows similar behavior or pattern of heat dissipation, with the same conclusion that the discharge has no impact to coastal environment including corals and/or other marine species;

(ii) Enhancement of the community and occupational health and safety measures by including a standard operating procedure (SOP) in response to the 2019 corona virus disease (COVID-19). The SOP is attached as Appendix 14. This is a compliance with ADB's recent advisory note on protecting the safety and well-being of workers and communities from COVID-19. (https://www.adb.org/sites/default/files/publication/614811/safety-well-being-workers-communities-covid-19.pdf); and

(iii) Other minor editorial clarifications for readability and consistency of project details all throughout the document.

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CURRENCY EQUIVALENTS

(as of 21 November 2019)

Currency Unit	=	Rufiyaa (Rf)
Rf1.00	=	$0.065
$1.00	=	Rf15.350

ABBREVIATIONS

ADB	Asian Development Bank
APC	air pollution control
APCS	air pollution control system
BPEO	best practicable environmental option
CEMS	continuous emission monitoring system
CFD	computational fluid dynamics
CCTV	closed circuit TV
DBO	design-build-operate
DCS	distributed control system
EIA	environmental impact assessment
EID	European Industrial Directives
EPA	Environmental Protection Agency
ESA	ecologically sensitive areas
EHS	environmental health and safety
EMOP	environmental monitoring plan
EMP	environmental management plan
EPPA	Environmental Protection and Preservation Act of 1993
GOM	Government of Maldives
GRM	grievance redress mechanism
MCR	maximum continuous rating
MOE	Ministry of Environment
MOF	Ministry of Finance
MMS	Maldives Meteorological Service
MNPI	Ministry of National Planning and Infrastructure
MPA	marine protected areas
MWSC	Malé Water and Sewerage Company
NAPA	National Action Program of Action
NBS	National Bureau of Statistic
NCV	net calorific value
NEAP3	Third National Environment Action Plan
NWMP	National Waste Management Policy
O&M	operation and maintenance
PMU	project management unit
RWMF	Regional Waste Management Facility
SNCR	selective non-catalytic reduction
STELCO	State Electric Company
SWM	solid waste management
TIZ	Thilafushi Industrial Zone
TOR	terms of reference
USEPA	United States Environmental Protection Agency
WAMCO	Waste Management Corporation

NOTE

In this report, "$" refers to United States dollar.

EXECUTIVE SUMMARY

A. Background

The Greater Malé region and its neighboring outer islands (project area) suffer from severe environmental pollution and deteriorating livability because of inadequate collection and haphazard disposal of solid waste. The project area covers the Greater Malé region, and 32 inhabited outer islands and 86 tourist resorts within the Alifu Alifu Atoll, Alifu Dhaalu Atoll, Kaafu Atoll, and Vaavu Atoll, with a population of 295,000 (53% of Maldives' total population).[1] Lack of a sustainable system to manage the 836 tons per day (tpd) of solid waste generated in the project area (2019) results in waste spillage into the ocean, and open dumping and burning of garbage at the 30-year old 10-hectare dumpsite on Thilafushi Island which has no pollution control measures creating a public health and an environmental hazard.[2] Plumes of smoke visible from the capital Malé, the international airport and nearby resorts compromise air quality and pose nuisance to residents and tourists, while leachate and plastics contaminate the surrounding marine environment. This poses a critical threat to tourism and fisheries, both of which rely heavily on the country's pristine environment and are cornerstones to Maldives' economy.[3]

The Greater Malé Waste to Energy project (the project) will focus on solid waste treatment and disposal infrastructure as part of a phased approach to provide a full-fledged SWM service to the project area through two ADB projects. It will complement the ongoing Greater Malé Environmental Improvement and Waste Management Project (GMEIWMP), approved by ADB in 2018, which is assisting the government to (i) improve the upstream segment of the SWM chain, including systemic collection and containerized transfer; (ii) implement temporary measures, such as baling of municipal solid waste, as an adequate interim solution to stop open dumping and burning on Thilafushi island until a modern solid waste treatment and disposal facility is operational; (iii) treat and recover construction and demolition waste; and (iv) strengthen institutional capacity and public awareness for sustainable SWM service delivery.[4] ADB and the government agreed on this phased strategy to match the implementation and financing capacity of the government, and to improve project readiness of the complex WTE infrastructure (i.e., reclaim 15 ha of land, take advance procurement actions, and conduct an environmental impact assessment [EIA]) while implementing urgent measures. GMEIWMP is under implementation and expected to be completed by 2023.

The project is aligned with the following impact: promote waste as a valuable resource for income generation (Strategic Action Plan 2019-2023).[5] The outcome will be disaster- and climate- resilient solid waste treatment and disposal services improved in the Greater Malé region and its outer

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[1] Government of Maldives, National Bureau of Statistics – Ministry of Finance and United Nations Population Fund. 2018. *Maldives Population Projections 2014-2054*. Malé.

[2] Breakdown of solid waste by type: construction and demolition = 530 tpd (68%), household = 149 tpd (19%), resort = 48 tpd (6%), commercial = 27 tpd (3%), airport = 9.3 tpd (1.2%), industrial = 6 tpd (0.8%), market = 2.5 tpd (0.3%), hazardous = 1.5 (0.2%), and end-of-life vehicles = 0.65 tpd (0.1%). Source: Government of Maldives, Ministry of Environment and Energy. 2018. Feasibility Study for an Integrated Solid Waste Management System for Zone III (including Greater Malé) and Preparation of Engineering Design of the Regional Waste Management Facility at Thilafushi. Malé

[3] A quarter of country's employment is in tourism and fisheries. Tourism account to 30% of gross domestic product and expected to expand in the area. Government of Maldives, National Bureau of Statistics – Ministry of Finance. 2015 Maldives Population & Housing Census 2014 – Statistical Release 4: Employment. Malé.

[4] ADB. 2018. *Report and Recommendation of the President to the Board of Directors: Proposed Grant and Technical Assistance Grant and Administration of Grant to the Republic of Maldives for the Greater Malé Environmental Improvement and Waste Management Project.* Manila.

[5] Government of Maldives. 2019. *Strategic Action Plan 2019-2023*. Malé.

islands. The project will have two outputs.

Output 1: Disaster- and climate-resilient regional waste management facility developed. This will include (i) a 500 tpd WTE plant with 15 years of O&M, including two treatment lines of 250 tpd each, a minimum 8-megawatt (MW) electricity surplus energy recovery facility, and an air pollution control system; and (ii) a landfill for safe disposal of hazardous air pollution control residues and non-marketable bottom ashes. The facility (WTE plant and landfill) will be implemented through a design-build and operate (DBO) contract to a specialized firm, which will integrate a design–build phase and a 15-year operation (O&M) phase to improve sustainability of service delivery. The facility will be able to accommodate a third 250 tpd treatment line in the future, which will be required to respond to further demand increase. The incineration with electricity generation (WTE) technology minimizes land requirements and produces renewable energy, addressing the critical land and electricity constraints in Maldives. Recycling of marketable incineration bottom ash and metals will be promoted to further reduce landfill requirements and provide valuable materials for the construction and recycling industry. All facilities will adopt disaster- and climate-resilient features, such as raised floor elevations, flood-proof mechanical and electrical equipment and landfill cells, and enhanced drainage systems.

Output 2: Institutional capacity in sustainable SWM services delivery (WTE) and environmental monitoring, and public awareness on WTE and 3R improved. This will include (i) preparing and implementing a capacity development plan to improve the capacity of MOE and EPA to supervise sustainable WTE service delivery; (ii) strengthening MOE and EPA staff capacity in supervising WTE operations, including monitoring WTE operational performance and environmental standards, and managing performance-based DBO contract; (iii) supporting enhanced financial sustainability for WTE O&M through implementation of an agreed O&M financing plan, including financial need forecasting and finalization of financing sources, a revenue enhancement plan, assignment of responsibilities, and fund flow arrangements for payment of O&M; and (iv) conducting public awareness campaigns on WTE and 3R benefits. The project will develop PMU and government capacity to prepare, monitor, and manage sustainable WTE through consulting services for contract management, monitoring, supervision, and institutional development.

The project is estimated cost is $151.13 million, including contingencies and financing charges. The government has requested (i) a grant not exceeding $35.18 million from ADB's Special Funds resources (Asian Development Fund [ADF]); and (ii) a concessional loan of $38.21 million from ADB's ordinary capital resources to help finance the project. The loan will have a 32-year term, including a grace period of 8 years; an interest rate of 1.0% per year during the grace period and 1.5% per year thereafter; and such other terms and conditions set forth in the draft loan and grant agreement. The government has also requested a loan not exceeding $40.00 million from the Asian Infrastructure Investment Bank (AIIB) to help finance the project. The AIIB loan will be partially administered by ADB. The AIIB loan's terms and conditions will be described in a loan agreement between AIIB and the government. The Japan Fund for Joint Crediting Mechanism will provide grant cofinancing equivalent to $10 million, to be administered by ADB.

B. Purpose of the EIA Study

This EIA focuses solely on the WTE plant (inclusive of its ancillary facilities and landfill for disposal of WTE residues) as most environmentally sensitive component of the project given its construction and operation is likely to have significant adverse environmental impacts that are irreversible, diverse, or unprecedented. These impacts may affect an area larger than the sites or facilities subject to physical works. Thus, the project is classified as Category A for environment per ADB Safeguard Policy Statement (SPS) and an environmental impact assessment (EIA) is required.

The purpose of this EIA is to meet ADB SPS requirement for Category A projects and to comply with Government of Maldives requirements under EIA Regulations of 2012. This EIA also aims to inform decision-makers and the public of the environmental consequences of implementing the WTE plant. This EIA identifies, predicts, and analyzes impacts on the environment and people in the project area of influence. It also identifies alternatives and mitigation measures to reduce the environmental impact of the WTE plant. The EIA process also serves as an important procedural role in the overall decision-making process by promoting transparency and public involvement.

C. Scope of the EIA

The scope of this EIA covers: (i) description of the WTE plant and ancillary facilities (the project); (ii) identification and description of the elements of the environment and community/stakeholders likely to be affected by the project and/or likely to cause adverse impacts to the project, including both the natural and man-made environment; (iii) information on the consideration of alternatives/options for design, site locations and layouts of the project to avoid and minimize potential environmental impacts to environmentally sensitive areas, other sensitive uses and sensitive receptors; to provide reasons for selecting the preferred option(s); (iv) description of environmental factors played in the selection of the preferred option(s); (v) identification and assessment of impacts on marine environment, groundwater, avifauna, biodiversity, air quality, water quality, waste management implication, land-based and marine traffic, socio-cultural and livelihood, occupational health and safety, landscape and visual; and determine the significance of impacts on sensitive receivers and potential affected uses; (vi) mitigation measures so as to minimize pollution, environmental disturbance and nuisance during construction and operation of the project; (vii) identification, prediction and evaluation of residual (i.e. after practicable mitigation) environmental impacts and the cumulative effects expected to arise during the construction and operation phases of the project in relation to the sensitive receivers and potential affected uses; (viii) identification, assessment and specification of methods, measures and standards, to be included in the detailed design, construction and operation of the project which are necessary to mitigate these environmental impacts and reducing them to acceptable levels; (ix) identification of constraints associated with the mitigation measures recommended in the EIA study and, where necessary, to identify the outstanding issues that need to be addressed in any further detailed EIA study; and (x) design and specifications in the environmental monitoring and audit requirements to ensure the effective implementation of the recommended environmental protection and pollution control measures.

D. Description of the Project

Components and implementation. The WTE plant will have the following components: (i) two lines of moving grate incinerators, each with capacity of 250 tpd, and detailed components in Table 1 below (per preliminary design as specified in the DBO bid document); (ii) bottom ash processing plant; (iii) air pollution control (APC) system including continuous emission monitoring systems (CEMS); (iv) landfill for residuals; (v) leachate treatment plant; and (vi) other allied components needed to operate the plant, including cooling water pipelines, access roads and drainage system, among others. The WTE plant will be developed and implemented under a design-build-operate (DBO) contract where the design-build period (or design phase and construction phase) is expected to be 4 years. The operation service period (or operation phase) is expected to be 15 years.

The project is designed for 10 MW power production, with 2 MW to be used for the facility itself (and other parasitic loads). The surplus power of 8 MW will be fed to the main grid through an overhead cable link between Thilafushi and Guhli Fahlu islands. The government is still at planning stage of putting this link to be constructed in between the islands. No definitive technical information about this cable is available as yet. Once information becomes available during the detailed design phase, updating of the EIA will include assessment of these proposed infrastructure facilities.

Table 1: Details of the WTE Plant and Ancillary Facilities

Components	Requirements Per Preliminary Design
Waste Reception, Storage and Feeding Facilities	The waste reception, storage and feeding process will have the mechanical equipment for the following process components: • weighing system; • waste reception hall (tipping hall); • waste bunker; • waste cranes; and • supply of waste oil.
Thermal System	• Feeding hoppers, waste chute and waste feeder • Moving grate • Bottom ash collectors and discharge system • Combustion chamber
Boiler and Water Steam System	Radiation and convection boiler passes including evaporator, super heaters and economizer, steam drum and all necessary sampling, venting, injection, blow-down and cleaning equipment, and others that will be needed for safe operations of the boiler and the water steam system
Air Pollution Control System	• Flue gas cleaning • Nitrogen oxide removal system
Turbine, Generator and Condenser	• Steam turbine • Steam turbine with auxiliary equipment • four-pole rotor (1,500 min-1) Generator System • 2-flow seawater surface condenser
Induced Draft Fan and Stack	• Radial fan with a single-flow impeller, statically and dynamically balanced • Two stacks built as a tube-in-tube system, with minimum stack height of 45.7m (bidding document to require 50m)
Continuous Emission Monitoring System	• 1 CEMS for each stack • flue gas sampling points for emission measurements
Condensate System	• Condensate collecting system • Main condensate tank • Boiler feed water pumps • Make-up water system
Cooling Water Supply System	• Sea water-cooled heat exchangers (mainly the condenser) • Pumps installed in an enclosed, water-tight area to cope with the climate change and disaster risks; • Pumps to be fully redundant • Pumps designed to accommodate the instant need to cool down the full steam flow rate bypassing the turbine

Components	Requirements Per Preliminary Design
Fuel and Chemical Supply and Storage	• Tanks and silos shall be designed to prevent the occurrence of encrustation and deposits. • With monitoring equipment such as but not limited to leakage detection shall be installed for all hazardous substances. • All containers shall be equipped with manholes and associated maneuvering aids. • The manholes shall be opened without the aid of hoists. • Trays of containers shall be diverted appropriately via the channel and pumping sump. • For chemical containers, sufficient retention volume shall be provided.
Piping and Valves	• Installation lengths and connection dimensions of fittings shall be selected according to internationally recognized standards. • Fittings for insulated pipelines shall be equipped with spindle extensions, if necessary. • All fittings shall be supplied with a full corrosion protection (including the hand wheels and chain wheels) in the factory, in accordance with the customer's order. • Fittings and piping components shall be equipped with factory-specific markings.
Pumps	• Dry-mounted pumps with suitable base plates or base frames pre-assembled for installation including motor and coupling. • The material of the pumps shall be capable of continuous operation under the appropriate conditions of delivery and operation. • Pumps shall have a stable characteristic and shall allow a quick start from the cold conditions without prior warming. • Sliding ring seals of the pumps shall preferably be made of silicon carbide or wolfram carbide. • All pumps shall be provided with dry-running protection. • Pumps with a motor power of 20 kW shall have a bearing temperature monitor. • Suitable shut-off devices before and after the pumps shall be provided so that the pumps can be replaced at any time.
Compressed and Instrument Air Supply	• Design and install a fully redundant compressed air supply plant for the provision of dry, particle and oil-free compressed air that allows an energy optimized supply at 110% maximum continuous rating (MCR) of each incineration train.
Thermal Insulation and Heat Protection	• All equipment or components carrying media at elevated temperatures or at temperatures below ambient conditions or that, due to its operations, work at such temperatures shall be provided with thermal insulation. • The thermal insulation design shall be in accordance with the requirements set in the contract documents. • The thermal insulation shall be designed so that the maximum temperature the working personnel are exposed to does not exceed 50 °C whenever feasible or shall install heat protection shields when the maximum surface temperature of any equipment which cannot be insulated exceeds 50 °C. • No asbestos shall be used for thermal insulation but only non-flammable, chemically and highly durable resistant rock wool mats that comply with internationally recognized standards.

Components	Requirements Per Preliminary Design
	• The lagging and jackets shall meet the ambient conditions of the marine corrosive environment, accommodate the thermal expansion of pipes and equipment and that shall allow access to base materials, valves, fittings, flanges, measuring devices and other equipment.
Lifting Devices	• The WTE plant shall have all required lifting devices during the operations phase and shall provide either permanent or temporary (including attachments) lifting devices such as cranes and hoists. • The surrounding steel structure of the equipment shall be designed to allow anchoring or attaching temporary lifting gear if needed via mounting additional beams, clamps, shackles etc. or directly to the steel structure. • A permanent crane shall be installed in the turbine hall. Removable openings in the roof of the machinery hall shall allow the access via mobile cranes to lift larger components that cannot be moved otherwise.

Location. The project will be located in Thilafushi, an island that has been reclaimed since December 1992 by dumping of wastes on the submerged "Thilafalhu" lagoon area. Thilafushi is located on the southern rim of North Malé atoll, and on the eastern line of atolls within the archipelago. Thilafushi is located in North Malé atoll, 9.5km from Malé. In terms of geographic coordinates, it is located at 04° 11' 00" N and 73° 26' 44" E. The nearest inhabited island is Villingili, approximately 7.1 km east of Thilafushi. The island was initially developed as a sand bank using dredged material from the Thilafushi Reef. Since then, land has been reclaimed by placing solid waste in dredged holes on the reef flat and later topping it up with fresh lagoon sand. This project will be located on a 15 hectares government-owned land, which has been reclaimed from shallow lagoon. The old dumpsite, adjacent to the project site, will be closed and remediated through a separate project when the WTE plant will become operational. The government has requested a loan not exceeding $20 million from the Islamic Development Bank to finance the remediation of Thilafushi dumpsite.

E. National Environmental Law, Policy, Legal and Administrative Framework

Environmental protection in the Maldives. The law governing the protection of the environment in the Maldives is the Environmental Protection and Preservation Act (EPPA) of 1993 (Act No 4/93). The law is brief and sets out the principles for sustaining and extending the benefits of the environment of the Maldives for the people and coming generations. The EPPA confers powers on the MOE to issue regulations and formulate policies for environmental protection and preservation.

National Solid Waste Management Policy of 2008 and 2015. The National Solid Waste Management Policy was developed in 2008, by the MOE, through consultations with the community and evaluation of existing waste management practices and scope for improved efficiency. The policy was then revised and adapted, and a new policy formulated and adopted in 2015. The policy is in line with government commitment to provide the resources required for waste management in all inhabited islands of the Maldives and is founded on the following 10 principles: (i) each person should be responsible for waste generated at the individual level and should comply with rules and regulations established locally; (ii) all household waste should be managed in accordance with the requirements of the local council; (iii) each inhabited island should prepare and submit an island waste management plan for the island; (iv) waste collection should be undertaken on a fee-based system for all waste producers, including households and industries; (v) agreements with government agencies in different inhabited islands to ensure management of waste in the islands; (vi) establishment of a waste management system in each inhabited island that is appropriate for the needs of the population and quantity and type of waste generated; (vii) establishment of RWMFs in each waste management zone; (viii) establishment of arrangements to transport all residual waste to a RWMF; (ix) promote adoption of waste management practices that generate revenue and to apply revenue to waste management at the island level; and (x) undertake waste management training and awareness campaigns at the national level.

Waste Management Regulation (No. 2013/R-58). The Waste Management Regulation of the Maldives was enacted under Article 3 of the EPPA in 2013 and is implemented by the Environmental Protection Agency. The regulation focuses on the following five areas: (i) waste management standards: defines standards for waste collection, transfer, treatment, storage, waste site management, landfills and managing hazardous waste; (ii) waste management permits: defines approval procedures for waste management sites; (iii) waster transfer: defines standards and permits required for waste transport on land and sea, including trans-boundary movements; (iv) reporting: defines reporting and monitoring requirements and procedures; and (v) enforcement: defines procedures to implement the regulations and penalties for non-compliance.

Environmental assessment requirements. Responsibilities and procedures for conducting environmental assessments, together with the requirements for environmental monitoring of projects, are set out in the EIA Regulations of 2012. All projects that may have an impact on the environment are referred to the Minister of Environment and Energy (EPPA 5[a]). The EIA Regulations assign primary responsibility for undertaking environmental assessment of projects to the project proponent and set out procedures, rights and responsibilities for the preparation and approval of EIAs. The EIA regulations include a schedule (Schedule D) of investment project types that require an EIA. For waste projects, these are landfills, waste incinerators and large-scale waste storage projects. The WTE plant is covered by Schedule D therefore an EIA is required.

Health and safety. Legislation covering occupational health and safety is currently included in the Employment Act (2008), Chapter 8 “Workplace Safety and Employer Health”. This requires employers to implement measures for the safety and protection of employees at the work place, including safe work place, procedures, safe equipment and materials, provision of protective equipment, safety training to employees, conducting health checks where work involves chemical or biological materials that may cause a hazard, providing medical care as well as first aid for employees injured while at work. The law also sets out employee’s obligations with regard to safety at work.

F. Safeguard Requirements of Lenders and International Best Practices.

Financing support for the project will be sought from multilateral financial institutions, such as ADB and AIIB. This support requires adherence to international best practices and safeguard requirements of the lenders.

ADB SPS. The ADB SPS governs environmental and social safeguards of ADB’s operations. It applies to all ADB-financed and/or ADB-administered projects and their components, regardless of the source of financing, including investment projects funded by a loan, and/or a grant, and/or other means, such as equity and/or guarantees. This project has been classified as Category A thus requiring an EIA. The project will comply with the ADB SPS requirements on stakeholders engagement, information disclosure, consultation and participation, grievance redressal mechanism, and monitoring and reporting.

Applicable environmental, health and safety (EHS) guidelines. During the design, construction, and operation of the project, pollution prevention and control technologies and practices consistent with international good practice, as reflected in internationally recognized standards such as, among others, the World Bank Group's EHS Guidelines and European Union Directives will be applied. These standards contain performance levels and measures that are normally acceptable and applicable to projects. When Government of Maldives regulations differ from these levels and measures, the project will achieve whichever is more stringent. If less stringent levels or measures are appropriate in view of the project circumstances, full and detailed justification will be provided for any proposed alternatives that are consistent with the requirements presented in ADB SPS.

F. Description of the Environment

A 2-kilometer radial zone around the project site has been considered as the study area. Additionally, the adjacent island of Gulhi Falhu where workers from Thilafushi live is also included in the study area. Data collection period covers November 2016 to September 2019. Table 2 summarizes the baseline data on physical environment, ecological environment, and socio-economic environment. In August to September 2019, a socio-economic survey was conducted to obtain the baseline socio economic profile of the workers in Thilafushi and Gulhi Falhu islands. The survey also determined the current waste disposal practices, the needs and willingness of the companies operating in the islands to pay for waste management services. The results were used as baseline for the EIA and in assessing the potential impacts to sensitive receptors in the island.

Table 2: Summary of Baseline Conditions

Parameters	Description
Existing condition	The location of the project is in the proximity of the dumpsite at Thilafushi, an industrial island with the oldest and largest landfill and numerous industrial companies. This project will be located on a 15 hectares government-owned land, which has been reclaimed from shallow lagoon. The old dumpsite, adjacent to the project site, will be closed and remediated through a separate project when the WTE plant will become operational. The government has requested a loan not exceeding $20 million from the Islamic Development Bank to finance the remediation of Thilafushi dumpsite.
Land reclamation	Thilafushi Island has been developed as a solid waste landfill since December 1992. The island was initially developed as a sand bank using dredged material from the Thilafushi Reef. Since then, land has been reclaimed by placing solid waste in dredged holes on the reef flat and later topping it up with fresh lagoon sand. The island referred to as Thilafushi-1 was and is being reclaimed using this method. A second island, zoned as Thilafushi-2 (where the project will be located), was reclaimed from lagoon sand. Subsequently a third island,Thilafushi-3, was initiated to reclaim 167 hectares of land from the remaining reef areas of Thilafushi. The reclamation works was undertaken by the government in anticipation of the WTE plant and was also subjected to an EIA process as part of the requirements of the Government of Maldives EIA Regulations of 2012. Reclamation works involved mainly filling and levelling activities. The land was reclaimed to a height of +1.5 m from mean sea level (MSL) from an average depth of -1.5 m above the

Parameters	Description
	sea floor. During preparation of this EIA, about 5% of the reclamation work is still being carried out to complete coastal protection structures around the newly reclaimed land. The finished ground level of the site will be at a level higher than the average ground level of the Thilafushi.
Oceanographic conditions (bathymetry)	The reef system of the Thilafushi Island comprises of an ocean ward reef flat, a lagoon ward reef and a central deep lagoon. The reef flat areas on the ocean ward side of the reef system (south of the proposed location) have a fairly flat depth ranging from -1.0 to -1.5m MSL. The reef system hosting Thilafushi does not host any other islands. The reef system is approximately 4.65 km long, 0.94 km wide (width of ring reef, including the lagoon area).
Geology and topography	The islands are low-lying Holocene features that began forming between 3000 and 5500 years ago. The islands represent the most recent deposition along a submarine plateau that is underlain by approximately 2,100 meters of mostly shallow-water carbonates resting on a slowly subsiding Eocene volcanic foundation. All islands of the Maldives are very low lying; more than 80% of the land area is less than 1 m above mean high tide level.
Sediment quality	The sediment regime around the present waste disposal area is likely to reflect the leaching of pollutants from the dumped wastes at the Thilafushi Island. As unplanned dumping of wastes on this island has the potential to contaminate sediments of the inner lagoon and outer reef flat area, six sampling stations were selected to get a representative status of the extent of contamination of the sediments due to the current waste disposal methods. Results of sediment analysis show no heavy metal (cadmium, lead, zinc, copper, chromium, nickel, mercury, arsenic) contamination.
Climate and meteorology	Regular meteorological observations and measurements in Maldives are limited to airports. A total of 12 airports are in operation, however meteorological observation takes place only on 5 airports. For the purposes of this EIA observations from the Velana International Airport at Hulhulhe, which is closest to the project site, will be used to describe the climate condition around the project area. The climate in Maldives is warm and humid, typical of the tropics. The average temperature ranges between 25°C to 30°C and relative humidity varies from 73 – 85%. The annual average rainfall is approximately 1,950mm. As the Maldives lie on or close to the equator, the islands of the Maldives receive plenty of sunshine throughout the year. Temperature is moderated by the presence of vast sea and oceans surrounding the small islands. The long-term average temperature ranges from 25°C to 31°C. With the influence of the monsoon, seasonal fluctuations are observed throughout the year. The warmest period is observed during March, April and May. The average annual rainfall for the archipelago is 2,124 mm. Monsoons of Indian Ocean govern the climatology of the Maldives. Two monsoon seasons are observed in Maldives: the Northeast (Iruvai) and the Southwest (Hulhangu) monsoon. The southwest monsoon lasts from May to September and the northeast monsoon occurs from December to February. The transition period of southwest monsoon, which is the driest part of the year, occurs between March and April while that of northeast monsoon occurs between October and November. The prevailing wind over the Maldives represents typical Asian monsoonal characteristics. The southwest monsoon, with winds predominantly between SW and NW, lasts from May to October. In May and June, winds are mainly from WSW to WNW, and in July to October, winds between W and NW predominate. The northeast monsoon, with winds predominantly from NE to E, lasts from

Parameters	Description
	December to February. During March and April, winds are variable. During November, winds are primarily from the west, becoming variable and can occasionally exceed 30 knots from the NE sector. However, yearly wind speed in the northeast and southwest monsoons are observed to be between 9-13 knots.
Ambient air quality	Ambient air quality monitoring was conducted to document the current baseline condition at the island. Three locations were selected at Thilafushi and one location at Villingili. Villingili is the nearest inhabited island and the sampling site at this island will serve as the control site for future monitoring activities under the project. The air quality monitoring activities were done for a period of one week each in 2018 and 2019. Ambient air quality monitoring was conducted at 4 locations. First station (AQ1) was selected in the downwind direction of the proposed project site (i.e. the potential direction of plume of smoke coming from the stack of the plant), and second station (AQ2) was placed at the crosswind direction of the plume. Third station (AQ3) was selected in the crosswind direction of the smoke plume from the existing dump site at Thilafushi. Fourth station (AQ4) was selected at Vilingili as a control site. Ambient air quality results obtained from the monitoring undertaken indicate that mixed results when compared with the WHO guidelines for ambient air quality. • The 24 hourly PM10 values recorded for the stations generally varied in the range of 4.0 - 690.0 $\mu g/m^3$. The mean values of PM10 recorded at AQ1, AQ2 and AQ4 were found to be in compliance with the WHO standard specified for such pollutant equivalent to 50 $\mu g/m^3$. However, the mean value of PM10 recorded at AQ3 is 88.4 $\mu g/m^3$, which exceeds WHO standard specified for such pollutant equivalent to 50 $\mu g/m^3$; • The 24 hourly PM2.5 values recorded for the stations generally varied in the range of 1.0 - 384.0 $\mu g/m^3$. The mean values for PM2.5 at AQ2 and AQ4 were found to be in compliance with the WHO standard specified for such pollutant equivalent to 25 $\mu g/m^3$. However, mean values for PM2.5 at AQ1 and AQ3 are 26.9 $\mu g/m^3$ and 42.8 $\mu g/m^3$, respectively, which exceed WHO standard specified for such pollutant equivalent to 25 $\mu g/m^3$; • The 24 hourly SO2 values recorded for the stations generally varied in the range of 0.0 - 112.2 $\mu g/m^3$. The mean values for SO2 at AQ2 and AQ4 were found to be in compliance with the WHO standard specified for such pollutant equivalent to 20 $\mu g/m^3$. However, mean values for SO2 at AQ1 and AQ3 are 25.3 $\mu g/m^3$ and 32.4 $\mu g/m^3$, respectively, which exceed WHO standard specified for such pollutant equivalent to 20 $\mu g/m^3$; and • The results of the 24-hourly standard values for NO2 have not been compared. WHO standards does not provide 24-hourly standard for NO2 to check for any possible non-compliances. However, if compared with the hourly averaging, the values are below the WHO standard of 200 $\mu g/m^3$. Based on field visits and visual observations, the non-compliances for various parameters at different sampling locations in Thilafushi may be attributed to the continuous and instantaneous burning of wastes at the existing dumpsite. The government plans to stop fires on Thilafushi and start baling waste by July 2020 as interim SWM solution to stop open dumping until the WTE facility is commissioned. It is expected that once these measures are implemented the air quality at the sampling locations will improve.
Ambient Noise Level	Baseline ambient noise level measurements were conducted at the proposed WTE project site and selected locations in Thilafushi. Results show that noise

Parameters	Description
	level are within the WHO Guideline Values for Ambient Noise Level for both day time and night time.
Groundwater quality	Groundwater sampling was conducted from eight wells in Thilafushi. If compared with the National Drinking Water Quality Standards (NDWQS), water samples collected did not comply with parameters on coliform, total dissolved solids, iron, and manganese. If not treated, the groundwater is not an acceptable source of drinking water.
Avifauna	The island is frequented by birds including water birds. An IBAT was run to identify if there are bird species in the area listed as endangered or critically endangered. The IBAT run results show that there are no avifauna species considered as endangered or critically endangered in per IUCN list.
Marine water quality	Marine water quality sampling was conducted at seven (7) locations around Thilafushi island to determine the baseline conditions of the marine water around the project area. Qualitative and quantitative assessments were made, and laboratory analysis were done for heavy metals (As, Cr, Cu, Ni, Pb, Zn, Hg, Cd), Ammonia, nitrates, PH, Turbidity, Oil and Grease and BOD. Result show compliance with the Maldives Marine Water Quality Standards, except for very slight exceedance with pH.
Marine underwater ecology	Marine underwater surveys were undertaken in 2018 at different locations around Thilafushi island. All surveys were carried out by underwater SCUBA diving. The marine surveys were carried out by surveyors who had been trained to undertake Reef Check surveys as outlined in the Reef Check Instruction Manual: A Guide to Reef Check Coral Reef Monitoring (2006). Based on the Guide to Reef Check Coral Reef Monitoring (2006), photo quadrat surveys were done in order to measure the benthic composition at the different sites. At each of the survey sites benthic composition and fish abundance was surveyed at depths of 5 meters and 10 meters. Results show varied findings. The highest coral cover was observed at the depth of 10 meters in site M2 adjacent to the current waste dumping area. Additional marine underwater surveys were undertaken in September 2019 at the proposed locations for the intake and discharge outfall of cooling water at the southern coastal boundary of the proposed project site. In this additional survey, reef profiling was included to identify the status of the coral reef in this area up to the depth of 30m. In particular, underwater survey was conducted to provide more in-depth information at three alternative sections of the where the intake and cooling water discharge outfall will be laid or positioned. Results show that that at the depth of more than 20 meters, no corals and marine life exist.
Natural hazards	The fragile ecological profile, low elevation, combined with its economic dependence on limited sectors makes Maldives highly vulnerable to natural hazards. The disaster risk profile of Maldives identifies earthquakes and tsunamis, cyclones/thunderstorms, floods (due to rain), drought (prolonged dry periods), storm surges, strong winds, and tornadoes (waterspouts) as critical disasters to the Maldives. Climate change further exacerbates the vulnerability of Maldives to these disasters. Most of these risk factors (apart from earthquakes, wind damage and rainfall flooding), stem from the extremely low elevation of all Maldivian islands: the average elevation is 1.5 m above sea level. In spite of the occasional natural hazards, the Maldives are in general relatively free from high risk natural disasters. Thilafushi Island is in a moderate cyclonic hazard zone which has the potential for a maximum probable cyclonic wind speed of 69.6 knots. It has the potential for a 1.53 m storm tide in a 500-year return period. The disaster risk profile of Maldives places Thilafushi as being located in a severe tsunami risk zone with a probable maximum wave height between 3.2 and 4.5 m. The high levels of fluctuations of sea level during the Indian Ocean Tsunami showed that rising and

Parameters	Description
	falling of the water levels are enough to inundate any unprotected coastline of Maldives including Thilafushi Island. However, there are no records of major damages on the island. Thilafushi is protected from predominant swell waves. However, the island is still exposed to abnormal swell waves originating from intense storms in the southern hemisphere.
Socio-economic conditions	There are no communities/residential areas in Thilafushi. The island is industrial zone. A socio-economic survey was conducted in August to September 2019 as the Government of Maldives does not have an updated database that could describe the socio-economic conditions in the islands. Four hundred and thirty (430) individuals and 35 companies were surveyed across Thilafushi and Gulhifalhu Islands. Respondents were mainly located in Thilafushi. There are 319 individuals surveyed that stay in Thilafushi (accommodation provided by employers), 52 workers stay in Gulhifahu, and remaining workers live in Male and other islands. The individuals surveyed range from 18 to 67 years old and are mostly Muslims (81%) from Bangladesh (66%). Over 50% of the individuals surveyed are unskilled workers. None of those surveyed are believed to be involved in fishing activities. Most of the laborers and companies are aware of the health issues related to inadequate waste management. The employers surveyed believe that the present waste disposal practices in Thilafushi affect their health and the health of their employees. Moreover, 25 companies have stated their willingness to pay a higher amount than what they're currently paying for improved waste collection services. The survey found that smoke inhalation is perceived to be the main problem as the smoke can at times impair the visibility in Thilafushi. No fishing activities within the study area.
Land use	The land use system of Thilafushi was developed in an ad hoc manner without a master plan. Hence, the present land use patterns show a mixed approach to development.
Health facilities	Nearby healthcare facilities and hospitals are located in Malé. A health facility was opened in Thilafushi only recently in July 2019. However, the facilities and services offered are limited.
Education facilities	There is no evidence of education facilities on Thilafushi. Nearby schools, high schools and other education facilities are located in Malé.
Commercial and industrial activities	The major activities in Thilafushi are industrial activities, importing and stockpiling of construction materials and warehousing facilities, wholesale and retail trade, workshops and other industrial and commercial activities. There are more than 60 different companies established in Thilafushi, the number is more likely to get higher each year. There are both foreigners and locals employed in the island.
Physical cultural resources	No evidence of physical and cultural heritage could be found at Thilafushi. Similarly, no evidence of historical or archeological sites could be found at Thilafushi. Not present in the study area.
Current use of land resources for traditional purposes	No evidence of current use of land for traditional purposes could be found at Thilafushi.

Additional Baseline Data Gathering. During the detailed design phase of the project, the baseline survey shall be conducted to include monthly baseline data on ambient air quality, and quarterly baseline data on marine water quality and marine underwater ecology. The DBO Contractor shall undertake progressive monitoring and sampling activities during this period to ensure robust baseline data and pre-works environmental conditions are documented. The results of the baseline survey are considered in the final detailed design of the project. In particular, the DBO Contractor shall:

(i) undertake ambient air quality measurements, marine water quality analysis, and marine underwater ecology surveys for each season of the year at the identified sampling locations in this EIA report (and any other locations in and around Thilafushi island as may be deemed by the DBO Contractor as important sampling locations);
(ii) follow required sampling methodologies and locations, including appropriate averaging time for ambient air quality measurements as indicated in the WHO Ambient Air Quality Guidelines; and
(iii) include results of analyses in the updating of the EIA during the detailed design phase and consider these results in the final detailed design of the project as applicable.

G. Analysis of Alternatives

ADB SPS requires projects with potential significant adverse environmental impacts to undertake analysis of alternatives. This step will ensure all reasonable alternatives or options are taken into account, including the effect of a no project option scenario, and that these are examined towards minimizing impacts to the environment and allowing decision-makers to choose the best alternatives to protect and enhance environmental quality. The EIA has undertaken various alternatives analysis for the project for the (i) project technology; (ii) design capacity; (iii) air emission control; and (iv) sea water intake and discharge location.

Project technology. Analysis of the various SWM and treatment options has been undertaken. Due to space or land availability limitations in Thilafushi, the analysis suggested the adoption of technologically driven waste treatment option, which led to the selection of incineration technology. Subsequently, a second round of alternatives analysis was undertaken to determine which incineration technology will work in view of characteristics and volume of wastes, environmental quality standards, cost of technology, land requirement, and operation and maintenance requirements, among others. Ultimately, the moving grate incinerator technology was chosen as the best option due to its robustness and proven applications.

Design capacity and Loading Conditions. Based on the analyses of the waste composition and the various recycling scenarios undertaken by the feasibility study conducted by the Government, the following design values were considered for the WTE plant:

(i)	Design value (“nominal”)	8,000 KJ/kg
(ii)	Minimum value	6,500 KJ/kg
(iii)	Maximum value	9,500 KJ/kg

At the maximum value, it was assumed that high amounts of plastic are still contained in the garbage due to a lack of separation. Furthermore, it was taken into account that the water content of the organic waste is lower during the dry season. With the assumption of a throughput of 500 tons per day (21 tons per hour) and the above-mentioned calorific values, the thermal load range of the system is from 43.8 MW to 48.2 MW with potential net electricity output in the range of 6-8MW.

Air emission control. The flue gases discharged from the secondary combustion chamber are passed through various air pollution control systems for cleaning. The type of air pollution control systems provided depends on the desired level of cleaning. All commonly available dry or semi-dry flue gas cleaning systems including a bag-house filter can be used to meet the emission standards for heavy metals and acid and organic pollutants. Absorbents based on either lime or sodium bicarbonate/lime which are enriched with activated coke or carbon may be applied. The NOx removal may be effected either via a catalytic or non-catalytic reaction injecting ammonia or urea. For the proposed WTE plant, any or all of the aforesaid systems can be used following international emission standards, in particular the emission limit values in Annex VI of Directive 2010/75/EU of the European Parliament and the Council (also referred to as EU Industrial Emission Directives).

Sea water intake and discharge location. The operation of the project will require the use of water for its cooling system, which will be drawn from the sea and then discharged back to the sea at a temperature that is not more than 3ºC from ambient sea water temperature. Discharge of this cooling water could potentially impact the underwater marine ecosystem in the area. An alternatives analysis was undertaken to identify the best section and location for the cooling water outfall. Based on proximity to the project site, three alternative locations have been identified and assessed. Underwater marine surveys were conducted to determine the extent of marine life, including the condition of the coral reefs, at these alternative sites. Results show that within those sites, no significant marine life and corals has been discovered. Hence, the cooling water discharge line may be located at any of these three locations without impacting any underwater marine ecosystem. As the final determining factor, the EIA has used the underwater topography profile in the three location to identify where the cooling water discharge line can be effectively laid at. The location with the least steep slope has been selected.

While the section through which the pipe will be laid has been identified, the depth of where to position the three outfalls (end of the discharge lines) was also analyzed. Based from the underwater marine survey, sporadic coral species and pelagic fishes were observed at the upper layer at depth or around 5 – 10 meters. At the depth of around 10 – 20 meters, the slope of the reef wall is steep without any significant geographical characteristics. At the depth of 30 meters and deeper, the seabed is characterized by large expanse of rocks and rubbles and where no evidence of corals or fishes was observed. As a precautionary measure, the outfalls will be designed to be positioned at this depth. The outfalls are set perpendicular to the shore in which the outlets are arranged to release the hot water jet parallel to the center line of their ports towards the deep sea. A hot water (heat dissipation) dispersion modeling was carried out at this depth of 30 meters. The modeling used simulation scenarios that took into consideration all possible monsoonal and tidal conditions. Results show that for the near-field model, the temperature difference of the cooling water over ambient drops to around 1ºC in less the 10 meters from the outfalls, and reduces further to 0.5ºC and less as the plume spreads farther beyond 10 meters from the outfalls. Hence, at this depth of the outfalls, impact of the cooling water on the corals (though found to be few and sporadic) is not expected. Using the results of the near-field model as input to the far-field model, the simulations show that the temperature difference approaches 0.03ºC in around 1 km from the outfalls. This temperature difference is regarded as very low and considered negligible in coastal environment. The graphical representation of hot plume dispersion for the near-field model and the temperature variation in 2D plain for the far-field model are presented in Section IV of this EIA report, while the full report of the modeling is attached as Appendix 8.

Intake. The results of the underwater survey at the southern coastal section of the project site (M1, M8, M9, and M10) reveals no significant underwater marine life at these locations. This provides greater flexibility for the DBO Contractor to position the intake location of cooling water at any of these locations. However, in order to reduce impacts on the shoreline during construction phase, intake location will be positioned at the vicinity of Sections M1 and M8. This will ensure that construction of intake and discharge line structures, will be integrated and undertaken coherently at the same or close alignment and location. The recommended position of the inlet structure is described and shown in the EIA using the exact location coordinates and google earth map.

H. Potential Impacts of the Project

The potential impacts have been identified and assessed through review of the project preliminary designs, discussion with the designers and experts involved in the project preparation, conduct of socio-economic survey, and stakeholders' consultations.

Impact on marine environment. The construction of the sea water intake and cooling water outfalls is potential to impact the reef wall. The marine survey conducted in September 2019 in the designated location for the pipes reveal there no corals and marine life exist in the area and depth. The method of construction will involve conventional pipe installation where the pipes will be prepared on the construction site, floated the right position, sunk and anchored, which is common practice in the Maldives and requirements for contractors are in place. Therefore, the potential impact is not significant.

The project is not located within or adjacent any ecologically critical areas. The nearest identified marine protected area is the Lions Head diving site which is 1 km away from the project site. The discharge of cooling water from the WTE plant's cooling systems and brine from the desalination unit may affect this protected area and the marine environment. However, the volume of brine generated from the desalination unit is expected to be too small compared with the volume of cooling water discharge. The salinity of the cooling water discharge is expected to remain normal. As such, only the elevated temperature of cooling water discharge may impact the immediate and surrounding marine environment. A temperature dispersion (heat dissipation) modeling was carried out to assess the extent of influence of cooling water discharge temperature outwards from the outfall location. It was found that the temperature of the cooling water drops to about 0.03^{o}C from ambient as it spreads out in about 1 km from the outfall. This temperature difference is very low and is considered negligible in coastal environment. Thus, the cooling water will not affect the Lions Head and surrounding marine environment.

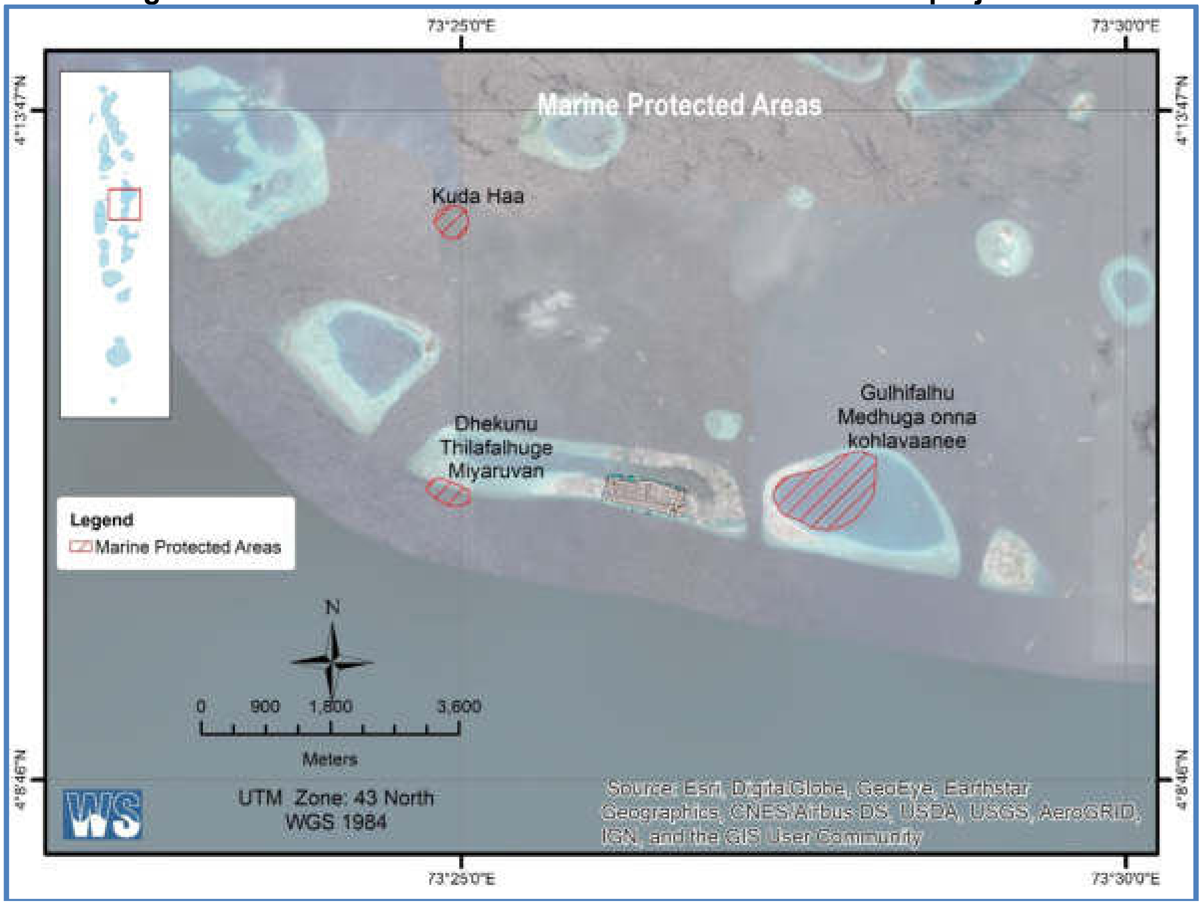
Impact on groundwater. The groundwater in Thilafushi has been tested and results show some parameters have been exceeded when compared with the National Drinking Water Standards. The construction phase and operation phase of the project will apply mitigation measures defined in the EMP of EIA report. During operation phase, the design shall ensure that leachate collection treatment plant and wastewater treatment plant will be installed in order to mitigate impact to groundwater as discussed in this EIA report. The design considerations and the EMP will be included as part of DBO contract documents. Therefore, the potential impact is expected to be not significant.

Impact on avifauna. The birds attracted to the island as well as water birds that frequent surrounding waters will benefit from both the improved handling and treatment to remove hazardous fractions onto the landfill or into surrounding waters. The potential impact will be positive impact and for the long-term.

Impact on biodiversity, protected areas and critical habitat. There are no significant adverse impacts anticipated due to the operation of this project. The closing of the existing dumpsite will prevent scavenger birds from ingesting hazardous substance and plastic. The marine biodiversity at Thilafushi may also improve with the reduction of pollution. The nearest protected area within the 1km radial distance from the project site is the Lions Head dive site. The nearest boundary of this protected is about 950m or nearly 1km from the project site. The only aspect of the project operation that could potentially impact this protected area is the discharge of cooling water. However, based on analysis, this location of the protected area is too far to be affected by the cooling water discharge from the WTE plant.

According to Maldives EPA, there are 3 Marine Protected Areas (MPA) within 5km radius from the project site. They are; (i) Dhekunu Thilafalhuge Miyaruvani – this area is also referred to as Lions Head and is on the outside of the South Malé Atoll facing south into Vaadhoo Channel. (ii) Gulhifalhu Medhuga Onna Kollavaanee – this area is referred to as Hans Hass Place, which is the deep lagoon area at Gulhifalhu and (iii) Kuda Haa – isolated reef standing up from a sandy bottom at 30m, north to Giraavaru Island. In addition to the marine protected areas there are other areas that are also designated as ecologically sensitive areas in Kaafu atoll. However, none is located within 5 km radius of the project site.

Figure 1: Marine Protected Areas within 5km radius of the project site



Dhekunu Thilafalhuge Miyaruvani (also known as “Lions Head”) is the closest MPA to the project area. The edge of Lions Head is about 1 km from the project site’s boundaries. Lions Head is on the outside of North Malé Atoll facing south into Vaadhoo Channel. From the reef edge at about 8m there is a step down to a steep rubble slope where one can sit to watch the sharks. To the right (west) as one faces out is a large overhang that leads down to over 30 m depth. To the left (east) there is a line of small overhangs in 10-15m that continues for about 150 m. The Maldives EPA consider the Lions Head as a protected seascape (IUCN Category V) which covers ocean with a natural conservation plan which accommodates a range of for-profit activities. It has been a marine protected site since 01 October 1995. As Thillafushi and its surrounding area have undergone a transformational development in the past two decades, Maldives EPA is considering declassifying Lions Head from being a marine protected area to a more appropriate status reflecting current land use (industrial zone).

Gulhifalhu Medhuga Onna Kollavaanee (also known as “Hans Hass Place”) is on the outer reef of North Malé Atoll facing south into Vaadhoo Channel. It is an area about 100m long set back in a large recess in the reef. The reef top is at about 3m and drops vertically to a line of over-hangs at 8-10m. The western end is marked by a large cavern at 10-15m. There are further overhangs at 20-25m. Hans Hass Place is named in honor of the great pioneer of diving in Maldives.

Kuda Haa is located about 4km north from the project site. It assumed that no direct impact will be caused to this MPA due to the distance and location.

Within the MPAs, activities such as anchoring (except in an emergency), coral and sand mining, dumping of waste, removal of any natural object or living creatures, fishing of any kind (with exception of traditional live bait fishing) and any other activity which may cause damage to the area or its associated marine life are prohibited under the Environment Act.

In order to assess whether the WTE project is located in a critical habitat, an initial screening was undertaken using the Integrated Biodiversity Assessment Tool (IBAT).[6] Results show that the location of the WTE project is likely a critical habitat. Therefore, a critical habitat assessment is needed to confirm the results. Critical habitat assessment ideally takes place across sensible ecological or political units that are sufficiently large to encompass all direct and indirect impacts from the project. These areas of analysis (AoAs) are thus often much broader than the direct project footprint. AoAs may be separate or combined, depending on the ecology of the biodiversity concerned. Considering the extent of potential impacts on aquatic biodiversity from the project, an aquatic AoA for the project was identified as the 50-km study area to make consistent with the default range in the IBAT Screening. This area is approximately within the Zone 3 of Maldives, within which common biological communities and/or management issues exist.

The critical habitat assessment considered if critical habitat-qualifying biodiversity candidates or species identified in the IBAT Screening are actually or potentially present within the AoA. The IFC Guidance Note 6 (2019)[7] has been used to identify if a certain biodiversity candidate or species can qualify the project AoA as Critical Habitat. Reasons are identified for each biodiversity feature likely meeting or not meeting Critical Habitat.

Results show that the AoA which encompasses the project site is likely to be a critical habitat only for a terrestrial insect (*Enallagma maldivense*). This insect normally thrives in freshwater habitats such as ponds. As the project is located in Thilafushi, an island with no freshwater body, it is highly unlikely that this insect is present within and around the island. More so that this insect is not found in the coastal areas and open seas surrounding Thilafushi island. However, as a precautionary measure, the critical habitat assessment and EIA recommend continuous monitoring around Thilfushi island to confirm the extent of biodiversity in various seasons of the year, including assessment of features pertinent to critical habitats. As part of the detailed design, the DBO contractor in coordination with PMU will be required to undertake additional biodiversity assessment around the project site. This is to ensure pre-construction works conditions and biodiversity risks are considered in the design, construction and operation, and to examine and mitigate the potential impacts of the project on areas significant for biodiversity. In cases when future information determines the existence of critical habitat, the WTE project should be able to demonstrate that:

(i) It does not lead to measurable adverse impacts on those biodiversity values for which the critical habitat was designated, and on the ecological processes supporting those biodiversity values;

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[6] The Integrated Biodiversity Assessment Tool (IBAT) is a multi-institutional programme of work involving BirdLife International, Conservation International, IUCN, and UNEP-WCMC. IBAT provides a basic risk screening on biodiversity. It draws together information on globally recognised biodiversity information drawn from a number of IUCN's Knowledge Products: IUCN Red List of Threatened Species, Key Biodiversity Areas (priority sites for conservation) and Protected Planet/The World Database on Protected Areas (covering nationally and internationally recognised sites, including IUCN management categories I–VI, Ramsar Wetlands of International Importance and World Heritage sites).

[7] https://www.ifc.org/wps/wcm/connect/5e0f3c0c-0aa4-4290-a0f8-4490b61de245/GN6_English_June-27-2019.pdf?MOD=AJPERES&CVID=mRQjZva

(ii) It does not lead to a net reduction in the global and/or national/regional population of any Critically Endangered or Endangered species over a reasonable period of time; and
(iii) It has integrated into its management program a robust, appropriately designed, and long-term biodiversity monitoring and evaluation program.

Impact on air quality. Impact to air quality during construction phase are similar to impacts expected from other construction activities elsewhere, which can be mitigated through good international construction and engineering practices. All mitigation measures to avoid all these situations are included in the EMP. Based on the detailed design, the DBO Contractor shall update the EMP and develop its site-specific EMP (SEMP) following applicable international best practices that will include World Bank's EHS Guidelines on Construction and Decommissioning Activities.[8]

During operations phase, measures to avoid impacts on air quality include selecting best technology for incineration, integration of APC system and stack height. Municipal waste incineration produces various pollutants that can affect air quality and human health. These pollutants are released through two specific waste products of incineration process known as bottom ash and fly ash. These wastes can include a combination of various heavy metals, dioxins and furans, and other persistent organic pollutants. Specifically, fly ash is the more hazardous waste product due to size and density that can go airborne with the combustion gases when released to the atmosphere and impact air quality.

Heavy metals and dioxin and furans are highly toxic compounds which when inhaled or ingested by humans may in the long term cause cancer and neurological damage, congenital malformations and infant mortality, respiratory illnesses, etc. Hence, it is paramount that the adoption of incineration technology has to come with it an accompanying APC technology or process which will enable efficient recovery of these toxic pollutants. However, even with the most advanced technologies to date, complete removal of these toxic substances in the flue gases is difficult to achieve. It is for this reason that good international industry practices and standards, such as the emission standards in Annex VI of Directive 2010/75/EU of the European Parliament and the Council, are established to ensure emissions from these specific facilities do not impact the ambient conditions of the environment. Concomitantly, height of stack from where emissions should be discharged needs to be calculated and followed to ensure pollutants from emissions do not degrade the ground level ambient air quality. Air dispersion modeling is normally used to simulate how air pollutants disperse in the atmosphere and to analyze the potential impacts of these pollutants to ambient air quality given specific project and site information.

For the WTE plant, dispersion modeling carried out using AUSTAL2000 showed that the emission (with the proposed flue gas cleaning), would have no additional harmful impact on the surrounding environment, particularly with regard to dust precipitation, sulfur dioxide, nitrogen oxides, fluorine and mercury deposition. In view of the perceived impact of emission from this type of project to ambient air quality, the air dispersion modeling was re-run using a different air dispersion model (AERMOD) as a confirmatory measure of the EIA. The modeling run using AERMOD also confirmed similar findings of AUSTAL2000 that no significant impact on the surrounding environment. AERMOD modeled the dispersion of parameters, including other parameters not screened by AUSTAL2000 such as ammonia, dioxins and furans, and group of heavy metals. With these findings, a significant negative impact on ambient air quality is not expected. Results

[8] IFC World Bank Group. 2007. Environmental, Health, and Safety (EHS) Guidelines – General EHS Guidelines: Construction and Decommissioning.

in comparison with internationally recognized standards such as WHO and USEPA are presented in the EIA report.

While air dispersion modeling shows the WTE operation will not bring significant impact to ambient air quality in Thilafushi island, the DBO Contractor shall ensure all measures are still appropriately integrated into the detailed design of the project. Air emissions from the incineration will depend on the specific waste composition and the presence and effectiveness of air pollution control systems. Polluting emissions may include carbon dioxide (CO_2), CO, NOx, sulfur dioxide (SO_2), particulate matter, ammonia, amines, acids (HCL, HF), VOCs, dioxins/furans, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), metals (Hg), and sulfides, etc., depending on the waste content and combustion conditions. During the detailed design, the DBO Contractor shall consider all applicable measures recommended by the European Union Best Available Technique Reference (BREF) documents 2018,[9] or the World Bank EHS Guidelines on Waste Management Facilities,[10] whichever is applicable and meaningful for the project. Subject to practicality and project circumstances, the project will consider the following examples of measures to prevent, minimize, and control air emissions:

(i) Conduct of waste segregation and/or presorting, subject to feasibility or practicality, by collaborating with the waste supplier to avoid incineration of wastes that contain metals and metalloids that may volatilize during combustion and be difficult to control through air emission technology (e.g., mercury and arsenic);
(ii) Follow applicable national requirements and internationally recognized standards for incinerator design and operating conditions, mainly rapid quenching of the flue gas after leaving all combustion chambers and before entering any dry particulate matter air pollution control device but also combustion temperature, residence time, and turbulence.[11] Standards for stationary incinerators which include temperature and afterburner exit gas quenching (i.e. rapid temperature reduction) requirements are preferred in order to nearly eliminate dioxins and furans. In case where rapid quenching is not practical for the WTE plant, follow applicable national requirements and internationally recognized standards for incinerator design and operating conditions, such as combustion temperature, residence time, turbulence, and reduced residence time of dust laden exhaust gases in the temperature range of 450 to 200 degrees Celsius;
(iii) Introduce wastes into the incinerator only after the optimum temperature is reached in the final combustion chamber;
(iv) The waste charging system should be interlocked with the temperature monitoring and control system to prevent waste additions if the operating temperature falls below the required limits;
(v) Minimize the uncontrolled ingress of air into the combustion chamber via waste loading or other routes;
(vi) Optimize furnace and boiler geometry, combustion air injection, and, if used, NOx control devices using flow modeling;

[9] https://eippcb.jrc.ec.europa.eu/reference/BREF/WI/WI_BREF_FD_Black_Watermark.pdf

[10] IFC World Bank Group. 2007. Environmental, Health, and Safety (EHS) Guidelines For Waste Management Facilities.

[11] For example, according to Article 6 of EU Council Directive 2000/76, the gas resulting from the incineration process should be raised, after the last injection of combustion air to a temperature of 850 degrees Celsius (1,100 degrees Celsius for hazardous wastes with a content greater than 1% of halogenated organics) for a period of two seconds. Additional details on operating conditions are provided in this reference. Other sources of emissions standards include the U.S. EPA regulations for air emissions from stationary sources at 40 CFR Part 60.

(vii) Optimize and control combustion conditions by the control of air (oxygen) supply, distribution and temperature, including gas and oxidant mixing; the control of combustion temperature level and distribution; and the control of raw gas residence time;

(viii) Implement maintenance and other procedures to minimize planned and unplanned shutdowns;

(ix) Avoid operating conditions in excess of those that are required for efficient destruction of the waste;

(x) Use auxiliary burner(s) for start-up and shutdown and for maintaining the required operational combustion temperatures (according to the waste concerned) at all times when unburned waste is in the combustion chamber;

(xi) Use a boiler to transfer the flue-gas energy for the production of electricity and/or supply of steam/heat, if practical;

(xii) Use primary (combustion-related) NOx control measures and/or selective catalytic reduction (SCR) or selective noncatalytic reduction (SNCR) systems, depending on the emissions levels required;

(xiii) Use flue gas treatment system for control of acid gases, particulate matter, and other air pollutants;

(xiv) Minimize formation of dioxins and furans by ensuring that particulate control systems do not operate in the 200 to 400 degrees Celsius temperature range; identifying and controlling incoming waste composition; using primary (combustion-related) controls; using designs and operation conditions that limit the formation of dioxins, furans, and their precursors; and using flue gas controls; and

(xv) Consider the application of waste-to-energy technologies to help off-set emissions associated with fossil fuel-based power generation.[12]

Additional Measures to Mitigate Impacts on Ambient Air Quality During Operation Phase.

(i) **Offset Activities Within Thilafushi**. The government plans to stop fires on Thilafushi and start baling waste by July 2020 as interim SWM solution to stop open dumping until the WTE facility is commissioned. It is expected that once these measures are implemented the air quality at the sampling locations will improve. The rehabilitation of the existing dumpsite will have the end view of shutting down the operation of the dumpsite and finally stopping the smoke emanating from it. This activity will serve as the biggest offset to substantially reduce the impact of the WTE plant operation to ambient air quality. Monitoring the benefits of this offset will continue throughout the operation phase and included in the environmental monitoring plan developed in this EIA report.

(ii) **Use of cleaner fuels or technologies**. The DBO Contract includes performance guarantees on use of cleaner fuels and technologies that have already been proven in other countries. These performance guarantees will ensure that the WTE plant will comply with the emission standards.

Impact on marine water quality. Impacts on the marine environment during the construction will largely be from the construction of the berth and the discharge pipes for cooling water from the incinerator and the utilities such as sewerage and brine from desalination. The berth is proposed

[12] The possibility of applying waste-to-energy technologies depends on a number of issues which may include the project design specifications established by local government as well as laws applicable to the generation and sale electricity. Also, it should be noted that recycling options may often save more energy than what is generated by incineration of mixed solid waste in a waste-to-energy facility.

to be located at the enclosed lagoon in the island. Excavation in the area will result in sedimentation. As this semi-enclosed area is quite stagnant, settlement rate will be higher than an area with regular currents and water flow. However, all mitigation measures to avoid all these situations are included in the EMP. During operation phase, the design shall ensure that leachate treatment plant and wastewater treatment plant will be installed in order to mitigate impact to marine water as discussed in this EIA report. The design considerations and the EMP will be included as part of DBO contract documents. Therefore, the potential impact is expected to be not significant.

The marine survey conducted for this EIA shows that this area mostly consists or rock and rubble and hardly any live coral. Therefore, impacts for coral due to sedimentation is negligible. The discharge pipes will be directed towards the South into deep sea. As some live corals are located in this area, according to the marine survey, pipes will be laid during calm sea conditions, with as much care as is feasible.

Sea vessels can cause risks of water pollution, in the events of leaks and spills of fuel, lubricants, hydraulic fluids or other fluids used for vehicle operation. Although this area is already contaminated, care will be taken to mitigate the risks and impacts of any spills. Mitigation measures for these impacts are included in the EMP.

Impact on waste management. Waste generation will be expected during the construction phase. Expected wastes will include packaging of construction materials, equipment, fuels, lubricants, food and some rubble where existing structures need to be demolished, if any. Mitigation measures for handling and disposal of these wastes are included in the EMP. Some specialist lubricants and paint may be hazardous. These will also be disposed of at the appropriate locations following the measures in the EMP. For toxic materials, approvals must be obtained from appropriate agency prior to importing materials rated as hazardous under the Globally Harmonized System of Classification and Labelling of Chemicals. Therefore, the potential impact is not significant.

Impact on land-based and marine traffic. The project will not need any special considerations regarding location since the project is easily accessible through the use of exclusive landing ports and delivery areas not used by local workers or other industries in Thilafushi. As there are few vehicles on Thilafushi, there will be no significant impact on land-based traffic. All vehicle and heavy equipment movements during construction phase will only be limited within the boundary of the project site.

Delivery of construction equipment and raw materials may increase marine traffic in the area. In order to avoid this impact, all delivery of equipment during mobilization phase and raw materials for the construction activities will be utilizing the exclusive docking ports for the project, which are near or adjacent the project site. These docking ports are where current solid wastes are unloaded from various parts of project area. With this scheme, it is expected that no marine traffic and port congestion are expected that will affect the locator industries and workers on the island. A marine route for project construction mobilization has been prepared. Therefore, potential impact on land-based and marine traffic is not significant.

Impact on socio-cultural and livelihood. No social impacts pertaining to land loss, land fragmentation, physical displacement, loss of income, loss of productive land, potential income loss for fishermen and preventing fishing related activities and fishing routes.

Based on the results of the socio-economic survey, sensitive receptors were assessed if the project has influence, impact or control over them. Assessment of the results of the survey show that the project will not have impact or control over their welfare, status of employment or livelihood. Therefore, potential impact on socio-cultural and livelihood is not significant.

Impact on community and occupational health and safety. Impacts and risks for community and occupational health and safety are associated with heavy equipment in trafficked areas. The DBO contractor will be required to appoint a full-time environmental health and safety managers and maintain a pool of trained engineers to ensure the effective implementation of both environmental and occupational health and safety measures at the project site. The DBO Contractor shall establish its health and safety plan to be adopted at the site following international best practices. The DBO contractor has the responsibility to provide labor camps for migrant workers, and sufficient space for equipment, construction materials, consumables, and other supplies that will be required during construction phase. Therefore, the potential impact on community and occupational health and safety is not significant.

During the detailed design phase, the DBO Contractor shall integrate international good practices on community and occupation health and safety in its construction methods and practices, such those included in Section 4.2 of World Bank EHS Guidelines on Construction and Decommissioning activities (footnote 8). Minimum requirements shall be the following:

Community Health and Safety

(i) implement risk management strategies to protect the community from physical, chemical, or other hazards associated with sites under construction and decommissioning;
(ii) restricting access to the site, through a combination of institutional and administrative controls, with a focus on high risk structures or areas depending on site-specific situations, including fencing, signage, and communication of risks to the local community;
(iii) removing hazardous conditions on construction sites that cannot be controlled affectively with site access restrictions, such as covering openings to small confined spaces, ensuring means of escape for larger openings such as trenches or excavations, or locked storage of hazardous materials; and
(iv) implement measure to prevent proliferation of vectors of diseases at work sites;
(v) adequate space and lighting, temporary fences, shining barriers and signage at active work sites;
(vi) contractor's preparedness in emergency response;
(vii) adequate dissemination of GRM and contractor's observance and implementation of GRM; and
(viii) upon availability, local people should be given an opportunity for work in the subproject activities.

Occupational Health and Safety

(i) Communication and Training

    (a) Training of all workers on occupational health and safety prior to construction works;
    (b) Conduct of orientation to visitors on health and safety procedures at work sites;

(c) Signages strategically installed to identify all areas at work sites, including hazard or danger areas;
(d) Proper labeling of equipment and containers at construction and storage sites; and
(e) Suitable arrangements to cater for emergencies, including: first aid equipment; personnel trained to administer first aid; communication with, and transport to, the nearest hospital with an accident / emergency department; monitoring equipment; rescue equipment; firefighting equipment; and communication with nearest fire brigade station;

(ii) Physical Hazards
(a) Use of personal protective equipment by all workers such as earplugs, safety shoes, hard hats, masks, goggles, etc. as applicable, and ensure these are used properly;
(b) Avoidance of slips and falls through good house-keeping practices, such as the sorting and placing loose construction materials or demolition debris in established areas away from foot paths, cleaning up excessive waste debris and liquid spills regularly, locating electrical cords and ropes in common areas and marked corridors, and use of slip retardant footwear;
(c) Use of bracing or trench shoring on deep excavation works;
(d) Adequate lighting in dark working areas and areas with night works;
(e) Rotating and moving equipment inspected and tested prior to use during construction works. These shall be parked at designated areas and operated by qualified and trained operators only;
(f) Specific site traffic rules and routes in place and known to all personnel, workers, drivers, and equipment operators; and
(g) Use of air pollution source equipment and vehicles that are well maintained and with valid permits;

(iii) General Facility Design and Operation

(a) Regular checking of integrity of workplace structures to avoid collapse or failure;
(b) Ensuring workplace can withstand severe weather conditions;
(c) Enough workspaces available for workers, including exit routes during emergencies;
(d) Fire precautions and firefighting equipment installed;
(e) First aid stations and kits are available. Trained personnel should be available at all times who can provide first aid measures to victims of accidents;
(f) Secured storage areas for chemicals and other hazardous and flammable substances are installed and ensure access is limited to authorized personnel only;
(g) Good working environment temperature maintained;
(h) Worker camps and work sites provided with housekeeping facilities, such as separate toilets for male and female workers, drinking water supply, wash and bathing water, rest areas, and other lavatory and worker welfare facilities; and
(i) Maintain records and make reports concerning health, safety and welfare of persons, and damage to property. Take remedial action to prevent a recurrence of any accidents that may occur.

Similarly during the detailed design phase, the DBO Contractor shall integrate international good practices on community and occupation health and safety in its operation of the WTE, such those included in World Bank EHS Guidelines on Waste Management Facilities (footnote 10). The most significant occupational health and safety impacts typically associated with workers at waste management facilities occur during the operational phase and include accidents and injuries, chemical exposure, and exposure to pathogens and vectors. Minimum requirements shall be the following:

Accidents and Injuries. Physical hazards encountered at waste management facilities are similar to those at other large industrial projects. Solid waste workers are particularly prone to accidents involving trucks and other moving equipment, so traffic management systems and traffic controllers are recommended. Accidents include fires, explosions, being caught in processing equipment, and being run over by mobile equipment. Other injuries occur from heavy lifting, contact with sharps, chemical burns, and infectious agents. Smoke, dusts, and bioaerosols can lead to injuries to eyes, ears, and respiratory systems.[13] In addition to other standard measures adopted in most industrial facility operations, appropriate procedures following international best practices are recommended to prevent, minimize, and control accidents and injuries at the WTE plant and associated facilities.

Chemical Exposure. Chemical hazards encountered at waste management facilities are similar to those at other large industrial facilities, such as toxic and asphyxiating gases, and are addressed in the General EHS Guidelines. However, the full composition of wastes and their potential hazards is often unknown. Even municipal solid waste (MSW) often contains hazardous chemicals, such as heavy metals from discarded batteries, lighting fixtures, paints, and inks. Appropriate procedures following international best practices are recommended to prevent, minimize, and control chemical exposure at the WTE plant and its associated facilities.

Pathogens and Vectors. Workers can be exposed to pathogens contained in manure and animal excreta found in MSW from the disposal of sludge, carcasses, diapers, and yard trimmings containing domestic animal waste. Uncontrolled dumping of MSW attracts rats, flies, and other insects that can transmit diseases. Processing of MSW can also generate bioaerosols, suspensions of particles in the air consisting partially or wholly of microorganisms, such as bacteria, viruses, molds, and fungi. These microorganisms can remain suspended in the air for long periods of time, retaining viability or infectivity. Workers may also be exposed to endotoxins, which are produced within a microorganism and released upon destruction of the cell and which can be carried by airborne dust particles. The following measures are recommended to prevent, minimize, and control pathogens and vectors at the WTE plant and its associated facilities:

(i) Provide and require use of suitable personal protective clothing and equipment;
(ii) Provide worker immunization and health monitoring (e.g., for Hepatitis B and tetanus);
(iii) Maintain good housekeeping in waste processing and storage areas;
(iv) Use automatic (non-manual) waste handling methods if practical;
(v) Clean and wash with disinfectant the cabins of heavy mobile equipment used at regular intervals;
(vi) Use integrated pest-control approaches to control vermin levels, treating infested areas, such as exposed faces and flanks with insecticide, if necessary;

[13] Refer to Cointreau. S. (2006) for additional information.

(vii) Provide and require use of dust masks or respirators under dry and dusty conditions. Charcoal-filled respirators also reduce odor perception;
(viii) Provide prompt medical attention for cuts and bruises. Cover open wounds to prevent contact with the incoming loads or feedstock;
(ix) Fully enclose the waste management site with fencing so that no livestock or wildlife is able to come in contact with the waste, which contains significant potential to enable the spread of livestock and zoonotic disease, as well as spillover disease to wildlife. Provide daily cover of wastes to minimize the attraction to birds, which can become infected with avian influenza and other bird diseases that can then be carried off-site.

General Occupational and Environmental Health Issues Associated with Waste Scavenging. The presence of informal sector workers laboring in municipal or mixed waste disposal sites in search of commercially valuable materials is a common place occurrence in developing countries. The causes and dynamics are the result of complex social, cultural, labor, and economic factors that are clearly outside of the scope of this guidance document. However, the following principles, if applicable, should be considered in managing the occupational, health, and safety risks at the WTE site and its associated facilities:

(i) Waste scavenging should not be allowed under any circumstances in hazardous and non-hazardous industrial waste management facilities;
(ii) Facilities dedicated to the management of MSW should work with government entities in the development of simple infrastructure that can allow for the sorting of waste, helping groups of scavengers form cooperatives or other forms of micro-enterprises, or formally contracting them to provide this function. The outright displacement of scavenging workers as an occupational health and safety management strategy, without the provision of viable alternatives, should be avoided;
(iii) Operators of existing facilities with scavenging workers should exercise commercially viable means of formalizing their work through the creation of management programs that include:
    (a) Allowing only registered adults on the site, excluding children and domestic animals. Striving to provide alternatives to access to childcare and education to children;
    (b) Providing protective gear, such as shoes. face masks, and gloves;
    (c) Arranging the disposal layout and provide sorting facilities to improve access to recyclables while reducing their contact with other operations, thus minimizing potential hazards;
    (d) Providing water supply for washing and areas for changing clothes;
    (e) Implementing education campaigns regarding sanitation, hygiene, and care of domestic animals;
    (f) Providing a worker health surveillance program including regular vaccination and health examinations.

Physical, Chemical, and Biological Hazards. Visitors and trespassers at waste management facilities may be subject to many of the hazards described for site workers. Exhaust fumes of waste collection trucks traveling to and from disposal sites, dust from disposal operations, and open burning of waste all contribute to potential occupational health problems.[14] Recommended

[14] Sandra Cointreau, The World Bank Group, Occupational and Environmental Health Issues of Solid Waste Management Special Emphasis on Middle- and Lower-Income Countries, Urban Papers UP-2, July 2006.

measures to prevent, minimize, and control physical, chemical, and biological hazards to the community around the WTE site include:

(i) Restrict access to waste management facilities by implementing security procedures, such as:

(a) Perimeter fencing of adequate height and suitable material, e.g. chain link, stock proof palisade;
(b) Lockable site access gate and buildings;
(c) Security cameras at key access points linked to recording equipment and remote access CCTV, where required;
(d) Security alarms fitted to buildings and storage areas;
(e) Review of site security measures annually or whenever a security breach is reported;
(f) Use of a site visitor register;
(g) Immediate repair of fencing/access points if damaged; and
(h) Lighting of site during night time where necessary. As this may cause light nuisance to neighbors, the lighting installations should be selected to minimize ambient light pollution.

Construction Camp Site and Workers Accommodation During Operations. The construction camp site and accommodation of workers shall be established following international best practices to ensure welfare of workers is protected.[15] The DBO Contractor shall consider the following requirements, whichever are applicable or practical depending on site situation in Thilafushi, in building these camps and accommodation facilities at the site, if any.

(i) The temporary campsite location should:

(a) Be free from any risk of flooding.
(b) Be sited a reasonable distance and have clear physical separation from any construction work, equipment and/or machinery.
(c) Provide clear separation between the camp and construction area through such means as a footpath, fence, etc.
(d) Where possible, be sited outside the boundary of the construction zone.

(ii) The site design should ensure:

(a) Adequate space to accommodate the number of workers throughout the project period, for accommodation, meals, toilets, bathing, etc.
(b) Considerations for needs of all types of workers: e.g. women, local laborers or travelers, etc.
(c) Adequate drainage is provided to prevent any stagnant water which can attract mosquitos and vermin and spread disease among workers,
(d) Buildings are structurally sound and can withstand wind and rain.

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[15] From the draft Construction Code of Practice developed for urban development projects in Kathmandu, Nepal. This COP was developed with reference to the following: "Workers' accommodation: processes and standards: A guidance note by IFC and EBRD", IFC and EBRD, 2009 https://www.ebrd.com/downloads/about/sustainability/Workers_accomodation.pdf; and "Malaysian standards of temporary construction site workers' amenities and accommodation – code of practice. (MS 2593, 2015) http://www.sirim.my/srmc/documents/Aug-Sept-2014/12D024R0_PC.pdf

(e) Ensure that the worker camp area will have adequate ground surfacing (e.g. gravel, wood sheeting, grass) such that residents may move freely between buildings in their off time without walking through mud and water.
(f) Designated area for small fires during colder months, located a safe distance from buildings and any flammable materials.

(iii) The workers' accommodation should comply with the following requirements:

Dimensions and Design

(a) The height of room shall not be less than 2.4 meters.
(b) The sleeping area or resting area shall not be less than 3 m^2 per person.
(c) Separate bed for each worker provided, with minimum of 1 meter space between each bed.
(d) Separate sleeping areas are provided for men and women, except in family rooms if needed.
(e) Sleeping area should be separate from cooking/canteen areas, and far enough distance from toilets to avoid odors.
(f) Where possible, prefab-type structures could be considered.

Light and Air

(a) Both natural and artificial lighting are provided and maintained in living facilities. It is best practice that the window area represents not less than 5% to 10% of the floor area. Emergency lighting is provided.
(b) For cold weather months, accommodation must be such that the temperature is kept at a level of around 20 degrees Celsius notwithstanding the need for adequate ventilation.
(c) In warmer months, adequate ventilation (either cross-ventilation and/or fans) is provided.

Materials

(a) Roofing materials must be such that the structure can withstand high winds without risk of collapse, and be leak-free during rainy season.
(b) Flooring material should be easily cleanable and free of bare nails or other sharp objects.

Provisions/furnishing

(a) Each worker is provided with a comfortable mattress, pillow, cover and clean bedding.
(b) Double or triple-deck bunk beds are prohibited. Double deck bunks may be used in special circumstances but must be approved by the Engineer.
(c) Each resident is provided facilities for the storage of personal belongings, such as a locker or shelving unit.
(d) Every resident is provided with adequate furniture such as a table, a chair, a mirror and a bedside light (small solar lights may be a good option). These may be shared among several workers.
(e) Separate storage provided for work boots and PPE. Drying/airing areas may need to be provided for PPE depending on conditions.

(f) Mosquito nets are provided in areas where mosquitos are present and/or at the request of workers.
(g) Rubbish bin with cover provided in each room and emptied regularly.
(h) Electrical outlets provided for charging mobile phones, radio, etc. Ensure that electrical wiring is done properly and presents no risk of electrical fire.
(i) All doors and windows should be lockable and be provided with mosquito screens.

(iv) The workers kitchen area should comply with the following requirements:

(a) The minimum area of kitchen should be not less than 4.5 m^2 and the minimum width should be more than 1.5 meters.
(b) Adequate height of kitchen should be not less than 2.25 meters.
(c) Provide where clean drinking water is always available – ensure that any open water tanks are covered.
(d) Kitchens are provided with facilities to maintain adequate personal hygiene including a sufficient number of washbasins designated for cleaning hands with clean water and materials for hygienic hand-drying.
(e) In order to enable easy cleaning, it is good practice that cooking stoves are not sealed against a wall, and benches and fixtures are not built into the floor.
(f) Design should consider if the kitchen within the camp will be used to service all workers for all meals (e.g. meals prepared for day laborers as well as residents) or will be limited to self-preparation of meals by residents.
(g) Wall surfaces adjacent to cooking areas are made of fire-resistant materials.
(h) Food preparation tables are equipped with a smooth, durable, easily cleanable, non-corrosive surface made of non-toxic materials.
(i) All cupboards and other fixtures have a smooth, durable and washable surface.
(j) All kitchen floors, ceiling and wall surfaces adjacent to or above food preparation and cooking areas are built using durable, non-absorbent, easily cleanable, non-toxic materials.
(k) Cooking gas canisters provided
(l) Fire extinguisher provided outside of cooking area.
(m) Rubbish bin(s) provided with cover
(n) Adequate facilities for cleaning, disinfecting and storage of cooking utensils and equipment are provided.

(v) The workers toilets should comply with the following requirements:

(a) Toilets should be located within same general area as accommodation, but at least 30 meters away from sleeping area/kitchen. Should not be more than 60m away.
(b) Toilets should be located at least 30 meters away from any water wells.
(c) An adequate number of toilets should be provided to workers. Standards range from 1 unit per 15 persons to 1 unit per 6 persons.
(d) Toilet rooms shall be located so as to be accessible without any individual having to pass through any sleeping room
(e) Toilet dimensions should be at least 1.5 m × 0.75 m (minimum width)

(f) Toilet facilities should be installed so as to prevent any odors reaching dining facilities or sleeping areas.
(g) Separate facilities provided for men and women.
(h) An adequate number of handwash facilities is provided to workers. Standards range from 1 unit per 15 persons to 1 unit per 6 workers. Handwash facilities should consist of a tap and a basin, soap and hygienic means of drying hands.
(i) Toilets should be constructed such that they are structurally sound during high winds and free from leaks during rains.
(j) Every toilet should be provided with natural lighting and natural ventilation by means of ≥ 1 openings, providing a total area of >0.2 m^2 per toilet. Such openings shall be capable of allowing a free, uninterrupted passage of air.
(k) In addition, all toilet rooms should be well-lit, with natural lighting and artificial lights at night.
(l) Ensure no discharge of toilets and showers that will contaminate water sources or common areas
(m) Sanitary and toilet facilities are designed to provide workers with adequate privacy, including ceiling to floor partitions and lockable doors
(n) Ensure toilets have rubbish bin in each cubicle

(vi) The shower and washing facilities should comply with the following requirements:

(i) An adequate number of shower facilities is provided to workers. Standards range from 1 unit per 15 persons to 1 unit per 6 persons.
(ii) Shower/bathing facilities are provided with an adequate supply of clean water.
(iii) Separate facilities for men and women.
(iv) The flooring for shower facilities should be of hard washable materials, damp-proof and properly drained.
(v) Suitable light, ventilation and soap should be provided.
(vi) Adequate space and hooks must be provided for hanging clothes/towels while bathing.
(vii) Area for washing/drying clothes provided, including washbasin, soap and drying lines. Either piped water to the basin or standpipe for filling basins should be within close distance.
(viii) Ensure area drains well and doesn’t create a muddy environment.

(vii) Optional Amenities and Other Good Practices that should be followed as applicable:

(a) Paint the camp buildings to present a tidy and satisfactory appearance – this will help encourage workers to keep their camp in good condition.
(b) Provide signage in kitchen area, canteen, toilets, and other common areas to encourage good hygiene practices, cleanliness of kitchen and personal spaces, worker conduct, worker responsibilities, safety evacuation plan, etc.
(c) Involve laborers in design of the camp, e.g. to get their inputs on siting of buildings, and any specific needs of women.

Impact due to land acquisition or resettlement. There will be no land acquisition and no private property will be affected. Therefore, no impact is envisaged.

Impact on landscape and visual. Creation of a vegetation buffer-zone along the coast near the project site and landfills would provide a natural protection of odor and blends into island aesthetic. The WTE plant will have a waste reception hall that shall comply with environmental, health and safety, and operational requirements. Odor emissions shall be prevented by a draft induced by the primary air supply fan. Entry and exit gates shall be closed by an electrically driven fast acting shutter with an airtight design. The dimension of the reception hall shall allow for safe flow of incoming and exiting vehicles. The WTE plant will have all necessary spaces dedicated for equipment, vehicles and waste storage during the operation phase. Therefore, potential impact is not significant.

Residual impacts (i.e. after practicable mitigation). The residual wastes from the waste incineration are bottom ash, slag and the residues from flue gas. Bottom ash and slag is a valuable fraction which may potentially be used for many purposes such as covering material for landfill, ballast layer or reinforcement layer in road construction or filler/aggregate for construction blocks. Under any circumstances that these options are not feasible, the sanitary landfill will be able to accommodate the residual wastes. The hazardous residues from the flue gas cleaning (fly ash) will be handled separately from the bottom ash following the APC Residue or Fly Ash Management Plan included in this EIA report (see below fly ash management). With reference to the waste characteristics, the wastes have the potential to contain hazardous substances. Therefore, both the bottom ash and fly ash may likewise contain these hazardous substances that could impact the environment if no sufficient measures are taken to contain them. In order to avoid this impact, the DBO Contractor shall design the landfill facility by applying international best practices on landfilling of hazardous wastes, such as the relevant requirements indicated in the EU Directive on the Landfill of Wastes.[16] Below table summarizes these requirements.

Table 3: General Requirements for Hazardous Waste Landfills

Design Parameters	Design Considerations and Requirements
Water control and leachate management	Appropriate measures shall be taken, with respect to the characteristics of the landfill and the meteorological conditions, in order to: (i) control water from precipitations entering into the landfill body, (ii) prevent surface water and/or groundwater from entering into the landfilled waste, (iii) collect contaminated water and leachate, (iv) treat contaminated water and leachate collected from the landfill to the appropriate standard required for their discharge following the guaranteed effluent quality that the DBO Contractor shall comply as stated in this EIA report.
Protection of soil and water	The landfill must be situated and designed so as to meet the necessary conditions for preventing pollution of the soil, groundwater or surface water and ensuring efficient collection of leachate as and when required. Protection of soil, groundwater and surface water is to be achieved by the combination of a geological barrier and a bottom liner during the operational/active phase and by the combination of a geological barrier and an impermeable bottom liner during the operational/active phase and by the combination of a geological barrier and a top liner during the passive phase/post closure. The geological barrier is determined by geological and hydrogeological conditions below and in the vicinity of a landfill site providing sufficient attenuation capacity to prevent a potential risk to soil and groundwater.

[16] Council Directive 1999/31/EC of 26 April 1999 on the Landfill of Waste.

<table>
<tr><th>Design Parameters</th><th>Design Considerations and Requirements</th></tr>
<tr><td></td><td>
The landfill base and sides shall consist of a mineral layer which satisfies permeability and thickness requirements with a combined effect in terms of protection of soil, groundwater and surface water at least equivalent to the one resulting from the following requirements:
- landfill for hazardous waste: $K <= 1.0 \times 10^{-9}$ m/s; thickness >= 5 m,

Where the geological barrier does not naturally meet the above conditions, it can be completed artificially and reinforced by other means giving equivalent protection. An artificially established geological barrier should be no less than 0.5 meters thick.

In addition to the geological barrier described above a leachate collection and sealing system must be added in accordance with the following principles so as to ensure that leachate accumulation at the base of the landfill is kept to a minimum.

Leachate collection and bottom sealing
<table>
<tr><th>Landfill category</th><th>non hazardous</th><th>hazardous</th></tr>
<tr><td>Artificial sealing liner</td><td>required</td><td>required</td></tr>
<tr><td>Drainage layer ≥ 0,5 m</td><td>required</td><td>required</td></tr>
</table>

If the DBO Contractor finds that the prevention of leachate formation is necessary, a surface sealing may be prescribed. Recommendations for the surface sealing are as follows:
<table>
<tr><th>Landfill category</th><th>non hazardous</th><th>hazardous</th></tr>
<tr><td>Gas drainage layer</td><td>required</td><td>not required</td></tr>
<tr><td>Artificial sealing liner</td><td>not required</td><td>required</td></tr>
<tr><td>Impermeable mineral layer</td><td>required</td><td>required</td></tr>
<tr><td>Drainage layer > 0,5 m</td><td>required</td><td>required</td></tr>
<tr><td>Top soil cover > 1 m</td><td>required</td><td>required.</td></tr>
</table>
</td></tr>
<tr><td>Nuisances and hazards</td><td>
Measures shall be taken to minimize nuisances and hazards arising from the landfill through:
- emissions of odors and dust,
- wind-blown materials,
- noise and traffic,
- birds, vermin and insects,
- formation and aerosols,
- fires.

The residual waste landfill shall be equipped with appropriate form of physical barriers so that dirt originating from the site is not dispersed onto public roads and the surrounding land.
</td></tr>
<tr><td>Stability</td><td>
The emplacement of waste on the site shall take place in such a way as to ensure stability of the mass of waste and associated structures, particularly in respect of avoidance of slippages. Where an artificial barrier is established it must be ascertained that the geological substratum, considering the morphology of the
</td></tr>
</table>

Design Parameters	Design Considerations and Requirements
	landfill, is sufficiently stable to prevent settlement that may cause damage to the barrier.
Barriers	The landfill shall be secured to prevent free access to the site. The gates shall be locked outside operating hours. The system of control and access to each facility should contain a program of measures to detect and discourage illegal dumping in the facility.

Fly Ash Management. To avoid any impact to the environment and to the DBO Contractor's personnel safety, the fly ash shall be conditioned safely in sealed bags and disposed in a controlled way at the residual waste landfill. Similarly, the fly ash collected from flue gas cleaning is cooled down, stored in big bags and disposed in the same residual waste landfill. The DBO Contractor shall follow the APC Residue or Fly Ash Management Plan attached in this EIA report. The DBO Contractor shall update the plan accordingly during the design phase, with the condition that no requirements therein shall be relaxed or removed. Consistent with this APC Residue or Fly Ash Management Plan, the DBO Contractor's design shall consider the following for conveying and loading APC residues or fly ash:

(i) APC residues or fly ash shall not be mixed with bottom or boiler ash prior to the bottom ash treatment;
(ii) APC residues or fly ash shall be conveyed in closed conveying systems that end up in storage silos whose exhaust air can be dedusted via a central dedusting system;
(iii) The top of the bag filter housing shall be enclosed and shall be connected to the central dedusting system (while pulling/replacing bag-filter hoses);
(iv) Discharging the APC residues or fly ash from the silos into water-tight jumbo bags (with inlet) or into the transfer vehicles shall be carried out via dust-tight discharging chutes;
(v) APC residues or fly ash shall be treated by either stabilization/solidification or via triggered pozzolanic reaction prior to landfilling to limit the leachability of heavy metals; and
(vi) Landfilling of contained APC residues or fly ash shall follow the standards of landfilling hazardous wastes based on EU Directive on the Landfill of Wastes as discussed in Table 3 above.

Cumulative effects. As of the assessment, there are no other similar planned projects that will be established or put up in Thilafushi or adjacent islands. Therefore, the WTE plant will not contribute to any cumulative negative impact with other sources of similar impacts in Thilafushi, and/or any existing project or condition, and/or other project-related developments that are realistically defined at the time the assessment. The future plan of the project to expand by 50% will not have any cumulative negative effects because it will instead address the potential environmental impact of increased solid waste generation in the future. Nevertheless, a strategic environmental assessment will be undertaken in the future to evaluate the cumulative and other potential environmental impacts of future SWM projects in Thilafushi, and Maldives in general, including the planned expansion of the WTE plant by 50%.

Greenhouse gas emissions. The operation of the WTE Plant will be a potential source of greenhouse gas emissions due to the inherent combustion processes involved in plant operations. This GHG emission poses a potential transboundary impact on endangered species and habitats. However, comparing with the current practice of landfilling solid wastes in Maldives, the incineration process will greatly reduce the volume of the waste that need to be disposed in sanitary landfills. Therefore, the production of greenhouse gases due to landfilling will be reduced. The WTE plant will generate electricity for the industries on Thilafushi, replacing their dependence on fossil fuel use for power generation (most of electricity is powered by diesel). Summing these all leads to an overall reduction of greenhouse gas emission by the Maldives. A complete accounting and analysis of GHG emission by the WTE Project resulted to GHG emission reduction of 40,000 tCO2e/year, which is the average annual reduction across the project life cycle.

I. Environmental management plan

A number of measures have been proposed to mitigate the impacts on the environment during the design, construction and operation phases of the project. The bid document requires the DBO contractor to meet the following performance requirements related to safeguards:

Table 4: WTE Plant Performance Requirements Per DBO Bid Document Related to Environmental Safeguards

Parameters	Performance Requirements[a]
1. Performance Guarantee (PG) 6: Total organic carbon-content bottom ash (TOC)	The Contractor shall ensure that the annual averaged TOC content of bottom ash shall be less than 3.0% by weight while none of the samples shall be with a TOC greater than 3.5%. The average TOC content shall be determined by analyzing two representative samples monthly (i.e. approximately one sample every 15 days). None of the measured TOC contents shall exceed 3.5% by weight dry matter. Measurement of TOC according to British Standard EN 131317. Six samples per year tested by external accredited laboratory.
2. PG 7: Temperature of cooling water outlet	The Contractor shall design and build the plant so that the cooling water outlet temperature shall be less than 3 degrees Celsius above the receiving ambient water temperature.
3. PG 8: Air emission standards	The Contractor shall operate the plant so that none of the half hourly and none of the daily aggregated pollutants' measurements and none of the discontinuously measured pollutants' concentrations exceed the emission limit values stipulated in Annex VI of Directive 2010/75/EU of the European Parliament and the Council (Technical Provisions Relating to emission standards for waste incineration plants and waste co-incineration plants any time. Measurement will be done thru CEMS and calibrated every third year (at least) by an accredited laboratory or certification agency.
4. PG 9: Combustion conditions	The Contractor shall ensure that combustion conditions (temperature = 850 degrees Celsius for at least 2 seconds residence time) are maintained at all times. The requirements as per Chapter 5.16 (Tests on Completion of Design-Build) of the bidding document shall be considered, which specifies the trail operations and performance guarantees test. Combustion conditions include the need for proof by Contractor of maintaining the temperature and residence time, by submitting a methodology for how to validate that residence time and temperatures are kept under most unfavorable conditions. Combustion conditions shall be met any time during tests to be done on the completion of WTE plant construction and thereafter.
5. PG 10: Leachate treatment plant (LTP) discharge standards	The maximum permissible concentrations of pollutants discharged from the LTP into the environment are specified in the bidding document, which lists the following effluent limits that should be complied with:

<table>
<tr><th>Parameters</th><th>Performance Requirements[a]</th></tr>
<tr><td></td><td>
<table>
<tr><th colspan="2">Parameters</th><th>unit</th><th>Limit</th></tr>
<tr><td>Chemical Oxygen demand</td><td>COD</td><td>mg/l</td><td>200</td></tr>
<tr><td>Biological Oxygen demand</td><td>BOD_5</td><td>mg/l</td><td>20</td></tr>
<tr><td>Total Inorganic Nitrogen</td><td>$N_{tot, inorg}$</td><td>mg/l</td><td>70</td></tr>
<tr><td>Nitrite</td><td>NO_2-N</td><td>mg/l</td><td>2</td></tr>
<tr><td>Sulfide</td><td>S</td><td>mg/l</td><td>1</td></tr>
<tr><td>Total Phosphate</td><td>P_{tot}</td><td>mg/l</td><td>3</td></tr>
<tr><td>Lead</td><td>Pb</td><td>mg/l</td><td>0.5</td></tr>
<tr><td>Cadmium</td><td>Cd</td><td>mg/l</td><td>0.05</td></tr>
<tr><td>Total Chromium</td><td>Cr</td><td>mg/l</td><td>0.5</td></tr>
<tr><td>Chromium (VI)</td><td>Cr VI</td><td>mg/l</td><td>0.1</td></tr>
<tr><td>Mercury (total)</td><td>Hg</td><td>mg/l</td><td>0.02</td></tr>
<tr><td>Nickel</td><td>Ni</td><td>mg/l</td><td>1</td></tr>
<tr><td>Zinc</td><td>Zn</td><td>mg/l</td><td>2</td></tr>
<tr><td>Copper</td><td>Cu</td><td>mg/l</td><td>0.5</td></tr>
<tr><td>Arsenic</td><td>As</td><td>mg/l</td><td>0.1</td></tr>
<tr><td>Conductivity at 25°C*</td><td>-</td><td>µS/ cm</td><td>2,500</td></tr>
</table>
*used to monitor the performance of the LTP only
</td></tr>
<tr><td>6. PG 11: Wastewater treatment discharge standards</td><td>
The maximum permissible concentrations of pollutants discharged from the wastewater treatment plant into the environment are specified in the following table of effluent limits:
<table>
<tr><th colspan="2">Parameters</th><th>unit</th><th>Threshold Value</th></tr>
<tr><td>Chemical Oxygen demand</td><td>COD</td><td>mg/l</td><td>150</td></tr>
<tr><td>Biological Oxygen demand</td><td>BOD_5</td><td>mg/l</td><td>40</td></tr>
<tr><td>Suspended Solids</td><td>-</td><td>mg/l</td><td>100</td></tr>
<tr><td>Ammonia-N</td><td>NH4</td><td>mg/l</td><td>15</td></tr>
<tr><td>Total N</td><td>N</td><td>mg/l</td><td>30</td></tr>
<tr><td>N-hexane extract (mineral oils, grease)</td><td>-</td><td>mg/l</td><td>10</td></tr>
</table>
</td></tr>
<tr><td>7. PG 12: Sound pressure level</td><td>Sound pressure levels shall not exceed the 80 dBA at 1 min distance from the emitting source and different sound pressure levels at the site boundary: 70 dBA from 0700 to 2200 hours and 50 dBA from 2200 to 0700 hours. Measurement will be in-situ using decibel meter. Frequency of measurement specified in the EMP.</td></tr>
</table>

[a] Performance standards from the Maldives Environmental Protection Agency and international guideline values as specified in EU Directives are compared and whichever is more stringent is applicable.

The DBO contractor shall consider the particular environment and location of the WTE plant and shall pay particular attention shall be included, but not limited, to the (i) air emissions and dust control; (ii) noise and vibration control; (iii) effluent management; (iv) waste management; (v) hazardous substance handling and storage management, including spill contingency; (vi) erosion, soil and vegetation management; (vii) traffic management; (viii) recruitment and labor management, including the skills development and local procurement; (ix) flooding and natural hazards; and (x) storm water management.

A set of waste characteristics have been specified in the bid document. While the design waste as shown in Table 5 indicates the design criteria for the thermal unit and the APC system, the plant shall perform as set forth in the stoker capacity diagram that defines the throughput (between 70 and 110% of the nominal throughput) and the NCV range (6.5 and 9.5 MJ/kg) for which the plant shall be operated without any auxiliary fuel. Waste that is outside this performance window can be incinerated though but it may be rejected and returned to the supplier.

Table 5: Design Waste Characteristics for the WTE Plant

Parameter	**Limit**
Net Calorific Value (NCV)	8.000 kJ/kg
Combustible	40 %
Water	31 %
Ash	29 %
Ash (dry)	42%
C (Carbon)	29.9 % (dry)
S (Sulphur)	0.4 % (dry)
H (Hydrogen)	4.4 % (dry)
O (Oxygen)	18.1 % (dry)
N (Nitrogen)	0.9 % (dry)
Cl (Chloride)	0.6 % (max. 1 %) (dry)
F (Fluoride)	0.1 %(dry)

Project-specific environmental management plan (EMP) is included as part of this EIA to avoid, reduce, mitigate or compensate for adverse environmental impacts/risks. The EMP discusses the following:

(i) mitigation measures for environmental impacts during construction phase;
(ii) mitigation measures for environmental impacts during operation phase; and
(iii) an environmental monitoring program (EMOP), and the responsible entities for mitigating, monitoring, and reporting throughout the project implementation and operation.

The methods to be used for site preparation, construction, operation, and commissioning, as well as associated arrangements to ensure sound environmental management and safety at all times, are already defined in the bid documents. The DBO Contractor shall prepare a Site-specific EMP (SEMP) based on the EMP presented in this EIA in order to make it relevant to the construction and operation phases. The Contractor shall prepare the SEMP by describing specific design features that will ensure environmental protection and setting out the working methods, management, and mitigation and monitoring measures that will be put in place, for each of the various construction activities, during the implementation of the project. The scope of the SEMP shall address all of the issues itemized in the EMP in this EIA report. The SEMP shall have the same level or stricter set of measures than those included in the EMP of this EIA report.

In the event that DBO Contractor will change the design, technology, layout, components, height and number of stacks, APC system, and sites for the sea water intake and outfall, this EIA together with the EMP and EMOP will require updating. The DBO Contractor shall submit the updated EIA report to PMU, and the PMU shall submit the updated EIA report to ADB for final review and disclosure.

J. Information Disclosure, Consultation and Participation

The project has undertaken numerous stakeholder consultations during the project preparatory stage from 2017 up to 2019. The objectives of the consultations are to ensure that project information is accurately and properly disseminated to all stakeholders and engage them in the environmental assessment process, ensure all issues from the stakeholders about the project are considered in the environmental management planning and ultimately addressed in the EMP. Stakeholder consultations also provide valuable guidance and direction to safeguard the interests of the stakeholders, developers and the environment. Stakeholder engagement will be a continuing activity of the PMU throughout project implementation.

The stakeholders were grouped into internal, external and others including private and civil society. The internal stakeholders comprise the project proponent, MOE, PMU and the Maldives EPA. The external stakeholders include other government regulators and service providers. Other stakeholders include NGOs and the civil society. Interviews with relevant persons from these groups were undertaken. During interviews, discussions focused on the perceptions on the project, the selected locations, environmental or social impacts when implementing the project, energy use and efficiency, harbor and road use, and other aspects. The consultations explored on issues with locations, concerns and suggestions for improving project implementation. Documentation of all stakeholder consultations is included in the EIA report.

K. Grievance Redress Mechanism

The project will adopt the grievance redress mechanism (GRM) established in GMEIWMP. The project GRM will not supersede any legal government grievance procedures. The existing GRM includes three tiers. Every effort shall be given to find an amicable solution before higher tiers could be engaged. Stakeholders and communities are to be informed about the GRM through media and public outlets. An information board providing the contact details will be made available at the project site at Thilafushi, and a register of grievances will be maintained by the DBO contractor and at the PMU.

L. Implementation Arrangement

GMWTEP will follow the safeguards implementation arrangement of ADB supported GMEIWMP. A PMU has been established in the MOE and comprising officials including an Environmental Safeguard Officer who is a permanent employee of MOE. The PMU will ensure that the EMP, including the EMOP, is implemented effectively. The PMU will be strengthened with external experts and supported by PMSC. PMU will obtain all necessary statutory clearances prior to award to award contract.

The DBO Contractor is required to designate a full time appoint a Health & Safety Manager (the "H&S Manager") who will: (i) update this EIA per final detailed design; (ii) establish environmental performance criteria and indicators per final detailed design; (iii) establish pre-work environmental conditions; (iv) implement EMP pre-, during and post-construction, and during O&M; (v) conduct safeguards induction ensuring all personnel and workers are familiar with EMP and relevant health and safety requirements for their work; (v) consult stakeholders and disseminate information related to the project; (vi) address grievances at the site level; (vii) ensure the O&M manuals include requirements as specified in the EMP for operation phase, (viii) report to PMU on a monthly basis, except if there are unanticipated impacts or emergency situations that may cause adverse impact to the environment and surrounding industries; and (ix) implement corrective action plan/s, if required.

M. Monitoring and Reporting

EMP compliance monitoring will be undertaken by the PMU. DBO Contractors will submit monthly reports to PMU. As will be set out in a Project Administration Manual for the project, PMU will prepare and submit reports to ADB on a quarterly basis during construction phase. The submission of semi-annual environmental monitoring reports to ADB during operation phase will continue until ADB issues a project completion report for the project.
Similarly, the PMU will be responsible for the preparation of required environmental monitoring reports and submission to Maldives EPA. Maldives EPA will field annual environmental review missions which will review in detail the environmental aspects of the project. Any major accidents having serious environmental consequences will be reported immediately.

In compliance with ADB SPS, an external environmental expert consultant will be retained under the project who will conduct independent monitoring and review of EMP implementation. The expert will work closely with PMU and DBO Contractor, but will report directly to ADB or occasionally through the PMU.

Additional compliance reports to the MOE required as part of environmental clearance process shall be prepared and based on the required monitoring and reporting format.

N. Conclusion and Recommendations

The EIA of GMWTEP has been prepared based on review of technical specifications of the project as included in the DBO bid documents, primary and secondary information of the site and its surroundings. The overall findings of this EIA are:

(i) The project will result in significant environmental benefits because the current condition in Thilafushi and the project area will be improved;
(ii) during construction, the project will not have significant adverse environmental impacts and potential adverse impacts are manageable through the effective implementation of the EMP;
(iii) During operations, the project will have potential impacts on ambient air quality, marine water quality, marine ecology, noise, and occupational and community health and safety. However, with the performance guarantees built in the DBO contract, significant impacts can be avoided, and residual impacts can be mitigated by measures specified in the EMP; and
(iv) No social impacts pertaining to land loss, land fragmentation, physical displacement, loss of income, loss of productive land, potential income loss for fishermen and preventing fishing-related activities and fishing routes.

In view of the results of the studies undertaken in this EIA, following are the major recommendations that DBO Contractor shall undertake:

(i) Engage external expert(s) for verification of environmental monitoring reports and EMP implementation. External expert(s) are not involved in day-to-day project implementation or supervision.
(ii) Establish the ambient air quality monitoring stations in Thilafushi and Villingili as identified in the AUSTAL2000 and AERMOD air dispersion modeling studies, and

utilize these stations for monitoring activities during the operation phase as indicated in the environmental monitoring plan. The proposed locations are in figures below;

(iii) Conduct validation modeling during the starting months of normal operation of the WTE plant using actual CEMS and stack testing results to simulate actual operation of the plant;

(iv) Install the cooling water discharge line at section M8 (as identified in the EIA report) and position the three outfalls of the discharge lines at a distance of 75 meters from the shoreline and 30 meters deep from the sea surface. The outfalls shall be laid 20 meters apart;

(v) Install the intake of the cooling water line at the vicinity of M1-M8 (the same vicinity of the outfalls as identified in the EIA report) to ensure minimal impact during construction phase; and

(vi) Continuous monitoring around Thilafushi island to confirm the extent of biodiversity in various seasons of the year, including assessment of features pertinent to critical habitats. This is to ensure pre-construction works conditions and biodiversity risks are considered in the design, construction and operation, and to examine and mitigate the potential impacts of the project on areas significant for biodiversity.

Mitigation measures during operation phase are described in the EMP of the EIA report. Apart from all the mitigation measures in the EMP, the following are further recommendations that DBO Contractor shall consider, whichever are practical and applicable:

(i) A system with controlled burning and a good air pollution control system should be included in the WTE plant design;

(ii) Incinerator with a stack height of minimum 45.7 m (per air dispersion modeling calculations) to reduce the impacts of air pollutants on the surrounding environment. Increasing this height further will be more favorable;

(iii) Environmental and occupational health and safety procedures for all processes should be established and enforced;

(iv) There should be strict inspection and testing during the installation of the HDPE membrane and the various protective / drainage layers for the landfill;

(v) Preventive measures should be implemented to avoid loss of waste during transport and loading / off-loading;

(vi) There should be appropriate sanitation facilities and workshops (for machinery), as well as secure storage facilities for fuel and chemicals, including toxic and hazardous wastes;

(vii) Boilers should be regularly maintained, while structures such as the stacks and ducts should be regularly checked to avoid fugitive dusts sources and particulate accumulation;

(viii) Control devices such as the Dry Scrubber and Baghouse should undergo regular checkup and maintenance;

(ix) Solid wastes should have acceptance criteria in terms of waste characteristics;

(x) Periodic watering of roads to minimize generation and resuspension of dust particles;

(xi) Greenery and plantation at the perimeter-buffer areas to serve as vegetation walls that can help control dispersion of air pollutants. All plant species to be introduced shall be a known species that thrive in Thilafushi or Maldives. If necessary, the DBO Contractor shall obtain permission from relevant agency of the government to ensure such plant is endemic or native species in Maldives

(xii) Ensure to follow the government policy on preventing introduction of invasive alien species in the island. In particular, DBO Contractor shall use as reference the guidance issued by the MOE attached as Appendix 21 in the EIA report;

(xiii) Regular ambient air quality monitoring should be conducted in hot spots and impacts areas based on the results of the modeling report. Actual ambient monitoring may be treated as validation of model results; and

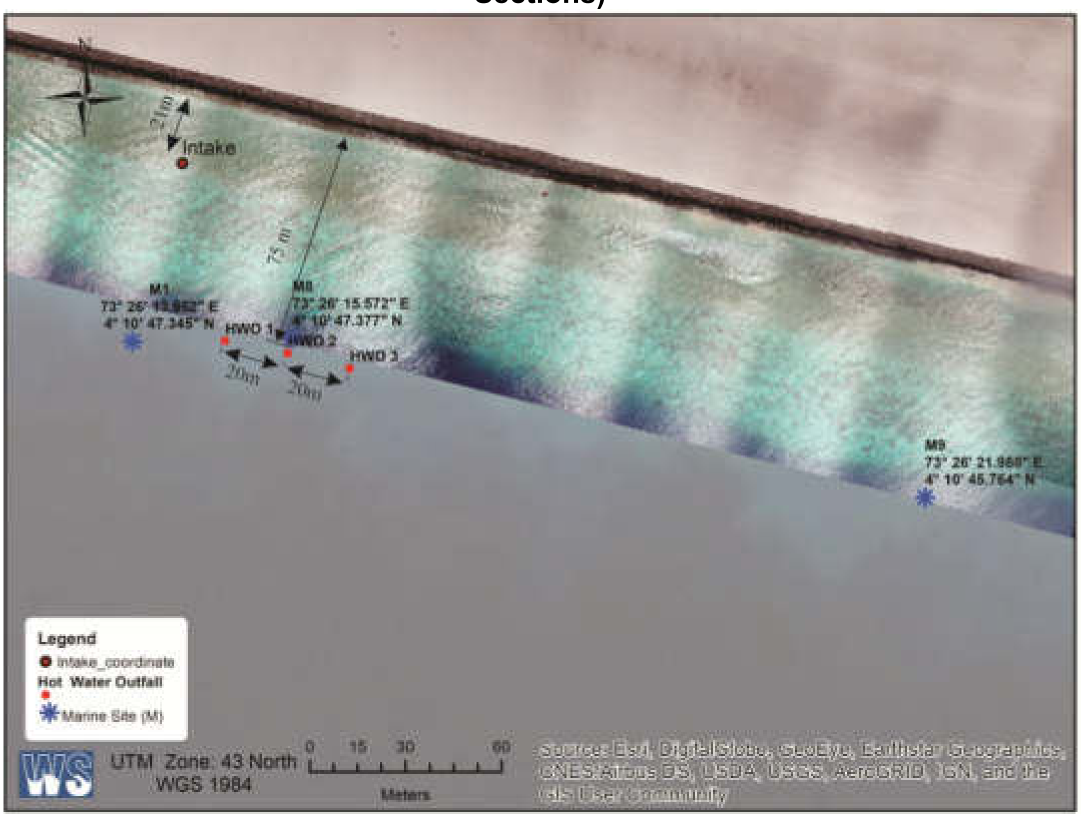
(xiv) Every modification and installation of new sources should be considered as additional contribution to emission of the plant. Hence, modeling updates should also be conducted to determine assimilative carrying capacity of the area based on the impacts of the new modification or installation.

Figure 2: Recommended Ambient Air Quality Monitoring Sites (AUSTAL2000) (Used as Sampling Sites for Baseline Ambient Air Quality Data Gathering)

Figure 3: Recommended Ambient Air Quality Monitoring Sites at Thilafushi

(AERMOD's confirmation of recommended sites by AUSTAL2000, plus additional recommended sites at ASR2, ASR3 and ASR5 locations)

Figure 4: Recommended Inlet and Outfall Location for Cooling Water (M1 and M8 Sections)



I. INTRODUCTION

A. Background

1. The Greater Malé region and its neighboring outer islands (project area) suffer from severe environmental pollution and deteriorating livability because of inadequate collection and haphazard disposal of solid waste. The project area covers the Greater Malé region, and 32 inhabited outer islands and 86 tourist resorts within the Alifu Alifu Atoll, Alifu Dhaalu Atoll, Kaafu Atoll, and Vaavu Atoll, with a population of 295,000 (53% of Maldives' total population). Lack of a sustainable system to manage the 836 tons per day (tpd) of solid waste generated in the project area (2019) results in waste spillage into the ocean, and open dumping and burning of garbage at the 30-year old 10-hectare dumpsite on Thilafushi Island which has no pollution control measures creating a public health and an environmental hazard. Plumes of smoke visible from the capital Malé, the international airport and nearby resorts compromise air quality and pose nuisance to residents and tourists, while leachate and plastics contaminate the surrounding marine environment. This poses a critical threat to tourism and fisheries, both of which rely heavily on the country's pristine environment and are cornerstones to Maldives' economy.

2. The Greater Malé Waste to Energy project (the project) will focus on solid waste treatment and disposal infrastructure as part of a phased approach to provide a full-fledged SWM service to the project area through two ADB projects. It will complement the ongoing Greater Malé Environmental Improvement and Waste Management Project (GMEIWMP), approved by ADB in 2018, which is assisting the government to (i) improve the upstream segment of the SWM chain, including systemic collection and containerized transfer; (ii) implement temporary measures, such as baling of municipal solid waste, as an adequate interim solution to stop open dumping and burning on Thilafushi island until a modern solid waste treatment and disposal facility is operational; (iii) treat and recover construction and demolition waste; and (iv) strengthen institutional capacity and public awareness for sustainable SWM service delivery. ADB and the government agreed on this phased strategy to match the implementation and financing capacity of the government, and to improve project readiness of the complex WTE infrastructure (i.e., reclaim 15 ha of land, take advance procurement actions, and conduct an environmental impact assessment [EIA]) while implementing urgent measures. GMEIWMP is under implementation and expected to be completed by 2023.

3. The project is aligned with the following impact: promote waste as a valuable resource for income generation (footnote 5). The outcome will be disaster- and climate- resilient solid waste treatment and disposal services improved in the Greater Malé region and its outer islands. The project will have two outputs.

4. **Output 1: Disaster- and climate-resilient regional waste management facility developed.** This will include (i) a 500 tpd WTE plant with 15 years of O&M, including two treatment lines of 250 tpd each, a minimum 8-megawatt (MW) electricity surplus energy recovery facility, and an air pollution control system; and (ii) a landfill for safe disposal of hazardous air pollution control residues and non-marketable bottom ashes. The facility (WTE plant and landfill) will be implemented through a DBO contract to a specialized firm, which will integrate a design–build phase and a 15-year operation (O&M) phase to improve sustainability of service delivery. The facility will be able to accommodate a third 250 tpd treatment line in the future, which will be required to respond to further demand increase. The incineration with electricity generation (WTE) technology minimizes land requirements and produces renewable energy, addressing the critical land and electricity constraints in Maldives. Recycling of marketable incineration bottom ash and metals will be promoted to further reduce landfill requirements and provide valuable materials for

the construction and recycling industry. All facilities will adopt disaster- and climate-resilient features, such as raised floor elevations, flood-proof mechanical and electrical equipment and landfill cells, and enhanced drainage systems

5. **Output 2: Institutional capacity in sustainable waste-to-energy service delivery and environmental monitoring, and public awareness on waste-to-energy and reduce-reuse-recycle improved.** This will include (i) preparing and implementing a capacity development plan to improve the capacity of MOE and EPA to supervise sustainable WTE service delivery; (ii) strengthening MOE and EPA staff capacity in supervising WTE operations, including monitoring WTE operational performance and environmental standards, and managing performance-based DBO contract; (iii) supporting enhanced financial sustainability for WTE O&M through implementation of an agreed O&M financing plan, including financial need forecasting and finalization of financing sources, a revenue enhancement plan, assignment of responsibilities, and fund flow arrangements for payment of O&M; and (iv) conducting public awareness campaigns on WTE and 3R benefits. The project will develop PMU and government capacity to prepare, monitor, and manage sustainable WTE through consulting services for contract management, monitoring, supervision, and institutional development.

6. The project is estimated cost is $151.13 million, including contingencies and financing charges. The government has requested (i) a grant not exceeding $35.18 million from ADB's Special Funds resources (Asian Development Fund [ADF]); and (ii) a concessional loan of $38.21 million from ADB's ordinary capital resources to help finance the project. The loan will have a 32-year term, including a grace period of 8 years; an interest rate of 1.0% per year during the grace period and 1.5% per year thereafter; and such other terms and conditions set forth in the draft loan and grant agreement. The government has also requested a loan not exceeding $40.00 million from the Asian Infrastructure Investment Bank (AIIB) to help finance the project. The AIIB loan will be partially administered by ADB. The AIIB loan's terms and conditions will be described in a loan agreement between AIIB and the government. The Japan Fund for Joint Crediting Mechanism will provide grant cofinancing equivalent to $10 million, to be administered by ADB.

B. Purpose and Scope of the EIA

7. This EIA focuses exclusively on the WTE plant (including its ancillary facilities) as most environmentally sensitive component of the project given its construction and operation is likely to have significant adverse environmental impacts that are irreversible, diverse, or unprecedented. These impacts may affect an area larger than the sites or facilities subject to physical works. Thus, GMWTEP is classified as Category A for environment per ADB Safeguard Policy Statement (SPS) and an environmental impact assessment (EIA) is required. Accomplished ADB Rapid Environmental Assessment Checklist is in Appendix 1.

8. The purpose of the EIA is to meet ADB SPS requirement for Category A projects and to comply with Government of Maldives requirements under EIA Regulations of 2012. This EIA report has been prepared in accordance with the requirements of ADB SPS and the terms of reference (TOR) dated 24 September 2018 issued by the Maldives Environmental Protection Agency (Maldives EPA). Matrix of compliance on the requirements of the TOR is attached as Appendix 2.

9. This EIA report will be submitted to ADB and Maldives EPA as a requirement for ADB financing and compliance with the Environmental Protection and Preservation Act (EPPA or Law 4/93) of Maldives, respectively. Clause 5 of the Law 4/93 states that a report should be submitted before implementation of any protect that may have a potential impact on the environment. A

gaps analysis between ADB SPS and EPPA is attached as Appendix 3.[17] The gaps analysis describes various recommended gap-filling measures in order to ensure EPPA is fully aligned with ADB SPS. All gap-filling measures applicable to the WTE project have been considered in undertaking this EIA.

10. The scope of this EIA covers the following: (i) description of the WTE plant and ancillary facilities (the project); (ii) identification and description of the elements of the environment and community/stakeholders likely to be affected by the project and/or likely to cause adverse impacts to the project, including both the natural and man-made environment; (iii) information on the consideration of alternatives/options for design, site locations and layouts of the project to avoid and minimize potential environmental impacts to environmentally sensitive areas, other sensitive uses and sensitive receptors, including reasons for selecting the preferred option(s); (iv) description of environmental factors played in the selection of the preferred option(s); (v) identification and assessment of impacts on marine environment, groundwater, avifauna, biodiversity, air quality, water quality, waste management implication, land-based and marine traffic, socio-cultural and livelihood, occupational health and safety, landscape and visual, and determination of significance of impacts on sensitive receivers and potential affected uses; (vi) mitigation measures so as to minimize pollution, environmental disturbance and nuisance during construction and operation of the project; (vii) identification, prediction and evaluation of residual (i.e. after practicable mitigation) environmental impacts and the cumulative effects expected to arise during the construction and operation phases of the project in relation to the sensitive receivers and potential affected uses; (viii) identification, assessment and specification of methods, measures and standards, to be included in the detailed design, construction and operation of the project which are necessary to mitigate these environmental impacts and reducing them to acceptable levels; (ix) identification of constraints associated with the mitigation measures recommended in the EIA study and, where necessary, to identify the outstanding issues that need to be addressed in any further detailed EIA study; and (x) design and specifications in the environmental monitoring and audit requirements to ensure the effective implementation of the recommended environmental protection and pollution control measures.

11. The impact assessment includes (i) collection and use of field data gathered during the period from January 2018 to November 2019, (ii) consultations with stakeholders, and (iii) professional judgment and experience of the EIA team members. In addition, satellite and aerial photos have been used to study the geography and environmental changes at the project site. Moreover, similar project reports have been reviewed and referenced in completing this report. Below are the reports that have been reviewed.

(i) Feasibility Study for an Integrated Solid Waste Management System for Project area (including Greater Malé) and Design of the Regional Waste Management Facility at Thilafushi, Ministry of Environment, Malé (MOE, 2018);
(ii) EIA for the Proposed Reclamation of Thilafushi for the establishment of the Regional Waste Management Facility for Project area, Kaafu Atoll, Maldives (MEE, 2017);
(iii) EMP for the establishment of Island Waste Management Center in L. Hithadhoo, (MEE, 2017);
(iv) EIA for the Permanent Sand Borrow Site for Repairing and Leveling of Roads at K. Thilafushi (MEECO, 2015);
(v) Environment & Social Assessment & Management Framework Climate Change Adaptation Project (MEE, 2014);

[17] Comparative Analysis of Maldives Framework and ADB Safeguard Policy Statement. ADB TA 7566. 2015.

(vi) Environmental and Social Impact Assessment for North Regional Waste Management Facility Construction and Operation (MEE, 2012);
(vii) EIA for the proposed solid waste management facility at Thilafushi, Kaafu Atoll Maldives, (CDE, 2011);
(viii) ESIA for Construction and Operation North Regional Waste Management Facility at R. Vandhoo (MEE, 2012); and
(ix) Engineering Investigation and Environmental Studies for Integrated Waste Management Facilities or managing municipal solid waste (MSW) Hong Kong, China (AECOM, 2011).

C. Stage of the project preparation

12. The project will be implemented through a design-build and operate (DBO) contract, under which the DBO contractor will be responsible to prepare detailed design, build and operate the WTE. A prequalification stage has shortlisted qualified bidders (with experience in successfully implementing and managing WTE plants of similar scope and complexity), which was completed in January 2020. The invitation for bids was issued in February 2020 to pre-qualified bidders and the bid submission deadline is in September 2020. The DBO bidding documents were reviewed by ADB and the government of Maldives.

D. EIA Preparation and Implementation

13. The EIA has been prepared by the Project Management Unit (PMU) through its consultant, Water Solutions, a duly registered consulting firm in Maldives which specializes in undertaking impact assessment of various projects in the country. Water Solutions, in turn, engaged with various international consulting firm partners to undertake several studies and modeling necessary for the assessment of impacts of the projects. Water Solutions engaged Ulbricht Consulting of Germany to do the air dispersion modeling using AUSTAL2000, including stack height calculations for the WTE plant. As confirmatory measure, the air dispersion modeling was re-run using the AERMOD model. Water Solutions also engaged Lanka Hydraulic Institute of Sri Lanka to do the heat dispersion modeling for the cooling water generated by the WTE plant during operation phase.

14. Initial biodiversity screening for a defined area of analysis encompassing the project location was undertaken. Results show the area of analysis is likely a critical habitat. Results also show the existence of marine protected areas (MPAs) and species included in the IUCN Red List. In view of this, Water Solutions undertook a critical habitat assessment from October to November 2019 and included as part of the EIA.

E. Methodology

15. **General Approach**. The preparation of this EIA report has been guided by ADB SPS and Maldives EIA Regulations 2012 to ensure that the significant environmental impacts of the proposed project have been considered and assessed at the project planning phase. Accordingly, the EIA process and report preparation follow the outline provided in ADB SPS.

16. **Environmental Scoping**. With the understanding of the nature and location of the project, the environmental scoping was done to narrow down the most critical issues for such kinds of project, which will require more careful and in-depth analysis during the assessment. The most critical aspects identified that need attention are the impact of air emission to surrounding

receptors and the impact of any form of discharge to the marine environment in the area. All environmental issues were categorized into physical, ecological and socio-economic aspects.

17. **Desk Research**. Based on the outline of the EIA process, several information needs may already be available from various sources. Desk review and research online have been done to obtain all this information that will aid in the assessment. This included documentary review on the nature of the proposed activities to be employed, background documents and published documents related to previous projects, procurement plans, draft bidding documents, policy and legislative framework of the government that will govern the implementation of the project, the environmental setting at the project site, and all other information. It also included discussions with project managers, government proponents, international procurement and contract experts engaged under the project, and other consultants.

18. The laws and regulations were reviewed such as the Environmental Protection and Preservation Act (4/93), Environmental Impact Assessment Regulation 2012, Environmental Liability Regulation, Waste Management Regulation, Land Act, Land Use Planning Regulation, General Laws Act, Coral and Sand Mining Regulation, Building Act (404/2017), Maldives Building Code, Dewatering Regulation (2013/R-1697), Maldives Energy Policy and Strategy, Desalination Regulation, General Guidelines for Domestic Wastewater Disposal, Maldives Intended Nationally Determined Contribution, Second National Communication of Maldives to UNFCCC, and Employment Act (02/2008).

19. **Baseline Data Gathering**. Conditions of the existing environment were analyzed by using appropriate scientific methods. The leading environmental components of the study area were divided into physical environment, biological/ecological environment and socio-economic condition. The physical environment is further divided into terrestrial, and coastal and marine environments. The marine environment of the island covered the lagoon and house reef south of the proposed project area. The coastal environment covered the coastline within the project boundary.

20. **Information Disclosure and Consultation**. In order to conduct a broad based and inclusive EIA, the proponent and the consultant have taken a participatory approach. The project details have been shared with stakeholders, and all issues and concerns from these stakeholders have been assessed and integrated as part of the EIA.

21. **Environmental Management Plan (EMP)**. The EMP has been formulated based on the project circumstances during the different phases of implementation. It provides all actions, mitigation measures, institutional arrangements, and reporting, among others, to ensure that the project will not cause significant impact to the environment and the people around the project site.

II. DESCRIPTION OF THE PROJECT

22. **Need and Justification**. Solid waste management is one of the main environmental issues in the Maldives. Rudimentary practices in solid waste management have resulted in vastly degrading marine and terrestrial environments throughout the country. A significant portion of this problem is due to the geographical scatter of islands and the scarcity of land on these islands. An accelerated population growth over a short period of time over the last several decades has ensured the growth of the solid waste problem with it, while the management of this solid waste has not been receiving the attention it should require. Thus, solid waste has been managed in the country in the form of dumpsites and open-air burning.

23. The island of Thilafushi in Kaafu Atoll has been utilized over the past few decades to serve as the dumpsite for solid waste generated from Malé, its biggest source, and other nearby inhabited islands and resorts. Large quantities of waste generated in Malé are taken to stockpile at the disposal site on the island of Thilafushi. The stockpile at the site is continuously burned sending massive plumes of dark smoke into the atmosphere, before open dumping in a bunded lagoon. Thilafushi also receives wastes from tourist resorts. Overall, there are significant potential impacts of solid waste on the environment and public health, and on the potential sustainability of tourism in the Maldives. However, the lack of a long-term strategy for solid waste management in Thilafushi has resulted in numerous environmental detriments, from immense visual pollution to locals and tourists alike, to significant marine pollution and an even greater problem, that of air pollution. Due to the lack of control over the dumping in Thilafushi, various flammable, reactive and hazardous substances have been dumped over time. As a result, surface fires occur on site on a daily basis, releasing a plume of smoke into the air that spreads to nearby islands, and as far as to Malé and Hulhumale'. The waste disposal site at Thilafushi is non-engineered low lying and by far the largest solid waste disposal site in the Maldives. The site has minimal environmental protection measures.

24. The issue of solid waste management in the Maldives is of critical importance, and the Ministry of Environment (MOE) seeks to address the issue. A key area is the Greater Malé region and nearby atolls, which together encompass a significant portion of the country's population. Therefore, the MOE has proposed a Regional Waste Management Facility for Project area of the Maldives, including Kaafu Atoll, North Ari Atoll, South Ari Atoll, and Vaavu Atoll. This facility will consist of the proposed Waste-to-Energy (WTE) plant project that is subject of this EIA. The WTE plant has been selected as the viable option to reduce the volume of solid wastes to a level of residual waste that can be disposed and managed given the limited land area in Project area.

25. There are a number of benefits with the implementation of the WTE plant, including:

(i) Substantial bulk reduction for landfill disposal - The amount of MSW to be disposed of at landfills will substantially decrease as the volume of waste remaining after the thermal treatment process would only be about 10% of the original volume. Hence, the residual waste landfills and their extensions can serve for a longer period of time.

(ii) Energy recovery - The WTE plant could generate and export electricity for gainful uses by the industries at Thilafushi.

(iii) Greenhouse gas reduction - The production of greenhouse gases due to landfilling of MSW will be reduced. The WTE plant will generate electricity for the industries on Thilafushi, replacing their dependence on fossil fuel-based power generation, leading to an overall reduction of greenhouse gas emission by the Maldives.

26. The project has been considered as strategical and vital by the Government of the Maldives for the improvement of the environment in the country and consequently for a better living condition of the surrounding population in the greater Malé region, and to improve the attractivity of the Maldives as an ecological friendly tourist destination.

27. **Location.** The project will be located in Thilafushi, an island that has been reclaimed since December 1992 by dumping of wastes on the submerged "Thilafalhu" lagoon area. Thilafushi is located on the southern rim of North Malé atoll, and on the eastern line of atolls within the archipelago. Thilafushi is located in North Malé atoll, 9.5km from Malé. In terms of geographic coordinates, it is located at 04° 11' 00" N and 73° 26' 44" E. The nearest inhabited island is Villingili, approximately 7.1 km east of Thilafushi. The island was initially developed as a sand bank using dredged material from the Thilafushi Reef. Since then, land has been reclaimed by

placing solid waste in dredged holes on the reef flat and later topping it up with fresh lagoon sand. This project will be located on a 15 hectares government-owned land, which has been reclaimed from shallow lagoon. The old dumpsite, adjacent to the project site, will be closed and remediated through a separate project when the WTE plant will become operational. Figure 1 illustrates the location of the project.

28. According to the Thilafushi Industrial Master Zoning 2014 an area of 27.8 ha. has been allocated for solid waste management, the breakdown of which is as follows:

(i) Existing Thilafushi Dumpsite : 10.1 ha
(ii) GMEIWMP infrastructure: 2.45 ha
(iii) GMWTE infrastructures:14.25 ha (project site)

29. The reclamation works for the project site was undertaken by the government in anticipation of the WTE plant, which was also subjected to an EIA process as part of the requirements of the Government of Maldives EIA Regulations of 2012. Reclamation works involved mainly filling and levelling activities. The land was reclaimed to a height of +1.5 m from mean sea level (MSL) from an average depth of -1.5 m above the sea floor. During preparation of this EIA, about 5% of the reclamation work is still being carried out to complete coastal protection structures around the newly reclaimed land. The finished ground level of the site will be at a level higher than the average ground level of the Thilafushi.

30. As the reclamation works is in anticipation of ADB project, an environmental audit has been undertaken on the reclamation project to determine whether the actions and activities were in accordance with ADB safeguard principles and requirements, and to identify and plan for appropriate measures to address outstanding compliance issues. The reclamation project has long been almost accomplished prior to this environmental audit. No actual dredging activities was observed as part of the audit. However, based on all documents and records reviewed, statutory requirements were complied with and that the necessary environmental impact assessment was undertaken and approved by the government. There is an indication that the environmental performance of the reclamation project was satisfactory, and that the development activities did not cause any significant adverse impacts to the environment. The EIA report for the land reclamation, field confirmation and discussion with PMU, stakeholders and Environmental Protection Agency confirmed siltation on the reef is present prior to the land reclamation activity for the project and can be attributed that the island itself is being reclaimed for the past 2 decades. The environmental audit is included in the EIA report and concluded (i) land reclamation has no adverse impacts on the environment, coastal ecosystem, and people in Thilafushi, (ii) all mitigation measures have satisfactorily complied by the contractor; (iii) the project proponent submitted required reports to Maldives Environmental Protection Agency; and (iv) no compliance issue. The land reclamation is small-scale (15 hectares) to affect motion of water and suspended sediments in the area around Thilafushi and adjacent island. The water sampling conducted post-land reclamation (for preparation of the EIA report) also confirmed land reclamation has not caused significant changes the quality of the surrounding areas of water. Summary of the findings of environmental audit is in Appendix 4.

31. Figure 2 shows the 3D impression of the entire RWMF at Thilafushi Island indicating the locations of the various components under the GWEIWMP and GMWTE, including the WTE Plant.

Figure 1: Project location

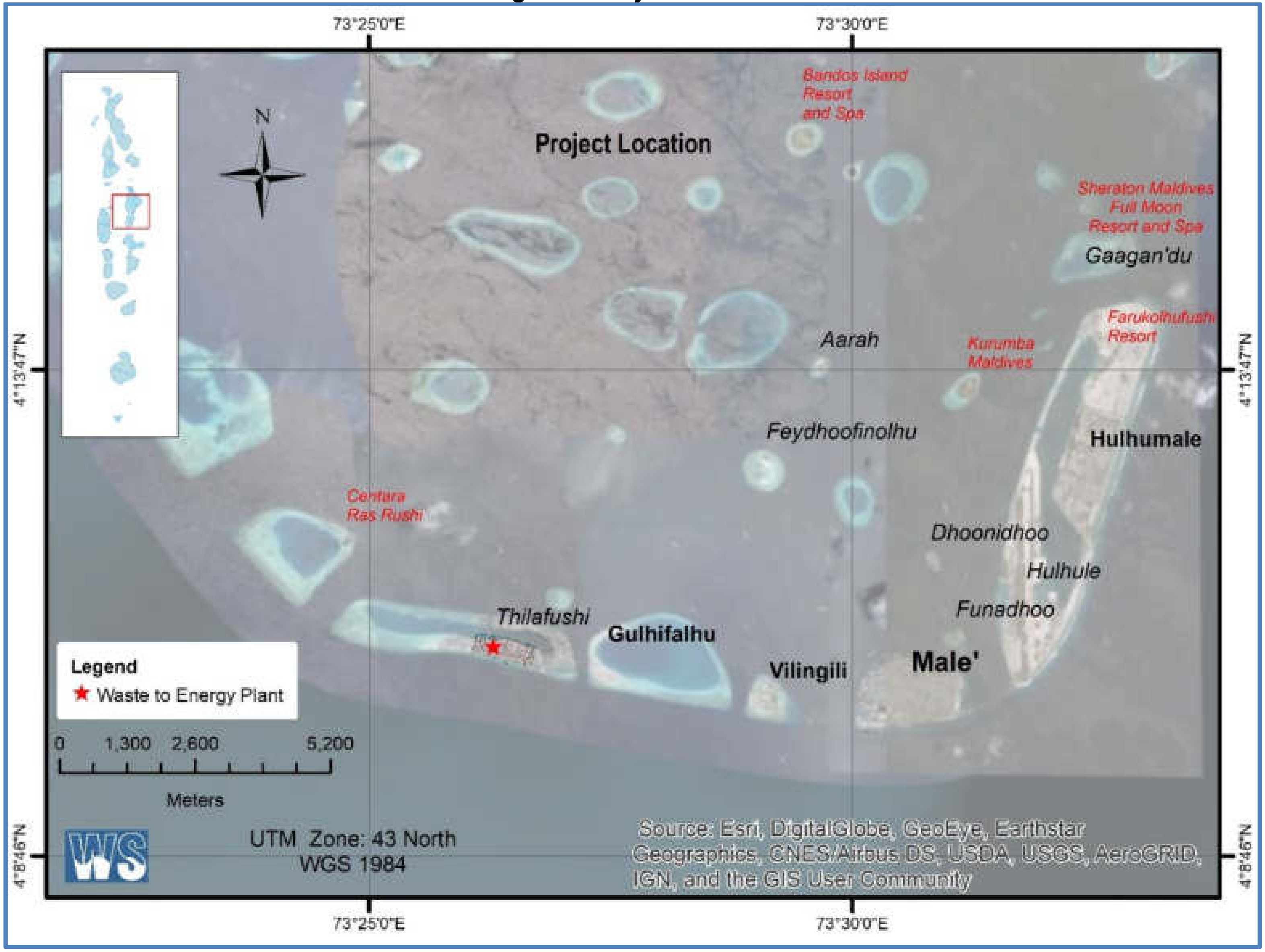


Figure 2: 3D Impression of the proposed RWMF for Project area at Thilafushi

Figure 3: Location of project at Thilafushi Island

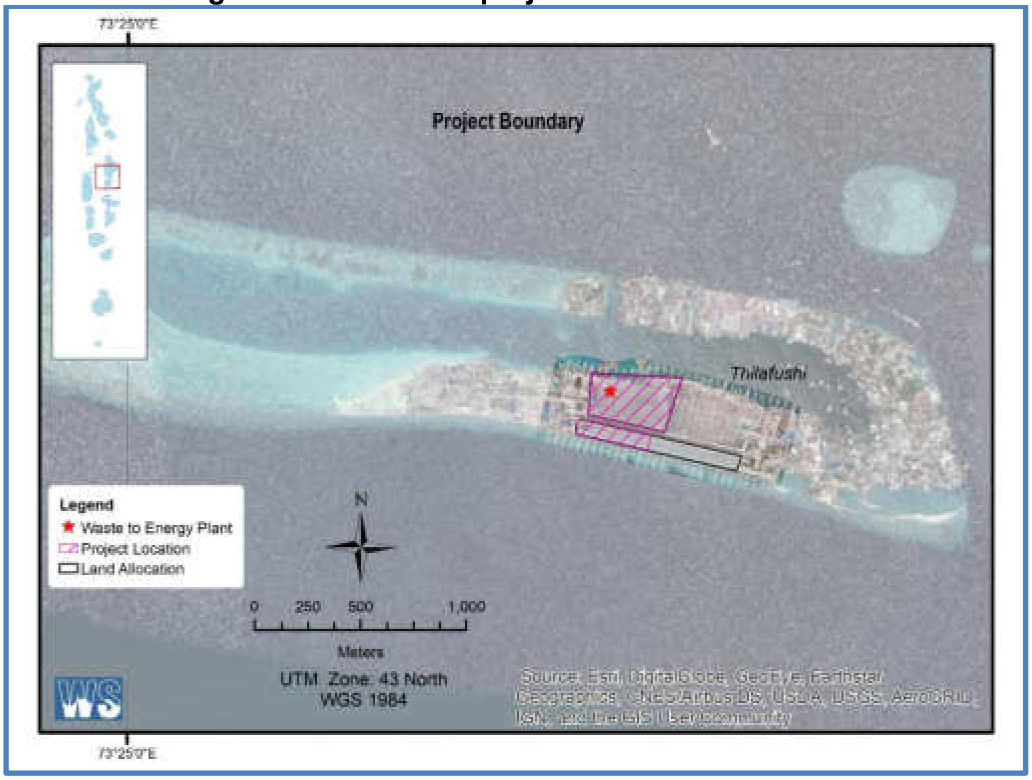
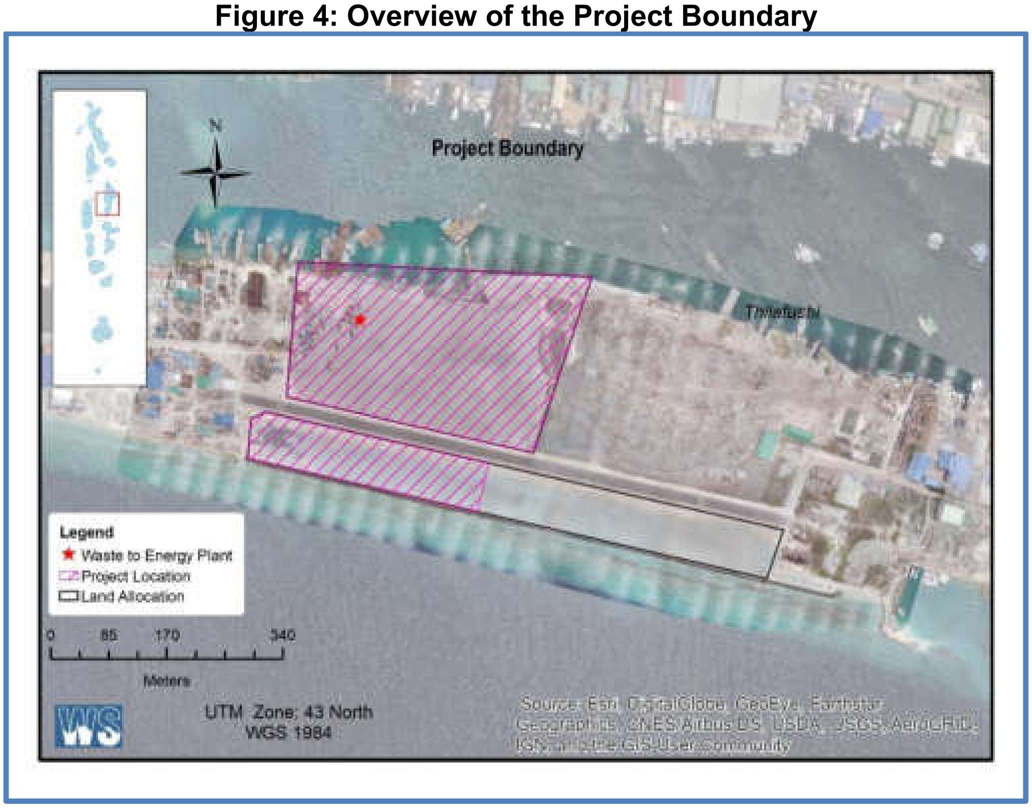


Figure 4: Overview of the Project Boundary



A. Project Components

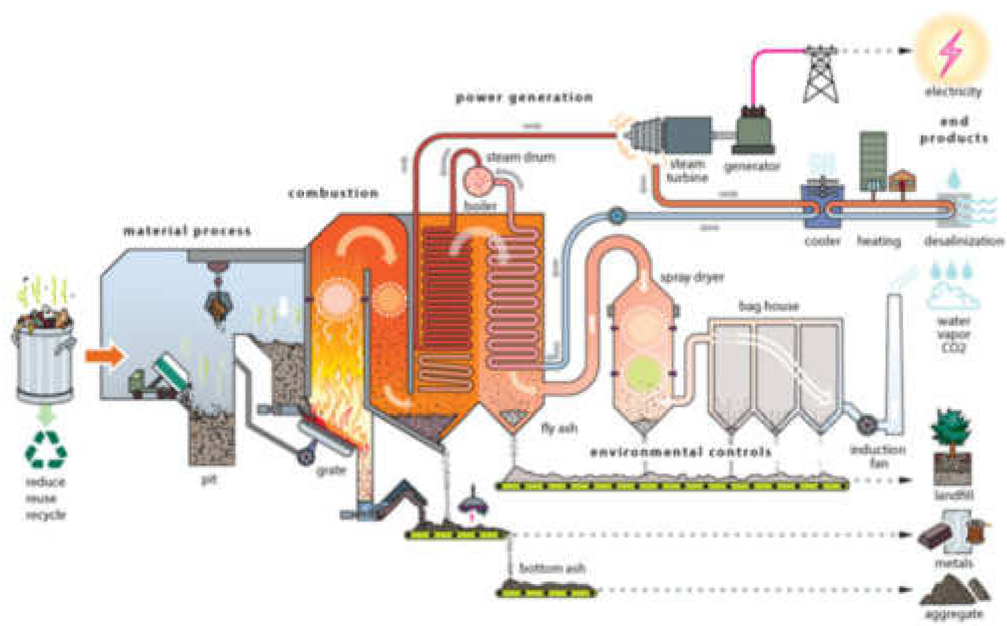
32. This EIA report utilizes components based on preliminary design of the WTE plant provided by the government. This subsection discusses the details of these project components. As the project will be implemented through a DBO contract, the DBO Contractor will finalize the detailed design and update this EIA report accordingly. Per preliminary design, the WTE will have 10MW power production with 2 MW to be used for the facility itself (and other parasitic loads). The surplus power of 8 MW will be fed to the main grid through a cable link between Thilafushi and Ghuli Fahlu island. The government is still at planning stage of developing this link to be constructed in between the islands.

33. The construction of the WTE plant infrastructures will include the following stages:

(i) Civil and building works;
(ii) Mechanical & electrical plant installation;
(iii) Road, utilities, services and landscaping; and
(iv) Ancillary instrumentation and control works.

34. A schematic diagram of the WTE plant processes based on preliminary design is shown in Figure 5 below.

Figure 5: Schematic Diagram of a Typical WTE Plant



Reference: Application to Access JFJCM Resources for Greater Male Waste to Energy Project (Phase 2 of Greater Male Environmental Improvement and Waste Management Project

35. Figure 5 illustrates a single line of the proposed WTE plant and shows the stages of waste treatment and processing in an incineration system, and the processes of how the energy is generated. As initial step, waste is dumped by the waste trucks into the waste bunker (pit) of the incineration plant. The waste is then lifted by a crane and hauled into the hopper, which feeds the combustion chamber of the incinerator. The waste moves slowly down through the grate and burns. The combustion chamber is fed with air from the waste bunker. The residence time of the

waste onto the incineration grates does not exceed 60 minutes. The primary air supply ensures the direct combustion of the waste, while the secondary air seeks to achieve turbulent mixing of the waste in order for the combustion to be complete. In order to accomplish complete combustion of the gases, it is necessary for the gases to be at a temperature above 850 °C for at least 2 seconds. Complete combustion is indicated by the levels of the carbon monoxide in the off gases. Auxiliary firing systems are used to keep the combustion gases at the desirable temperature levels. In the process, the grates need to be cooled through the air coming from underneath because high temperatures can damage the grate. The flue gas generated will pass through the flue gas cleaning system. The cleaned and cooled gases are discharged into a stack. The gases are discharged by means of an induced drafted fan.

36. The utilization of the generated heat (since combustion is an exothermic process) is most commonly made via the generation of high-pressure, superheated steam from the heat exchange between the flue gas (which absorb the majority of the heat produced) and the water/steam circuit, within a boiler. The flue gas treatment system is the biggest part of a waste to energy plant. The flue gas has to be cleaned very carefully before entering the stack.

37. After the combustion process, two types of residual wastes are generated. These are (i) bottom ash from the grate chamber, and (ii) fly ash from the flue gas cleaning. After recovery of these ashes, they are cooled down. The bottom ash passes through a section with electromagnetic field, which separates any metals from the ashes. It then passes through a sieve and finally stored in an ash bunker.

38. The residual wastes from the waste incineration are bottom ash, slag and the residues from flue ash. Bottom ash and slag is a valuable fraction which may potentially be used for many purposes such as covering material for landfill, ballast layer or reinforcement layer in road construction or filler/aggregate for construction blocks. Under any circumstances that these options are not allowed or not safe, the landfill will be able to accommodate the residual wastes. The hazardous residues from the flue gas cleaning (fly ash) will be conditioned safely in sealed bags and disposed in a controlled way at the sanitary landfill. Similarly, the fly ash collected from flue gas cleaning is cooled down, stored in big bags and disposed in the same residual waste landfill. This landfill shall be designed to follow internationally recognized best practices and standards as discussed in this EIA report.

1. Waste Reception, Storage and Feeding Facilities

39. The waste reception, storage and feeding process will have the mechanical equipment for the following process components:

(i) weighing system;
(ii) waste reception hall (tipping hall);
(iii) waste bunker;
(iv) waste cranes; and
(v) supply of waste oil.

40. The mechanical equipment shall be complemented by electrical, control and safety components which, jointly with the civil works relating to this process unit, shall be arranged to a fully functional process unit that allows for weighing of incoming and exiting materials, for unloading of waste delivery vehicles, for storage of waste and for feeding of waste to the subsequent process unit. Further to this, the design shall include the necessary odor and fire

control system and any other related safety feature to facilitate a constantly safe operation of the process unit.

41. **Waste reception**. Waste will be delivered by WAMCO predominantly, while commercial and industrial entities having premises on Thilafushi will, upon approval by WAMCO, deliver waste using their vehicles as well. Waste will be delivered mostly via closed containers (up to 25 m^3 volume). In addition, WAMCO will reduce the baled stock and deliver baled and wrapped waste up to a ratio of the mechanical capacity.

42. The design shall include a waste reception hall that shall comply with environmental, health and safety, and operational requirements for all personnel entering the tipping hall, including all necessary electrical and control components to allow for a 24/7 operations. Whenever required due to emergency operations requirements, all shutters shall be controlled according to applicable emergency procedures. The waste reception hall shall be an enclosed area equipped with adjustable louvers that allow ventilation of the hall. Odor emissions shall be prevented by a draft induced by the primary air supply fan. Entry and exit gates shall be closed by an electrically driven fast acting shutter with an airtight design. The dimension of the reception hall shall allow for safe flow of incoming and exiting vehicles. Access to the waste reception hall for all waste delivery vehicles shall be restricted by automatic traffic lights in the event all tipping bays are occupied. The traffic lights shall be positioned to avoid vehicles entering the access ramp when access is denied.

43. Wherever reasonable and applicable, the supporting structures of the building and the access gate shall be equipped with impact protectors while elevated curbs shall be protected with edge angles or embedded steel plates to prevent damages from wheel loader buckets.

44. The design shall also include tipping bays, which shall be closed by electrically or hydraulically driven flap door or roller gate when not in use. The doors or gates shall be made for heavy duty to withstand the likely dust laden atmosphere of the bunker. For all tipping bays, safety curbs shall be provided to prevent reversing vehicles from falling into the bunker. Tipping bays shall be made of wear resistant concrete or shall be covered by wear resistant steel sheets.

45. The waste reception hall and the tipping bays shall be surveyed by tilting CCTV cameras with a central control room. For cleaning purposes, the reception hall shall be provided with a sufficient number of power sockets and water supplies to allow a high-pressure steam cleaner to operate. Water shall be collected by the drainage system. Subject to the design considerations, a waste inspection area shall be provided either inside or outside of the reception hall, which shall enable inspection of suspicious wastes.
The shredder for bulky waste, tree trunks, mattresses (if need be) and other larger objects to be incinerated shall be a slowly rotating machine to prevent any sparking. In any case, the shredder shall be equipped with a spark detection and fire suppression system prior to conveying the shredded material to the bunker. The shredder shall be of a robust design which facilitates high endurance with limited wear and tear. The shredder shall be electrically driven and shall be equipped with a local control.

46. **Weighing facility**. The weighing system shall consist a weigh bridge and weighing software that will be used to:

(i) weigh incoming wastes;
(ii) control the supply of fuels and chemicals;
(iii) weigh any kind of residue which leaves the facility either directly (APC residues)

or after processing (bottom ash, metals);
(iv) weigh any other material whose mass shall be controlled; and
(v) enable a mass balance of the WTE plant.

47. The design of the weigh bridge and its computerized recording of incoming and exiting vehicles shall facilitate the operations without any manual intervention during weight recording. It shall be at the discretion of the DBO contractor to decide whether to install an Automatic Vehicle Recognition System or whether to determine the weights via manually triggered weighing or by scanning bar codes, tokens or the like. Load (or weighing) cells shall be calibrated by a third party or by the supplier certifying the correctness of their functions. The weighing system shall allow for each weighing event to be logged and allocated to a delivery vehicle jointly with a time stamp for entering and exiting. Weighing records shall be archived without any option to modify or manipulate data, unless there is a valid reason to do so. The weighing software shall enable the exchange of data with the Plant Management Information System (PIMS). All components of the weighing system which are prone to corrosion shall be manufactured using corrosion protected steel. The entire system shall not be affected by electromagnetic fields, e.g. radio frequencies, industrial frequencies. Appropriate storm surge, earthing and lightning protection shall be provided and installed.

48. **Waste bunker**. The waste bunker shall accommodate wastes to allow continuous operation of the WTE plant. The bunker shall be designed to meet all safety and environmental requirements including, but not limited to:

(i) General work safety, by, e.g., assuring sufficient signaling and warning notices;
(ii) Prevention of falling into the bunker (through, e.g., handrails, providing secured maintenance or service platforms etc.);
(iii) Prevention of fire incidents by a constant fire detection via an infrared fire detection system**;**
(iv) Installation of an automatically controlled and monitored (with manual override from the crane control room) fire detection and suppression system with at least four externally controllable fire monitors;
(v) Heat and smoke extraction system meeting the requirements of both the local fire department and the Contractor's insurance company; and
(vi) Avoidance of odor emissions by extracting primary combustion air from the bunker.

49. The bunker design shall consider a parking position for the redundant crane and an aperture that, under normal operations, is kept closed to facilitate the grapple's maintenance outside the bunker. Access to the bunker from the roof shall be provided to access the crane bridges and rails for maintenance or replacement. CCTV system shall be installed to allow the crane operators to survey bunker areas out of their sight and the control room personnel to monitor the crane operations and the waste feeding into the feeding hoppers of the subsequent process unit.

50. The design includes a leachate collection sump which shall be used to collect leachate during bunker revisions and inspection only. Any accumulated leachate shall be disposed of via the combustion system after the system is back to operations.

51. **Waste crane**. The waste supply to the feeding hoppers shall be secured by two identical waste cranes. The cranes shall allow operations in an automatic, semi-automatic and a manual (override) control mode. Manual operations shall facilitate the operations of the cranes from the crane control room which shall provide the necessary control devices. The control room's window

shall be fire and impact resistant according to international standards. The control room shall be equipped with air conditioning.

52. The cranes shall be equipped with automatic load cells to weigh the waste quantity and log the feeding data (time, quantity) within the DCS. Load cells shall be calibrated by an accredited third party or by the supplier who shall certify the accuracy. The cranes and their rails shall be designed for high durability (24/7 operations in a dust laden environment at high temperatures), easy maintenance (e.g. double-sided maintenance walkway along the bridge) and safe operations (e.g. anti-collision system, IP65 protection class). The design of the waste cranes shall consider, among others, the standards of crane safety BS 7121, BS EN 13000 and BS EN 12077-2, and with BS EN 13001-3-1 dealing with design and material aspects. The crane shall meet FEM 1.001 standard A8 with mechanism groups for hoist (M8), travelling drive (M7) and trolley traversing drive (M7).

53. **Waste oil storage and feeding system**. As per feasibility study, an amount of approximately 1 m^3 waste oil per day is expected to be delivered to the WTE plant. Waste oil will be delivered in drums (up to 200 liters each). To accommodate the fueling of waste oil, the design includes waste oil storage, the necessary supply pumps to the waste oil lances including. supporting steel structure, piping, instrumentation and control.

2. Thermal System

54. For each of the thermal systems to be delivered, the Contractor shall provide an identical set of components from the waste feeding hopper, to the combustion chamber including air supply system and wet de-asher and the two-boiler incl. economizer. Each of the thermal trains shall be capable being operated independently from the other. Each thermal system shall be designed to burn waste within the range of net calorific values and composition and for the defined throughput range as per preliminary stoker capacity diagram (as specified in bidding document) without any auxiliary fuel, and shall achieve the bottom ash characteristics as defined in bidding document.

55. At maximum thermal overload conditions (110% MCR per line), each thermal train shall allow operations for at least 2 hours every 4 hours. Intake of any air other than via the primary or secondary air supply system or discharge of any gaseous combustion products either via the feeding system or the bottom ash discharge shall be prevented under all operational conditions.

56. Appropriate fail-safe systems shall prevent access to or operation of the combustion system whenever necessary. Access doors to the furnace, which shall be sufficient in number and size, shall be locked automatically while the system is operating. Feeding waste shall be blocked if the temperature in the combustion chamber is below 850 °C. Lubrication and grease of moving components shall be arranged centrally for ease of control and maintenance. Other minimum design requirements for components and equipment are listed in bidding document.

57. **Feeding hoppers, waste chute and waste feeder**. Feeding hoppers shall facilitate blockage-free feeding of waste towards the waste chutes. Both the waste crane grapple and the feeding hopper shall allow the grapple to intervene in the event of any clogging of waste in the feeding hoppers. The design of the feeding hopper shall use wear resistant and replaceable steel sheets.

58. Similar to the feeding hoppers, the waste chute shall assure non-clogging operation characteristics via an appropriately shaped widening of the chute towards the furnace. The waste chute shall be equipped with a hydraulically driven cut-off gate and expansion joints and shall be

water cooled. The cut-off gate shall have fail-safe provisions (e.g. in the event of a low waste level) to prevent back-firing from the furnace into the bunker. Materials for the cut-off gate shall be corrosion resistant. The DBO contractor shall provide suitably designed fire alarm, firefighting and fire suppression equipment.

59. Waste shall be fed into the furnace via a hydraulically driven waste feeder, which shall be controlled by the DCS to allow the desired feeding rate. The pusher walls shall be made of wear resistant steel.

60. **Moving grate.** Design and assembly of the moving grate shall ensure a robust and durable non-clogging, easy to clean, operate and maintain system which shall limit downtime due to failure or breaking of grate bars and other driving or moving components. The design of the grate and the material used for the grate bars shall have a proven track record of at least 3 years continuous operation in other facilities incinerating co-mingled MSW.

61. All grate zones shall be designed to be controlled and operated individually. Cooling of the grate shall be provided via the primary air. Air flow for the grate zones shall be adjustable individually. The moving grate components shall be driven hydraulically. No unburnt material shall accumulate beneath the grate.

62. Operations and control of all grate components shall be realized automatically via the DCS.

63. **Bottom ash collectors and discharge system**. Bottom ash collectors beneath the grate and a wet de-ashing system shall be provided. All bottom ash collecting and conveying equipment shall be wear resistant, easy to clean, and easy to operate and maintain. Necessary flexible compensators shall be supplied. Access to the discharge system shall be provided through adequately designed apertures to remove any blocking objects or for inspection purposes. Dust emissions from the bottom ash discharge, collection and conveying system shall be prevented.

64. The design of the bottom ash conveying system downstream of the wet de-asher shall incorporate any needed redundancy or intermediate storage to avoid shut down of the combustion system or the subsequent units due to failures of the conveying system. During continuous and steady state operations, bottom ash shall be conveyed without any intermediate manual handling to the bottom ash processing plant.

65. **Combustion chamber**. The design of the combustion chamber above the grate after injection of secondary air shall take into account the combustion conditions pursuant to the Performance Guarantees that are included in the DBO contract (i.e. at least 2s residence time at a minimum temperature of 850 °C) under all operating conditions. The design shall be substantiated by CFD simulations which shall form part of the Contractor’s detailed design documentation. The combustion chamber shall be equipped with measuring devices to allow the proponent to verify combustion conditions via an appropriate record of the DCS. The compliance of the combustion chamber with the combustion conditions shall be certified by an impartial external third party.

66. Any area exposed to flames shall be covered with appropriate materials. Design of the combustion chamber shall ensure a uniform flue gas distribution, an enhanced mixing efficiency of the secondary combustion air and minimizing fouling and/or slagging of the furnace walls. Walls of the water cooled combustion chamber shall be gas tight (membrane-type wall) and shall be covered by a back ventilated silicon carbide lining in those areas that are prone to flame impingement or shall be cladded using an appropriate cladding material which shall be certified according to international standards.

67. All equipment to measure the parameters which are necessary to control the incineration shall be supplied. Data supplied by the measurement equipment shall be used by the combustion control system within the DCS to avoid unfavorable combustion and operating conditions of the incineration train such as, but not limited to, uneven oxygen and carbon monoxide concentration across the combustion chamber cross section, thermal overload, variation of steam generation rate, peak temperatures and to assure a complete combustion of the flue gases within the combustion chamber thus leading to minimum carbon monoxide and organic carbon emissions. To allow visual inspection, each combustion chamber shall be equipped with a sufficient number of apertures to both have a direct view on the grate and to install a CCTV camera.

3. Boiler and Water Steam System

68. The boilers and water-steam systems shall be designed to allow the heat extraction within the limits of the stoker capacity diagram including the required piping, insulation, valves and control equipment, and others. All components shall be easy to inspect, to maintain and to replace (e.g. via apertures in the roof, in combustion chamber or in the boiler passes). The boilers' operations shall be controlled by the DCS system.

69. In particular, the boiler and water steam system shall be designed with operation pressure of 42 bar (g) and steam temperature of 405°C. These design temperature and pressure shall be kept in the thermal load range between 85 and 110% MCR. If the thermal load range is between 70 and 85%, the steam temperature shall be maintained at 375°C.

70. The boiler and water steam system shall consist of radiation and convection boiler passes including evaporator, super heaters and economizer, steam drum and all necessary sampling, venting, injection, blow-down and cleaning equipment, and others that will be needed for safe operations of the boiler and the water steam system. The de-ashing equipment, including chutes, (pneumatic) conveying systems, compensators, and others shall be included in the scope of design and supply by the DBO contractor. All shut-off valves shall be fast-acting fulfilling the relevant internationally accepted standards.

71. All water/steam feeding pipes, safety valves, silencers and necessary pipe sections shall allow drainage. The necessary drainage shall be provided with a double shut-off fitting.
The safety devices of the boiler shall likewise comply with applicable internationally accepted standards. A silencer shall be installed in the boiler safety valve blow-off. Each injection station shall include an injection control valve including a dirt trap, bypass and corresponding shut-off valves.

72. The protection of the membrane walls shall be taken into account. For the cladding, the following shall be considered:

Element	Percent by weight
Ni	minimum 58
Cr	20 - 23
Fe	5
C	0.1
Mo	8 - 10
Co	1
Ti	0.4

Element	Percent by weight
Al	0.4
Mn	0.5
Si	0.5
Nb (+ Ta)	3.15 – 4.15
Density	8.44 g/cm³

73. The cladding shall be applied with a thickness of 2 mm in total and an overlapping of 30 - 50% of each welding line. The service life of the cladding shall be at least 3 years, calculated from the application.

74. The steam drum, made of alloy steel, shall be dimensioned so that a sufficiently large water reserve is be available. Extended boiler travel times shall be achieved by applying, among others, appropriately designed:

(i) Gas velocities to prevent local overloads particularly in convection passes, entrainment of fly ash and its deposits;
(ii) Transverse divisions sufficiently large and decreasing in exhaust flow directions;
(iii) Cooling of the exhaust gas before the final super heater (super heater 3) to a maximum of 650 ° C (at 100% load, end of travel time);
(iv) Evaporator bundle (protective evaporator) prior to the final super heater;
(v) Co-flow arrangement of the final superheater;
(vi) Aligned arrangement of all pipes;
(vii) Live steam pipes with minimum welded joints;
(viii) Mechanical and water jet cleaning devices.

75. The boiler lining in the first pass shall be optimized to meet the following requirements:

(i) Good ignition of the fuel on the grate (ignition cover);
(ii) Good burnout of the fuel on the grate;
(iii) Protection of the pipe walls against erosion by the fuel on the grate and in the filling area;
(iv) Insulation of the combustion chamber and the afterburner chamber to achieve the required residence times of the exhaust gas at high temperatures;
(v) Protection of the pipe walls against hot and not completely burnt off exhaust gases (corrosion protection);
(vi) Minimize heat accumulator for varying heat dissipation due to varying fuel throughput and calorific value; and
(vii) Avoiding too high surface temperatures (low heat transfer resistance of the design where possible) to avoid caking, deposits and slag flow.

76. Each boiler shall allow independent operation from the other.

4. Air Pollution Control System

77. The air pollution control (APC) system of the WTE plant shall be equipped with dry flue gas cleaning with a reactor, sodium bicarbonate injection and limestone, activated carbon injection, bag filter and selective non-catalytic reduction (SNCR) for NOx to meet the emission limits as stated in the Performance Guarantees required from the DBO contractor. While the government does not have any emission standards, the WTE plant will comply with the emission

limit values stipulated in Annex VI of Directive 2010/75/EU of the European Parliament and the Council. The APC system shall be designed so that bypass operations are not required.

78. **Flue gas cleaning.** The reactor shall be designed so that flue gases sodium bicarbonate, limestone and activated carbon are mixed efficiently. For the regulation of the flue gas temperature, a quench with water shall be provided. The residues from the landfill leachate treatment shall be disposed of via the reactor. The bag house filter shall be designed with a maximum filter surface area load of 0.8 m^3/m^2 min. and a maximum operation temperature of 200°C. The pressure loss shall be smaller than 14 mbar. The bag filter shall be equipped for fully automated and controlled (by differential pressure measurement) cleaning of the filter hoses by compressed air impulses. The separated dust shall be transported via a water-cooled discharge screw into a big-bag filling station. The filled big bags shall be stored in a separate area of the adjacent landfill.

79. **Nitrogen oxide removal system.** The NO_x-removal system shall be a selective non-catalytic reduction (SNCR). With a SNCR-system ammonia water with ammonia content of less than 25% or a water-urea solution shall be injected in the first pass of the boiler at a temperature level of approximately 900°C. The system shall be required with 3 levels of injection nozzles in the first boiler pass. The tank for the ammonia water shall be an unpressurized vessel with a capacity of 30m^3.

5. Turbine, Generator and Condenser

80. **Steam turbine.** The turbine generator set shall include all necessary ancillaries to supply process steam and electrical energy to satisfy the demand at the project site and to export electricity to the STELCO grid based on the power purchase agreement to be concluded between the proponent and STELCO.

81. The turbine shall allow a steam intake equivalent to 110% MCR of both boilers. The exhaust steam of the steam turbine shall be cooled down in a seawater-cooled condenser in the energy building. The condenser and the hereto relating cooling water pumps shall be designed to facilitate the condensation of 100% of the steam generated in the boiler if needed. The turbine generator set shall allow both island mode and external grid-backed operations.

82. **Steam turbine with auxiliary equipment.** Besides the steam turbine itself, the system shall include all auxiliary equipment such as, but not limited to, valves, internal pipes, extraction points, gearbox, instrumentation, and lubricating system including oil coolers and filters that are required for fully automated and safe operations. Crucial equipment shall be installed redundantly. The turbine shall be single-casing design in axial construction. Thermal stresses during load changes or temperature fluctuations shall be reduced to a minimum. To satisfy steam and operating conditions, the housing shall be made of alloyed cast steel. The fast closing valve shall be medium-actuated that shall close in the event of malfunction in milliseconds. The nozzle segments shall be designed for a wide load range between 35% to 110% of the MCR (thermal). The exhaust housing is selected from the modular system and - depending on size and type of turbine – shall be cast or welded. The turbine rotor shall be designed as a fully forged rotor. The torsion-critical calculation shall be carried out using modern computer calculation methods. In particular, the vibrations are pre-calculated and minimized, taking into account the bearing conditions as well as the influence of the plain bearings. The design shall minimize the start-up-time and shall allow fast load changes. All rotor blades material shall be a steel with not less than 13% chrome.

83. The steam turbine and auxiliary components shall be mounted on a single frame and shall be packaged by one supplier. Insulation of the turbine and its internal piping must not contain any asbestos. Equipment and components that are crucial for the facility and the turbine performance shall be provided fully redundant (2 x 100%), such as, but not limited to, oil coolers, pumps and filters. For failures of the steam turbine, a bypass shall be provided, which directs the live steam directly into the condenser.

84. **Generator System.** The generator shall be a four-pole rotor (1,500 min-1), of a brushless design using rotating diodes for excitation, and cooled by a closed air-cooling circuit. The heated air shall be re-cooled over cooling water. The design shall be selected in such a way that the generator does not suffer damage by water.

85. **Condenser.** The exhaust steam from the steam turbine shall be cooled in a 2-flow seawater surface condenser that shall be designed for bypassing the entire steam rate generated at 110% MCR of the two incineration trains in the event the turbine trips. To start the turbine, a vacuum shall be generated in the condenser using two parallel water ring pumps. In order to maintain the vacuum in the condenser during operation, a standby water ring pump shall be provided. Alternatively, the vacuum may also be generated via steam emitters. The condensate shall be collected in the hot well and pumped by the redundant condensate pumps into the condensate collecting tank.

6. Induced Draft Fan and Stack

86. The induced draft (ID) fan shall be arranged downstream of the bag house filter. This shall be designed as a radial fan with a single-flow impeller, statically and dynamically balanced. The shaft shall be double-mounted. A labyrinth shaft seal shall be provided as a shaft seal. An elastic coupling shall be used between the drive motor and the shaft. The housing shall be designed as a steel plate construction with external stiffeners. The fan is installed together with the drive motor on a steel base frame and is equipped with a noise protection hood.

87. The auxiliary driver shall be supported by emergency power. The ID fan shall be designed for 130% load at a nominal flue gas flow. In order to minimize the wear and the noise emission the maximum air fan speed shall below 1,200 rpm.

88. Two stacks shall be built as a tube-in-tube system, the minimum stack height based on the calculations in the air dispersion modeling done for the project is 45.7 m. However, the project will use 50 m as the height. Each stack shall be accessible via an external climbing ladder.

7. Continuous Emission Monitoring System

89. Each of the two stacks will be provided with a continuous emission monitoring system (CEMS), including the necessary flue gas sampling ports for emission measurements. The flue gas sampling ports shall be located at an appropriate height above the ground that shall allow easy access.

90. In addition to the continuously measured parameters and monitoring requirements discussed in Section IX, the pressure, flue gas temperature and flow, oxygen, water and carbon dioxide concentration shall be also continuously measured. The flue gas samples shall be routed via heated pipes to avoid condensation under all operating conditions to the measuring room or a measuring container. The analyzers shall be installed in cabinets. In addition, a computer and the holders for the test gas cylinders (zero gases and calibration gases), sample gases and carrier

gases shall be arranged in the measuring room. The measuring room or container shall be air-conditioned. The analyzers shall be equipped with a periodically self-calibrating system using the test and calibrating gas. Each analyzer shall be provided with a suitable measurement range to allow the collection of emission data beyond the half hourly emission standards without compromising the accuracy in its lower measurement range. The measuring instruments used shall comply with internationally accepted standards.

91. Raw emission data shall be compiled by the emission evaluation program to facilitate emissions statements according to the regulatory requirements. The emissions computer shall be equipped with special software, e.g. according to DIN EN 16258, which fulfills the following requirements:

(i) Formation of overage values;
(ii) Correction calculation for O_2, temperature, pressure and flue gas humidity;
(iii) Simultaneous calculation of the concentration; and
(iv) Archiving the raw data and the classified averages values with date and time stamp for stamp minimum 5 years.

92. All measurement results shall be forwarded to the DCS and be displayed in the central control room. Results shall be submitted to the project management unit (PMU) for its review with the help of the external environmental expert who will be retained under the project. The same shall be submitted to ADB in accordance with the reporting requirements in Section IX. Subject to government requirements, the emission data shall also be transmitted to Maldives EPA.

8. Condensate System

93. The condensate system shall consist of the condensate collecting system, the condensate tank and the make-up water system.

94. **Condensate collecting system.** A hotwell shall be arranged in the condenser at the lowest point in which the condensate from the turbine exhaust is collected. With a redundant condensate pump, the condensate shall be pumped to the main condensate tank. All other condensate from internal heat exchangers, air-pre-heaters etc. shall be collected in a separate condensate tank and pumped into the main condensate tank.

95. **Main condensate tank.** The condensate tank shall be designed as an insulated horizontal tank. The size of the main condensate tank shall be adapted at the maximum condensate flow. The minimum storage capacity shall be not lower than 15 m^3.

96. **Feed water.** The condensate shall be pumped in the boiler feed water tank which shall be designed as a horizontal preheater. The preheater shall be operated by LP steam. The volume of the boiler feed water tank shall be not smaller than 35 m^3, the degassing capacity not smaller than 70 m^3/h.

97. **Boiler feed water pumps.** Each boiler shall be equipped with 2 x 100% electrical driven feed water pumps. The boiler feed water pumps shall be connected to the emergency power system for a save shut down of the plant. The design shall be according to internationally recognized standards.

98. **Make-up water system.** A water treatment plant producing the make-up water shall be able to supply a full boiler filling within 24 hours. The conductivity of the make-up water shall be

lower than 0.2 μS/cm.

9. Cooling Water Supply System

99. The WTE plant shall include a cooling water supply system utilizing sea water-cooled heat exchangers (mainly the condenser). Cooling water shall be returned to the sea with a maximum temperature of not more than 3°C from ambient temperature. The design of the cooling water supply system shall take into consideration the recommendations in this EIA, which is aimed at protecting sensitive coral fauna and flora and the marine ecosystem in general. The cooling water intake position and cooling water outfall position shall follow the recommendations of the EIA. Design implication are, but are not limited to, inlet and outlet pipe position, and supporting structure of the inlet and outlet pipes.

100. For the design of the cooling water pumps, the DBO contractor shall take into account that the pumps shall be:

- (i) installed in an enclosed, watertight area to cope with the climate change and disaster risks;
- (ii) fully redundant; and
- (iii) designed to accommodate the instant need to cool down the full steam flow rate bypassing the turbine.

101. The cooling water collected from the intake shall be appropriately cleaned prior to its use in the facility to limit fouling of the condenser (or any other heat exchanger).

10. Fuel and Chemical Supply and Storage

102. The tanks and silos shall be designed to prevent the occurrence of encrustation and deposits. Necessary monitoring equipment such as but not limited to leakage detection shall be installed for all hazardous substances. This shall also apply to securing against vacuum, e.g. by suction during emptying. All containers shall be equipped with manholes and associated maneuvering aids.

103. The manholes shall be opened without the aid of hoists. Trays of containers shall be diverted appropriately via the channel and pumping sump. Odor emissions shall be prevented. For chemical containers, sufficient retention volume shall be provided.

11. Piping and Valves

104. Installation lengths and connection dimensions of fittings shall be selected according to internationally recognized standards. For fittings and piping components, at least certificates of the acceptance test in the factory and a 2.2 certificate in accordance with BS EN 10204 for mechanical-technological tests shall be submitted. For materials of stressed pipelines (e.g. thick sludge lines), approval test 3.1B according to BS EN 10204 shall be submitted.

105. Fittings for insulated pipelines shall be equipped with spindle extensions, if necessary. All fittings shall be supplied with a full corrosion protection (including the hand wheels and chain wheels) in the factory, in accordance with the customer's order. Fittings and piping components shall be equipped with factory-specific markings. For fittings these are nominal size, nominal pressure, permissible operating temperature and pressure, type, year of manufacture, material manufacturer or manufacturer's code, and flow direction. Whereas for piping components, these

are manufacturer's mark, material, melting number (percent), if relevant, nominal pressure for flanges, and dimensions (nominal width and pipe connection).

12. Pumps

106. Dry-mounted pumps shall be delivered on suitable base plates or base frames pre-assembled for installation including motor and coupling. The aligned arrangement of engine-clutch-pump shall be measured and, if necessary, adjusted. Pumps shall be designed in horizontal design and shall be able to absorb cavitation in the short term. The material of the pumps shall be capable of continuous operation under the appropriate conditions of delivery and operation. Pumps shall have a stable characteristic and shall allow a quick start from the cold conditions without prior warming.

107. Sliding ring seals of the pumps shall preferably be made of silicon carbide or wolfram carbide. Seals, which are exposed to sealing water are equipped for a continuous monitoring and recording of the flow or pressure or temperature.

108. All pumps shall be provided with dry-running protection. Pumps with a motor power of 20 kW shall have a bearing temperature monitor. Suitable shut-off devices before and after the pumps shall be provided so that the pumps can be replaced at any time.

13. Compressed and Instrument Air Supply

109. The DBO contractor shall design and install a fully redundant compressed air supply plant for the provision of dry, particle and oil-free compressed air that allows an energy optimized supply at 110% MCR of each incineration train. The compressed air supply unit shall consist of the following systems:

(i) A compressed air supply system for continuous consumption such as but not limited to, cooling air for furnace cameras, SNCR, sealing air, and temporary consumption for, amongst others, tools, cleaning purposes etc. Drying shall be achieved by refrigerant cooling (dew point 3°C, at max pressure), filtration rate with grain size 3 μm 99.99%;
(ii) An instrument air supply system for all measurement and control instrumentation meeting the quality requirements of the measuring and instrumentation devices. Based on the design considerations of the Contractor, the instrument air shall be either made up from compressed air or a completely separate supply system shall be installed (with refrigerant cooling, 3°C dew point, adsorption drying, -40°C dew point, and filtration rate of 99.99% with grain size 0.01μm);
(iii) It shall be at the Contractor’s discretion to supply a compressed and instrumentation air supply system either catering for 2x100% or a 3x75% of the required capacity. In any case, the supply of the compressed and instrument air shall be secured any time without any interruption;
(iv) The compressed air system shall be soundproofed and operated fully automatically;
(v) The compressed air lines shall be made of stainless steel; and
(vi) Sufficiently sized tanks with pressure relief valves shall be provided for both compressed air and instrument air.

110. Consumers shall be supplied via a redundant supply line or via a ring supply system.

14. Thermal Insulation and Heat Protection

111. All equipment or components carrying media at elevated temperatures or at temperatures below ambient conditions or that, due to its operations, work at such temperatures shall be provided with thermal insulation to assure high energy efficiency and to prevent condensation or shall be covered with heat protection shields to avoid accidental contact. The thermal insulation design shall be in accordance with the requirements set in the contract documents.

112. The thermal insulation shall be designed so that the maximum temperature the working personnel are exposed to does not exceed 60 °C whenever feasible or shall install heat protection shields when the maximum surface temperature of any equipment which cannot be insulated exceeds 60 °C. It shall be designed so that no heat losses or condensation occur via pipe and equipment supports and that valves, fittings and measurement devices are accessible yet are covered by insulation material. For the design of the insulation thickness, it shall consider the maximum heat flow due to operational conditions, such as, but not limited to, maximum inner temperature and by-passing the turbine.

113. No asbestos shall be used for thermal insulation but only non-flammable, chemically and highly durable resistant rock wool mats. The mats shall not have any chemical impact on the base material. Materials shall comply with internationally recognized standards such as BS 5970 and BS 5422. Pipes or components working below ambient temperatures shall be insulated using flexible elastomeric foam material in accordance with BS 5422.

114. The lagging and jackets shall meet the ambient conditions of the marine corrosive environment, accommodate the thermal expansion of pipes and equipment and that shall allow access to base materials, valves, fittings, flanges, measuring devices and other equipment.

15. Lifting Devices

115. The WTE plant shall have all required lifting devices during the operations phase and shall provide either permanent or temporary (including attachments) lifting devices such as cranes and hoists. The surrounding steel structure of the equipment shall be designed to allow anchoring or attaching temporary lifting gear if needed via mounting additional beams, clamps, shackles etc. or directly to the steel structure. A permanent crane shall be installed in the turbine hall. Removable openings in the roof of the machinery hall shall allow the access via mobile cranes to lift larger components that cannot be moved otherwise.

B. Environmental Considerations in Project Design

116. During the feasibility study stage for the project, household, resorts and hotels and general domestic waste generation in Maldives was assessed and characterized. Results of the study revealed waste composition in Table 1 and Table 2 below.[18]

Table 1: General Waste Composition

Waste composition	Household %	Hotel %
Organics	60	74
Garden waste	10	10

[18] Feasibility Study for an Integrated Solid Waste Management System for Zone III (including Greater Male') and Preparation of Engineering Design of the Regional Waste Management Facility at Thilafushi. Ministry of Environment. Maldives. March 2018.

Waste composition	**Household %**	**Hotel %**
kitchen waste	40	54
other organics	10	10
Paper and cardboard	10	9
Glass	3	5
Plastics	10	5
Metals	4	2
Hazardous waste	3	0.5
Others (inert and dust)	10	4.5
Combustible	39 – 50% (OS)	
Water	18 – 33% (OS)	
Ash	23 – 35% (OS)	

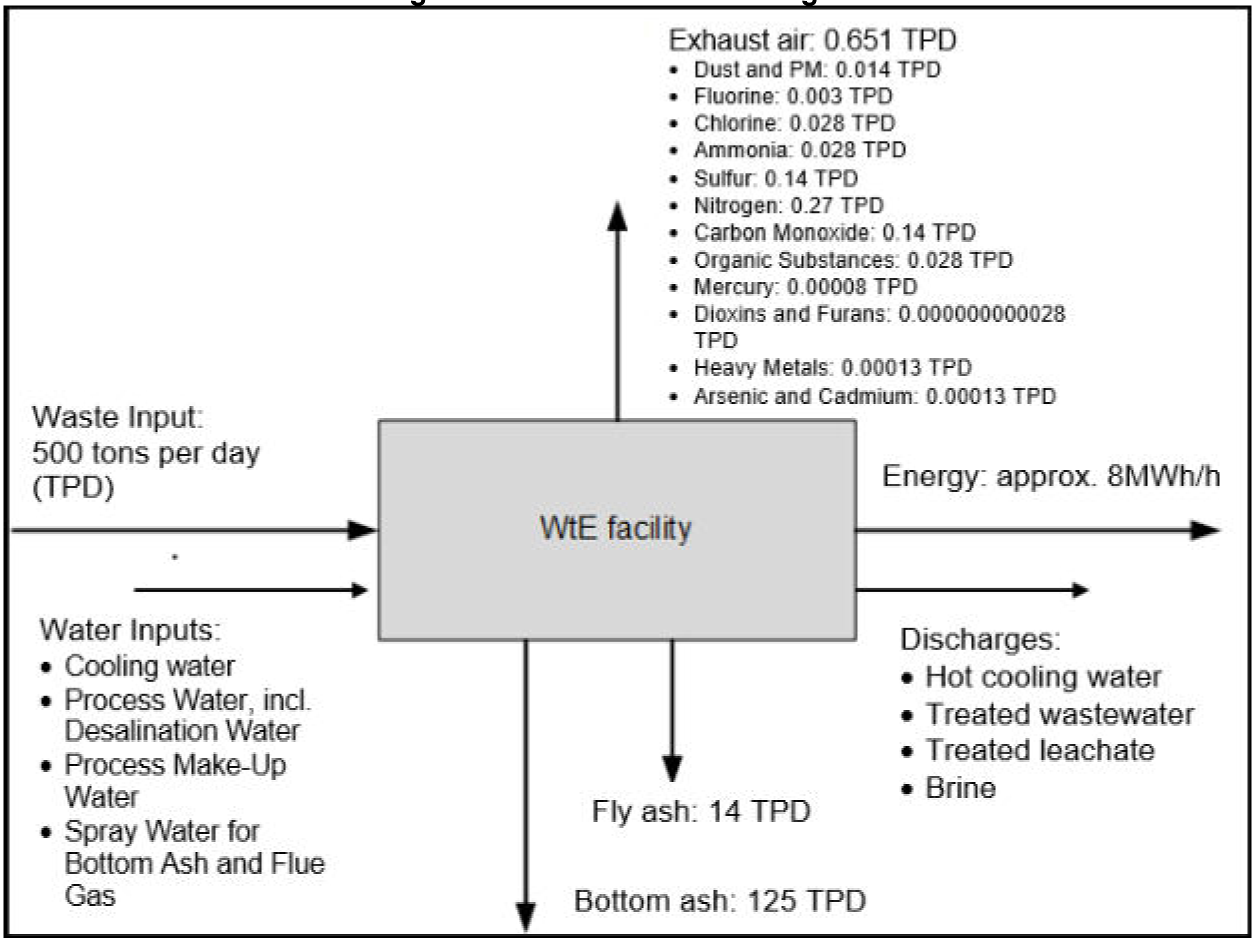
Table 2: Elemental Composition of Domestic Wastes

Parameter	**% Composition**
Combustible	40 %
Water	31 %
Ash	29 %
Ash (dry)	42%
C (Carbon)	29.9 % (dry)
S (Sulphur)	0.4 % (dry)
H (Hydrogen)	4.4 % (dry)
O (Oxygen)	18.1 % (dry)
N (Nitrogen)	0.9 % (dry)
Cl (Chloride)	0.6 % (max. 1 %) (dry)
F (Fluoride)	0.1 %(dry)

117. Figure 6 below illustrates the material balance of input solid waste materials and output streams during full capacity operation or when the two lines are in full operation. It also shows the generated energy expected from the WTE plant operation.

118. During the feasibility study for the project, several strategies following the waste hierarchy (waste prevention, followed by preparing for reuse, recycling, other recovery and finally disposal as the least desirable option) have been assessed in terms of applicability in the Maldives. Accordingly, not all common waste management strategies are applicable in the country. Notwithstanding the establishment of the WTE project, the government, through its various laws, rules and regulations, shall continuously promote its programs on waste prevention. During the operation phase of the WTE project, all possible waste recycling options proven to be sustainable under the situation in Maldives shall continue as well (e.g. recovery and recycling of PET bottles through partnerships with NGOs). However, recovery and recycling of other materials may not be applicable and/or practical due to limited land or space and the lack of recycling facilities in the country. Bringing these other recyclable materials overseas is not a financially sustainable option. Ultimately, these waste materials will have to be treated in the WTE plant. Nevertheless, any potential environmental impacts of burning these wastes will be addressed in the detailed design of the project, including adoption of internationally accepted and proven measures as discussed in various sections of this EIA report.

Figure 6: Material Balance Diagram



119. **Air Emission**. The WTE plant will be designed to include air emission control system and infrastructures in order to ensure no significant impact to the environment occurs. Consistent with Table 8 in Section II, the WTE plant will be designed to meet the target emission limits as shown in Table 3 below. These mass concentration limits are integral part of the performance guarantees provided under the DBO contract of the project.

Table 3: Air Emission Limits for the Waste-to-Energy Plant

Substance	Mass concentration[a]	Unit	Averaging Time
Total Suspended particulates (PM_{10})	10	mg/m^3	24 – hour
Sulfur Dioxide (SO_2)	50	mg/m^3	24 – hour
Oxides of Nitrogen (NO_x)	200 – 400	mg/m^3	24 – hour
Hydrochloric Acid (HCl)	10	mg/m^3	
Dioxins and furans,	0.1	ng TEQ/m^3	6 – 8 - hour
Cadmium	0.05 – 0.1	mg/m^3	0.5 – 8 - hour
Carbon Monoxide (CO)	50 – 150	mg/m^3	
Mercury (Hg)	0.05 – 0.1	mg/m^3	0.5 – 8 - hour
Hydrogen Fluoride (HF)	1	mg/m^3	
Sum of heavy metals and their compounds as Antimony, Arsenic, Lead, Chromium, Cobalt,	0.5	mg/m^3	Between 30 min. and 120 min.

Substance	Mass concentration[a]	Unit	Averaging Time
Copper, Manganese, Nickel, Vanadium, Tin, Zinc			
Cadmium/Thallium and compounds expressed as Thallium/Cadmium	0.05	mg/m³	Between 30 min. and 120 min.
Arsenic/Cadmium and their compounds (As and Cd), Benz(a)pyrene, water soluble Cobalt compound (as Co), Cr(Vi) compounds as C	0.05	mg/m³	Between 30 min. and 120 min.

[a] related to 11% O2 in the flue-gas.

120. In conjunction with the design, an advanced air pollution control (APC) system, including selective catalytic reduction (SCR) for nitrogen oxides (NO_x) removal, activated carbon for removal of dioxins and furans, bag filters for particulates removal, a dry/semi-dry scrubber for acid gas removal, and a continuous emissions monitoring system (CEMS) will be installed for the WTE plant to ensure that the emissions from the stacks will meet the target emission limits.

121. **Stack Height.** The stack height has been established through the use of modeling. More discussion on the modeling are in Section VI. Details of the modeling report is in Appendix 5. The assessment was done with reference to the Technical Instructions on Air Quality Control (TIAQC). TIAQC sets out the standards applied for air quality control in Germany and complies with the European Commission (EC) Directive on the Incineration of Wastes. The stack height required to comply with the technical instruction was determined, following which concentrations of pollutants in the emissions from the WTE were predicted, and dispersion modeling undertaken for those exceeding a designated minimum level.

122. Determination of the requisite stack height was undertaken using a nomogram and calculation steps provided in the German TIAQC. The input values for this process are the inside diameter of the stack, the temperature of the waste gas at the mouth of the stack, the volume of flow of the waste gas in standard conditions after subtraction of the water vapor content, and the rate of emission mass flow of the air pollutants from the plant. In determining these parameters, a feed of 500 tons of household waste per day was assumed. The final stack height is determined based on the dimensions of adjoining buildings. Results of the modeling and calculations show that stack height needs a minimum 45.7m to ensure sufficient dilution of the exhaust gases and an undisturbed transport with the free air flow is ensured. As added measure, 50m has been selected as the stack height. Summary of the stack description, including the other parameters used in the modeling is in Table 4 below.

Table 4: Parameters Used in Stack Height Calculations

Number of Stacks	**2**
Distance between stacks	7 m
Diameter of each stack	1.5 m
Calculated equivalent diameter of the two stacks	2.12 m
Total emission area	3.53 m²
Flue gas volume stream for each stack	57,856 m³/h
Total Flue gas volume stream for both stacks	115,712 m³/h
Flue gas exit temperature	180° C
Ambient air temperature	293 K

123. **Cooling System**. The heat energy of the exhaust air from the furnace is transmitted to water, converting the water to high pressure steam. The high-pressure steam is used to rotate a steam turbine and generate electricity. After the electricity generation process, steam pressure is reduced, and the steam is further cooled down by a cooling system. The proposed cooling system uses a seawater-cooled condenser and involves exchange of the heat of the low-pressure steam to sea water, which is then discharged to the sea at the southern side of Thilafushi. Selection of the outfall location for the hot condenser water has been analyzed based on where the minimum or no impact to marine life is expected. Discussions on the location selection is included in Section IV on alternatives analysis.

124. An alternative cooling system using an air-cooled condenser, was considered. An air-cooled condenser involves exchange of the heat of the low-pressure steam to air, which is then discharged to the atmosphere. This kind of system was not considered to minimize the land requirement at the proposed site.

125. **Desalination Unit**. An on-site desalination plant will be provided for supplying water to the WTE plant. The desalination plant would involve membrane separation of dissolved ions such as chloride ions from seawater, and would not involve any boiling or burning processes. The equivalent volume to be processed by the desalination plant will be enough to cover the makeup water for the boilers, which is typically 0.5% of the boiler feed water throughput. The desalination plant will also be used as an alternative source of potable water supply at the plant if external source is not sufficient. The waste brine or concentrated saltwater with approximate volume of 14 m^3/day from the desalination unit will be mixed with the hot water (heated cooling seawater) from the condenser. With relatively negligible volume of the brine (compared with cooling water volume), it is expected that it will not cause any change in concentration of the seawater and assimilation could be achieved as the flow reaches the outfall.

126. **Bottom Ash Processing Plant**. The DBO-Contractor shall be responsible for designing and building the bottom ash processing plant including bottom ash storage to satisfy the requirements of the envisaged bottom ash reuse. A study was commissioned under the project on the potential use of incinerator bottom ash for commercial purposes. Conclusion on the study says that the incinerator bottom ash has the potential for use in the construction industry. A copy of the complete report is in Appendix 6. For a proper and economical reuse of the bottom ash in the national market, the bottom ash shall have the following characteristics that allow the reuse of bottom ash as aggregate to concrete with different grading.

Figure 7: Bottom Ash Requirement for Reuse

Sieve size	Percentage by mass passing sieve
10 mm	100
5 mm	89-100
2.36 mm	60-100
1.18 mm	30-100
600 µm	15-100
300 µm	5-70
150 µm	0-150*

* For crushed rock sands the permissible limit is increased to 20%

127. Subject to the design considerations of the DBO Contractor, an intermediate bottom ash storage shall be provided. The floor of the bottom ash storage hall shall allow run-off from the wet bottom ash via a drainage system. The drained run-off from the bottom ash storage area shall be forwarded after either mechanical or gravity cleaning to buffer tanks prior to the leachate treatment system. The intermediate bottom ash storage area shall be sized to accommodate short term stoppages in the conveying system (e.g. the overhead cranes and belt conveyors). Bottom ash storage areas shall be equipped with CCTV to monitor operations. The bottom ash conveyors shall be dimensioned such that any item able to pass the bottom ash discharge chute can be conveyed to the bottom ash processing plant within the bottom ash treatment building.

Table 5: Design Parameters for Bottom Ash Treatment Plant

Bottom ash handling system (design parameter)	
Ash content in SW (dry ash/wet)	Max. 35%
Water content in bottom ash downstream extractor	Max. 15%
Capacity	Min. 160% of the maximum bottom ash flow
Yield of grading < 3.35 mm	Min. 60% of mineral fraction

128. **Fly Ash Management**. To avoid any impact to the environment and to the DBO Contractor's personnel safety, the fly ash shall be conditioned safely in sealed bags and disposed in a controlled way at the sanitary landfill. Similarly, the fly ash collected from flue gas cleaning is cooled down, stored in big bags and disposed in the same sanitary landfill. The DBO Contractor shall follow the APC Residue or Fly Ash Management Plan attached as Appendix 6 in this EIA report. The DBO Contractor shall update the plan accordingly during the design phase, with the condition that no requirements therein shall be relaxed or removed. Consistent with this APC Residue or Fly Ash Management Plan, the DBO Contractor's design shall consider the following for conveying and loading APC residues or fly ash:

(i) APC residues or fly ash shall not be mixed with bottom or boiler ash prior to the bottom ash treatment;
(ii) APC residues or fly ash shall be conveyed in closed conveying systems that end up in storage silos whose exhaust air can be dedusted via a central dedusting system;
(iii) The top of the bag filter housing shall be enclosed and shall be connected to the central dedusting system (while pulling/replacing bag-filter hoses);
(iv) Discharging the APC residues or fly ash from the silos into water-tight jumbo bags (with inlet) or into the transfer vehicles shall be carried out via dust-tight discharging chutes;
(v) APC residues or fly ash shall be treated by either stabilization/solidification or via triggered pozzolanic reaction prior to landfilling to limit the leachability of heavy metals;
(vi) Landfilling of contained APC residues or fly ash shall follow the standards of landfilling hazardous wastes based on EU Directive on the Landfill of Wastes[19] as discussed in Table 6.

129. **Landfill for Residual Waste Disposal**. The DBO Contractor shall ensure that the design of the residual waste landfill will be able to accommodate the volume of all generated incinerator

[19] Council Directive 1999/31/EC of 26 April 1999 on the Landfill of Waste.

bottom ash and fly ash during the entire operation of the WTE Plant, with the assumption that no bottom ash will be recycled and/or reused. The DBO Contractor will include in the design the following criteria:

(i) The landfill arrangement shall be designed to maximize the useable landfill volume of the site;
(ii) The landfill cell arrangements shall be designed to allow for the progressive closure of individual landfill cells on completion and thereby to minimize the amount of leachate requiring treatment over the lifetime of the landfill;
(iii) The design shall allow for the development of individual cells in a coherent and logical sequence and in a manner, which ensures the stability of all working faces and of the waste mound as a whole.
(iv) The design shall incorporate appropriate back-up systems in the event of failure of any component of the environmental control and management systems;
(v) The landfill concept shall be designed to minimize the lateral and vertical extent of the working face and thereby the amount of deposited waste that is exposed to the environment;
(vi) The design shall ensure that waste can be deposited in a manner that prevents damage to the engineered barrier or liner, the leachate control system, and the collection and transfer system.
(vii) The landfill design shall incorporate an internal access corridor to allow for safe traffic movement and to accommodate site services and monitoring devices;
(viii) Measures shall be provided for controlling unauthorized access to the landfill including, as appropriate, the provision of ditches, berms, planting and fencing;
(ix) Slopes shall be graded to ensure long term slope stability. Graded slopes shall be a maximum of 25%;
(x) Soil erosion and dust generation shall be minimized;
(xi) All landfill construction materials shall be free of organic matter and debris;
(xii) Measures shall be provided to monitor and manage groundwater beneath and adjacent to the landfill area.

130. With reference to the waste characteristics in Table 1, the wastes have the potential to contain hazardous substances. Therefore, both the bottom ash and fly ash may likewise contain these hazardous substances that could impact the environment if no sufficient measures are taken to contain them. In order to avoid this impact, the DBO Contractor shall design the landfill facility by applying international best practices on landfilling of hazardous wastes, such as the relevant requirements indicated in the EU Directive on the Landfill of Wastes (footnote 19). Table 6 below summarizes these requirements.

Table 6: General Requirements for Hazardous Waste Landfills

Design Parameters	**Design Considerations and Requirements**
Water control and leachate management	Appropriate measures shall be taken, with respect to the characteristics of the landfill and the meteorological conditions, in order to: (i) control water from precipitations entering into the landfill body, (ii) prevent surface water and/or groundwater from entering into the landfilled waste, (iii) collect contaminated water and leachate, (iv) treat contaminated water and leachate collected from the landfill to the appropriate standard required for their discharge following Table 13 of this EIA report.

<table>
<tr><th>Design Parameters</th><th>Design Considerations and Requirements</th></tr>
<tr><td>Protection of soil and water</td><td>
The landfill must be situated and designed so as to meet the necessary conditions for preventing pollution of the soil, groundwater or surface water and ensuring efficient collection of leachate as and when required. Protection of soil, groundwater and surface water is to be achieved by the combination of a geological barrier and a bottom liner during the operational/active phase and by the combination of a geological barrier and a bottom liner during the operational/active phase and by the combination of a geological barrier and a top liner during the passive phase/post closure.
The geological barrier is determined by geological and hydrogeological conditions below and in the vicinity of a landfill site providing sufficient attenuation capacity to prevent a potential risk to soil and groundwater.
The landfill base and sides shall consist of a mineral layer which satisfies permeability and thickness requirements with a combined effect in terms of protection of soil, groundwater and surface water at least equivalent to the one resulting from the following requirements:
- landfill for hazardous waste: $K <= 1.0 \times 10^{-9}$ m/s; thickness >= 5 m,
Where the geological barrier does not naturally meet the above conditions, it can be completed artificially and reinforced by other means giving equivalent protection. An artificially established geological barrier should be no less than 0.5 meters thick.
In addition to the geological barrier described above a leachate collection and sealing system must be added in accordance with the following principles so as to ensure that leachate accumulation at the base of the landfill is kept to a minimum.
<table>
<tr><th colspan="3">Leachate collection and bottom sealing</th></tr>
<tr><th>Landfill category</th><th>non hazardous</th><th>hazardous</th></tr>
<tr><td>Artificial sealing liner</td><td>required</td><td>required</td></tr>
<tr><td>Drainage layer ≥ 0,5 m</td><td>required</td><td>required</td></tr>
</table>
If the DBO Contractor finds that the prevention of leachate formation is necessary, a surface sealing may be prescribed. Recommendations for the surface sealing are as follows:
<table>
<tr><th>Landfill category</th><th>non hazardous</th><th>hazardous</th></tr>
<tr><td>Gas drainage layer</td><td>required</td><td>not required</td></tr>
<tr><td>Artificial sealing liner</td><td>not required</td><td>required</td></tr>
<tr><td>Impermeable mineral layer</td><td>required</td><td>required</td></tr>
<tr><td>Drainage layer > 0,5 m</td><td>required</td><td>required</td></tr>
<tr><td>Top soil cover > 1 m</td><td>required</td><td>required.</td></tr>
</table>
</td></tr>
<tr><td>Nuisances and hazards</td><td>
Measures shall be taken to minimize nuisances and hazards arising from the landfill through:
(i) emissions of odors and dust;
</td></tr>
</table>

Design Parameters	Design Considerations and Requirements
	(ii) wind-blown materials; (iii) noise and traffic; (iv) birds, vermin and insects; (v) formation and aerosols; and (vi) fires. The landfill shall be equipped so that dirt originating from the site is not dispersed onto public roads and the surrounding land.
Stability	The emplacement of waste on the site shall take place in such a way as to ensure stability of the mass of waste and associated structures, particularly in respect of avoidance of slippages. Where an artificial barrier is established it must be ascertained that the geological substratum, considering the morphology of the landfill, is sufficiently stable to prevent settlement that may cause damage to the barrier.
Barriers	The landfill shall be secured to prevent free access to the site. The gates shall be locked outside operating hours. The system of control and access to each facility should contain a program of measures to detect and discourage illegal dumping in the facility.

131. **Storm water collection system**. The Contractor's design shall include surface water and storm water collection and diversion systems in order to protect the landfill area and minimize the generation of leachate. Sedimentation ponds shall be established to contain polluted drainage and runoff containing soil and sediment.

132. **Leachate Treatment Plant (LTP)**. The DBO Contractor shall ensure that design of the LTP will also follow applicable requirements in the EU Directive on Landfill of Wastes as enumerated in Table 6 in order to prevent leachate contamination of marine water and groundwater. Consistent with these requirements, the DBO Contractor shall also include the following requirements in the design of the LTP:

(i) An acid and alkali resistant floor finish shall be provided for all sections of the leachate treatment facility that may be exposed to acid or lye;
(ii) A drainage system shall be provided to collect liquids, spills etc. that is connected to the site's sewer system;
(iii) A collection and disposal system shall be provided for reverse osmosis rinsing and flushing liquids;
(iv) The necessary IT linkage shall be made to the site's LAN and telephone network and linkage to the DCS network;
(v) The level of the engineered barrier shall be no deeper than 1.5 meters above mean sea level and in accordance with the applicable environmental standards;
(vi) The leachate collection system shall provide for the progressive installation of control measures for the management of leachate;
(vii) The design shall ensure that piping is not blocked by sedimentation, debris, algal or fungal growth and that structural integrity is maintained at all times;
(viii) The system shall be capable of dealing with the maximum leachate flow at any time during the lifespan of the landfill;
(ix) Leachate shall be treated to meet the effluent discharge standards;
(x) The design shall provide for the segregation of surface water from leachate;

(xi) The design and selection of materials for the leachate management and storage system and location of discharge point into the sea shall be discussed with, and approved by, the Maldives EPA.

(xii) The design shall provide a suitable system for the transfer of leachate from the collection system to the leachate treatment plant;

(xiii) Leachate levels shall be monitored continuously and shall be capable of being read electronically;

(xiv) The leachate treatment system shall be capable of running automatically between and above specified leachate levels and volumes;

(xv) Constructing a shed above the hazardous waste compartment, separating not contaminated water from leachate by installing gate valves, constructing bunds to control the leachate flows, etc.;

(xvi) Leachate from different compartments for APC residues and residues from the bottom ash processing are collected and treated so that the leachate discharge standards are met any time. Applying strictest discharge standards is the only way to control the APC residue disposal in the Maldives case;

(xvii) Subject to its design, re-inject the concentrate after the leachate treatment in the air pollution control system or shall evaporate it. In the latter case, the residues shall be disposed on the landfill so that no accumulation of the highly soluble material is to be concerned; and

(xviii) Monitoring wells to detect any potentially escaping leachate shall be installed.

133. All components of the leachate collection, extraction, transfer and treatment system shall be capable of being maintained in a clean condition to ensure effective operation. Concentrate may be re-injected in the flue gas treatment process of the WTE plant. The Contractor shall design and build or organize a system for the re-injection of the LTP concentrate.

134. **Wastewater Treatment Plant.** An on-site wastewater treatment plant will be provided to treat the wastewater generated from floor/vehicle washing and from staff/visitors. The treated effluent will be reused in the incineration plant or for washdown and landscape irrigation within the RWMF. Efforts will be taken so that no effluent would be discharged to the ground or sea. Should wastewater be discharged, the DBO Contractor shall ensure the design of the wastewater treatment plant will comply with the effluent standards in Section III hereof.

C. Project Layout Arrangement

135. The RWMF has been designed to provide long term environmentally sustainable solution for waste management in Project area of the Maldives. Limitations and scarcity of land and the requirement to protect the fragile eco-system have also been considered during the design of RWMF. With a view to minimize the land use and the associated environmental impacts, the preferred location for the WTE Plant was the area adjacent the old dumpsite of Thilafushi. This has the advantage to reduce environmental risks on another location and islands . The vocation of Thilafushi as an industrial island plays also in favor of a site location of the facility on this island.

136. The layout for the WTE Plant is considered appropriate, taking into consideration the functional need for operation of the WTE Plant, reasonable flexibility in design for the DBO contractor and allowance of suitable size of land for provision for the future. The design of the WTE Plant has been done considering factors such as waste composition, quantity reaching the WTE Plant, applicability in the local condition and regulatory compliance. Based on the proposed layouts, the footprint requirement for treating per tonnage of MSW daily is approximately 32 m^2. The area for coastal protection, waste receiving area were excluded in the unit footprint

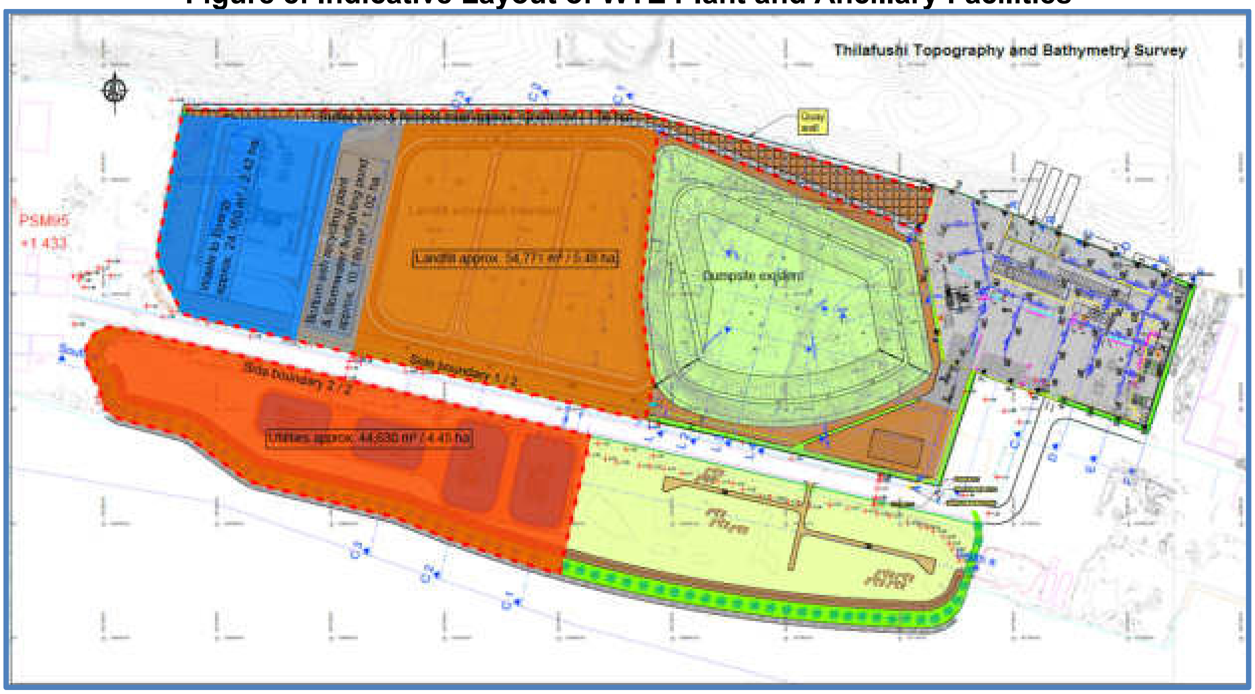
calculation. A larger footprint requirement at the RWMF at Thilafushi is due to the additional land required for the berth area.

137. The unit footprint requirement of the RWMF is comparable with other overseas incineration plants, including:

(i) The Afval Energie Bedrijf (AEB) Incineration Plant with design capacity of 4,000 TPD in the Netherlands;
(ii) The RWMF at the Tsang Tsui Ash Lagoons site with a design capacity of 3,000 TPD in Hong Kong, China; and
(iii) The Tokyo Edogawa Incineration Plant with design capacity of 600 TPD in Japan.

138. Based on the layout of existing overseas installations, the footprint requirement for treating per tonnage of MSW daily is normally in the range of 30m² to 40m². Figure 8 below shows the indicative layout arrangement of the WTE Plant and ancillary facilities.

Figure 8: Indicative Layout of WTE Plant and Ancillary Facilities



D. Bottom Ash Reuse and Disposal

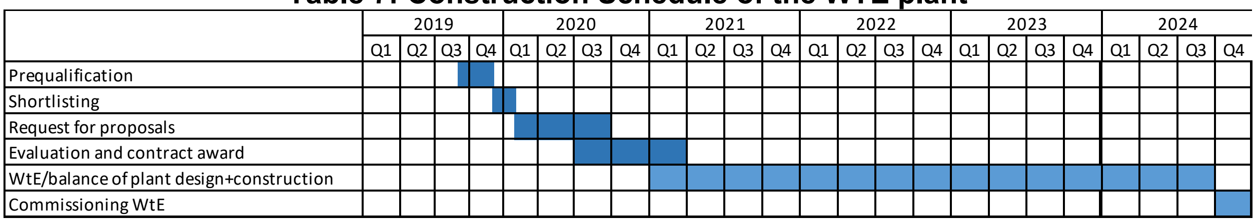
139. The primary residual wastes from the WTE Plant are the incinerator bottom ash, slag and the residues from flue gas cleaning. The bottom ash may be used as raw material in the general construction industry. Because of the land area constraints in the Maldives, the DBO Contractor shall process bottom ash to marketable products to the highest possible extent and thus shall minimize the volume of waste from the incineration process to be disposed of in the residue landfill.

140. From the commissioned study on the reuse of treated bottom ash, there is a considerable potential to use treated bottom ash as aggregate for non-structural concrete. The processed bottom ash and recovered metals will be marketed and sold by WAMCO.

E. Construction Schedule

141. The tentative construction schedule for the WTE plant is shown in Table 7. The conceptual design of the facility as per feasibility study level and the Employer's requirements has been developed. A prequalification stage has shortlisted qualified bidders (with experience in successfully implementing and managing WTE plants of similar scope and complexity), which was completed in January 2020. The invitation for bids was issued in February 2020 to pre-qualified bidders and the bid submission deadline is in September 2020. The design and commissioning period includes all necessary permitting applications and the relevant approvals. Permitting is expected to last 6 months. Contract award is scheduled by early 2021 and commissioning of the works by end-2024.

Table 7: Construction Schedule of the WTE plant



III. POLICY, LEGAL AND ADMINISTRATIVE FRAMEWORK

F. ADB Safeguard Policy Statement

1. Screening and categorization

142. The nature of the environmental assessment required for a project depends on the significance of its environmental impacts, which are related to the type and location of the project; the sensitivity, scale, nature, and magnitude of its potential impacts; and the availability of cost-effective mitigation measures. Projects are screened for their expected environmental impacts, and are assigned to one of the following four categories:

(i) **Category A**. A proposed project is classified as category A if it is likely to have significant adverse environmental impacts that are irreversible, diverse, or unprecedented. These impacts may affect an area larger than the sites or facilities subject to physical works. An environmental impact assessment (EIA) is required;

(ii) **Category B**. A proposed project is classified as category B if its potential adverse environmental impacts are less adverse than those of category A projects. These impacts are site-specific, few if any of them are irreversible, and in most cases mitigation measures can be designed more readily than for category A projects. An IEE is required;

(iii) **Category C**. A proposed project is classified as category C if it is likely to have minimal or no adverse environmental impacts. No environmental assessment is required although environmental implications need to be reviewed; and

(iv) **Category FI**. A proposed project is classified as category FI if it involves investment of ADB funds to or through a financial intermediary (FI). The FI must apply an environmental management system, unless all projects will result in insignificant impacts.

2. Environmental Management Plan

143. An environmental management plan (EMP), which addresses the potential impacts and risks identified by the environmental assessment, shall be prepared. The level of detail and complexity of the EMP and the priority of the identified measures and actions will be commensurate with the project's impact and risks.

3. Public disclosure

144. ADB will post the following safeguard documents on its website so affected people, other stakeholders, and the general public can provide meaningful inputs into the project design and implementation[20]:

(i) for Environmental Category A projects, a draft EIA report at least 120 days before Board consideration;
(ii) final or updated EIA and/or IEE upon receipt; and
(iii) environmental monitoring reports submitted by the project management unit (PMU) during project implementation upon receipt.

4. Pollution Prevention and Control Technologies

145. During the design, construction, and operation of the project the PMU through the DBO Contractor will apply pollution prevention and control technologies and practices consistent with international good practice, as reflected in internationally recognized standards such as the World Bank Group's Environment, Health and Safety Guidelines, and Annex VI of Directive 2010/75/EU of the European Parliament and the Council. These standards contain performance levels and measures that are normally acceptable and applicable to projects. When the Government of Maldives regulations differ from these levels and measures, the executing agency will achieve whichever is more stringent. If less stringent levels or measures are appropriate in view of specific project circumstances, the executing agency will provide full and detailed justification for any proposed alternatives that are consistent with the requirements presented in ADB SPS 2009.

G. National Environmental Impact Assessment Law and Regulation

146. Responsibilities and procedures for conducting environmental assessments, together with the requirements for environmental monitoring of projects, are set out in the EIA Regulations of 2012. All projects that may have an impact on the environment are referred to the Maldives EPA.

147. The EIA Regulations assign primary responsibility for undertaking environmental assessment of projects to the project proponent and set out procedures, rights and responsibilities for the preparation and approval of EIAs. The Maldives EPA undertakes review and approval of environmental assessment reports.

148. Project proponent is defined in the EIA regulations as a person, department or agency that is seeking to carry out or proposing to carry out development projects. The EIA regulations include a schedule (Schedule D) of investment project types that require an EIA. Examples of these projects are waste management projects such as landfills, waste incinerators and large-

[20] As per ADB SPS, 2009, prior to disclosure on ADB website, ADB reviews the "borrower's/client's social and environmental assessment and plans to ensure that safeguard measures are in place to avoid, wherever possible, and minimize, mitigate, and compensate for adverse social and environmental impacts in compliance with ADB's safeguard policy principles and Safeguard Requirements 1-4."

scale waste storage projects. Therefore, the WTE plant project that is subject of this EIA also requires an approval of the EIA by the Government of Maldives, through the Maldives EPA.

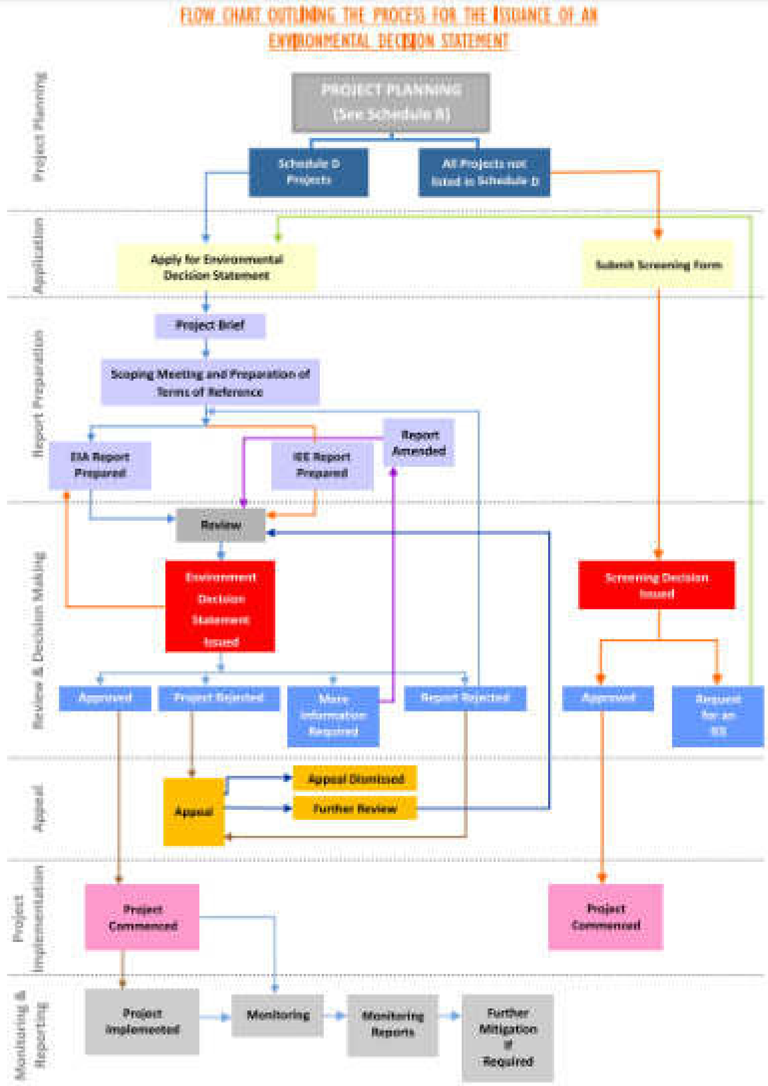
149. The EMP, following the EIA process, is prepared on a specified format and reviewed for compliance by Maldives EPA.

150. The Maldives EPA issues the decision in the form of a decision note issued to the proponent, which sets out specific binding requirements for the conduct of the project on the basis of review of the EIA report.

1. 151. Summary of application stages and steps is outlined in

Figure 9 below.

Figure 9: Flow Chart of Maldives Environmental Impact Assessment Process[21]



H. Issuance of Environmental Decision Statement under the National EIA Law

152. The timelines for clearance and approvals are as follows:

- (i) On completion of a screening form for non-schedule D projects – 10 working days for a screening decision from Maldives EPA;
- (ii) For review of compliance of an EMP by Maldives EPA – 7 working days;
- (iii) For review of a project brief on Schedule D projects – 5 days to confirm the date of a scoping meeting;
- (iv) For consideration of Terms of Reference drafted by the project proponent following the scoping meeting – 10 days to confirm the Terms of Reference;
- (v) For the review of a completed EIA report for completeness – 2 working days;
- (vi) For circulation of an EIA report to other ministries and to the public for comment – 10 working days; and

[21] Source: Environmental Assessment Regulations (2007), Schedule A.

(vii) For issuance of a decision or to request revisions, following circulation of the EIA report and receipt of comments – 28 working days.

I. Applicable Environmental Standards

153. The government of Maldives does not have regulations on emission standards for Waste-to-Energy (WTE) facilities or any other similar infrastructure projects. Following requirements of ADB SPS, the project shall apply pollution prevention and control technologies and practices consistent with international good practices. While the project will be awarded under a DBO contract, preliminary design has been prepared following the European Union (EU) standards and practices. These preliminary designs are included in the draft DBO contract documents. Consistent with the basis of the preliminary design, the project will likewise comply with the applicable emission standards as indicated in the Directive 2010/75/EU of the European Parliament and the Council on industrial emissions (the EU Industrial Emissions Directive or EU IED). Table 8 below shows the standards that will be followed by the project as lifted from the EU IED. If less stringent levels or measures are appropriate in view of practicality or specific project circumstances, the government of Maldives will provide full and detailed justification for any proposed alternatives that are consistent with the requirements presented in ADB SPS.

Table 8: Applicable Emission Standards for the Project

Parameter	Averaging Time	Applicable to the Project (EU IED[a])
Total Suspended particulates (PM_{10}), mg/m³	24 – hour	10
Sulfur Dioxide (SO_2), mg/m³	24 – hour	50
Oxides of Nitrogen (NO_x), mg/m³	24 – hour	200 – 400
Hydrochloric Acid (HCl), mg/m³		10
Dioxins and furans, ng TEQ/m³	6 – 8 - hour	0.1
Cadmium, mg/m³	0.5 – 8 - hour	0.05 – 0.1
Carbon Monoxide (CO), mg/m³		50 – 150
Mercury (Hg), mg/m³	0.5 – 8 - hour	0.05 – 0.1
Hydrogen Fluoride (HF), mg/m³		1
Sum of heavy metals and their compounds as Antimony, Arsenic, Lead, Chromium, Cobalt, Copper, Manganese, Nickel, Vanadium, Tin, Zinc, mg/m³	Between 30 min. and 120 min.	0.5
Cadmium/Thallium and compounds expressed as Thallium/Cadmium, mg/m³	Between 30 min. and 120 min.	0.05
Arsenic/Cadmium and their compounds (As and Cd), Benz(a)pyrene, water soluble Cobalt compound (as Co), Cr(Vi) compounds as Cr, mg/m³	Between 30 min. and 120 min.	0.05

[a] All values are related to 11% oxygen.

154. Similarly, the project shall monitor the ambient air quality and noise levels around the project sites during construction and operation phases. Sampling locations and the baseline information over which results will be compared are discussed in this EIA report. If less stringent levels or measures are appropriate in view of practicality or specific project circumstances, the government of Maldives will provide full and detailed justification for any proposed alternatives that are consistent with the requirements presented in ADB SPS. Table 9 and Table 10 below show the applicable ambient air quality standards and noise level standards to be followed under the project.

Table 9: Applicable Ambient Air Quality Standards for the Project

Parameter	Maldives Ambient Air Quality Standard ($\mu g/m^3$)[a]	Averaging Time	WHO Air Quality Guidelines ($\mu g/m^3$) Global Update[b] 2005	Applicable Per ADB SPS[c] ($\mu g/m^3$)
PM_{10}, $\mu g/m^3$	-	24 – hour	50	50
PM_{10}, $\mu g/m^3$	-	1 – year	20	20
$PM_{2.5}$, $\mu g/m^3$	-	24 – hour	25	25
$PM_{2.5}$, $\mu g/m^3$	-	1 – year	10	10
SO_2, $\mu g/m^3$	-	10 – min	500	500
SO_2, $\mu g/m^3$	-	24 – hour	20	20
NO_2, $\mu g/m^3$	-	1 – hour	200	200
NO_2, $\mu g/m^3$	-	1 – year	40	40
Ozone (O_3), $\mu g/m^3$	-	8 – hour	100	100

[a] Maldives currently does not have national ambient air quality standards set.
[b] WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. *Global update 2005*. WHO. 2006
[c] Per ADB SPS, the government shall achieve whichever of the ambient air quality standards is more stringent. If less stringent levels or measures are appropriate in view of specific project circumstances, the executing agency of the government will provide full and detailed justification for any proposed alternatives that are consistent with the requirements presented in ADB SPS.

Table 10: Applicable Ambient Noise Level Standards for the Project

Receptor/ Source	Maldives National Noise Level Standards[a] (dBA)		WHO Guidelines Value For Noise Levels Measured Out of Doors[b] (One Hour LA_q in dBA)		Applicable Per ADB SPS[c] (dBA)	
	Day	Night	07:00 – 22:00	22:00 – 07:00	Day time	Night time
Residential, institutional, educational	-	-	55	45	55	45
Industrial, commercial	-	-	70	70	70	70

[a] Maldives currently does not have noise level standards.
[b] Guidelines for Community Noise. WHO. 1999
[c] Per ADB SPS, the government shall achieve whichever of the ambient air quality standards is more stringent. If less stringent levels or measures are appropriate in view of specific project circumstances, the executing agency of the government will provide full and detailed justification for any proposed alternatives that are consistent with the requirements presented in ADB SPS.

155. In view of the need to provide safe drinking water to its workers during construction and operation phase, the project will ensure that drinking water made available complies with the applicable drinking water quality standards. Table 11 below shows the standards to be followed under the project.

Table 11: Applicable Drinking Water Quality Standards for the Project

Group	National Standards for Drinking Water[a]			WHO Guidelines for Drinking-Water Quality, 4th Edition, 2011[b]	Applicable Per ADB SPS[c]
	Parameter	Unit	Standard		
Physical	Turbidity	NTU	<1	-	<1
	pH		6.5 to 8.5	none	6.5 – 8.5
	Color		Clear and	none	Clear and

Group	National Standards for Drinking Water[a]			WHO Guidelines for Drinking-Water Quality, 4th Edition, 2011[b]	Applicable Per ADB SPS [c]
	Parameter	**Unit**	**Standard**		
			colorless		colorless
	Taste and Odor		-	-	-
	Electrical conductivity	µs/cm	<1,000	-	<1,000
	TDS	mg/l	<500	-	<500
	Suspended Solids	mg/l	5 – 750	-	5 – 750
Chemical	Iron	mg/l	<0.3	-	<0.3
	Manganese	mg/l	0.1	-	0.1
	Arsenic	mg/l	<0.01	0.01	<0.01
	Boron	mg/l	<0.3	-	<0.3
	Bromine	mg/l	0.05 – 4.50	-	0.05 – 4.50
	Cadmium	mg/l	<0.003	0.003	<0.003
	Chromium	mg/l	<0.05	0.05	<0.05
	Cyanide	mg/l	<0.07	-	<0.07
	Fluoride	mg/l	<1.5	1.5	<1.5
	Hydrogen Sulfide	mg/l	0.05	-	0.05
	Lead	mg/l	<0.01	0.01	<0.01
	Phosphate	mg/l	<5	-	<5
	Potassium	mg/l	0 - 50	-	0 - 50
	Ammonia	mg/l	<0.02 – 2.50	none established	<0.02 – 2.50
	Chloride	mg/l	<200	none established	<200
	Sulphate	mg/l	<250	none	<250
	Nitrate	mg/l	<50	50	<50
	Copper	mg/l	<2.0	2	<2.0
	Total Hardness	mg/l	<75	-	<75
	Calcium Hardness	mg/l	<60	-	<60
	Mercury	mg/l	<0.001	0.006	<0.001
	Free Chlorine	mg/l	0.04 – 0.2	-	0.04 – 0.2
	Anionic detergents	mg/l	0.002 – 0.275	-	0.002 – 0.275
	Phenolic compounds	mg/l	0.002 – 0.2	-	0.002 – 0.2
	Sodium	mg/l	<200	-	<200
	Total petroleum hydrocarbon	mg/l	0	-	0
Microbiological	Total coliform	Counts per 100ml CFU	0	-	0
	Fecal coliform	Counts per 100ml CFU	0	-	0
	Enterococci	Counts per 100ml CFU	0	-	0
	Salmonella Typhi	Counts per 100ml CFU	0	-	0

Group	National Standards for Drinking Water[a]			WHO Guidelines for Drinking-Water Quality, 4th Edition, 2011[b]	Applicable Per ADB SPS [c]
	Parameter	Unit	Standard		
	Shigella spp.	Counts per 100ml CFU	0	-	0
	Vibrio Cholerae	Counts per 100ml CFU	0	-	0

[a] Maldives Environmental Protection Agency Supply Quality Standard
[b] Health-based guideline values.
[c] Per ADB SPS, the government shall achieve whichever of the ambient air quality standards is more stringent. If less stringent levels or measures are appropriate in view of specific project circumstances, the executing agency of the government will provide full and detailed justification for any proposed alternatives that are consistent with the requirements presented in ADB SPS.

156. For any wastewater generated and discharged during construction and operation phases, the project will ensure that the effluent will comply with the effluent standards as shown in Table 12 and Table 13 below, or other set of standards that may be stricter than the standards set in these tables and confirmed by the Maldives EPA.

Table 12: The maximum permissible concentrations of pollutants discharged from the WTE leachate treatment plant into the environment

Parameters		unit	Limit
Chemical Oxygen demand	COD	mg/l	200
Biological Oxygen demand	BOD_5	mg/l	20
Total Inorganic Nitrogen	$N_{tot, inorg}$	mg/l	70
Nitrite	NO_2-N	mg/l	2
Sulfide	S	mg/l	1
Total Phosphate	P_{tot}	mg/l	3
Lead	Pb	mg/l	0.5
Cadmium	Cd	mg/l	0.05
Total Chromium	Cr	mg/l	0.5
Chromium (VI)	Cr VI	mg/l	0.1
Mercury (total)	Hg	mg/l	0.02
Nickel	Ni	mg/l	1
Zinc	Zn	mg/l	2
Copper	Cu	mg/l	0.5
Arsenic	As	mg/l	0.1
Conductivity at 25°C*	-	µS/ cm	2,500

*used to monitor the performance of the leachate treatment plant only

Table 13:The maximum permissible concentrations of pollutants discharged from the WTE wastewater treatment plant into the environment

Parameters		unit	Threshold Value
Chemical Oxygen demand	COD	mg/l	150
Biological Oxygen demand	BOD_5	mg/l	40
Suspended Solids	-	mg/l	100
Ammonia-N	NH4	mg/l	15
Total N	N	mg/l	30
N-hexane extract (mineral oils, grease)	-	mg/l	10

J. Other Relevant National Laws and Regulations

Name of Legislation	Area	Relevant to the Project?	Details
Environmental Protection and Preservation Act (1993, Law 4/93)	Generally covering the Environment	Yes	Clause 5a states that an impact assessment study shall be submitted to the Ministry of Environment and Energy, Energy and Water before implementing any development project that may have a potentially detrimental impact on the environment. Therefore, Clause 5 is of specific relevance to this EIA. The EIA Regulation (2012), which came into force in May 2012 has been developed by the powers vested by the Environmental Protection and Preservation Act (1993). This EIA has also been prepared accordance with the guidance provided in the EIA Regulations (2012/R-27). This EIA will follow the environmental management aspects stated in the Environment Act 4/93 by ensuring that the Environmental Management Plan and proposed mitigation measures will enable the project from incurring any undesirable impacts on the environment.
EIA Regulation (2012/R-27)	Environment	Yes	The EIA Regulation (2012/R-27) guides the process of undertaking the EIA in the Maldives. The regulation provides detailed guidelines outlining the EIA process, including the roles and responsibilities of consultant and the proponent. It outlines every step of the EIA process beginning from EIA application to undertaking an EIA, it details the contents, minimum requirements for consultants undertaking the EIA, format of the EIA/IEE report. The Ministry of Environment and Energy has issued 3 amendments to this regulation over the past years, as follows: Amendment 1 (issued on 9th April 2013) covers the fines for proponents who fail to obey the regulation 2012/R-27. Amendment 2 (issued on 30th August 2015) covers the EIA report review criteria and review fees. This amendment also includes the latest update to the list of the projects that require EIA and the latest update to the list of the projects that do not require EIA. Amendment 3 (issued on 11th August 2016) covers the point systems for consultants, categories of the consultants and amendment of the penalties to consultants and proponents who fail to follow the regulation. This EIA is prepared in order to comply with the EIA Regulation (2012/R-27), as the regulation specifies the need for EIA clearance for waste management projects before the commencement of physical work. The guidance provided in this Regulation and its amendments

			was followed in the preparation of this EIA report. The EIA has also been prepared by registered EIA consultants at Maldives EPA.
Waste Management Regulations (2013/R-58)	Environment	Yes	The Ministry of Environment and Energy implements a Waste Management Regulation to minimize the impact of waste on the natural environment of the Maldives. The purpose of this regulation is to implement national policies regarding waste management. In this regard this regulation shall implement these policies to conserve the environment by: minimizing the direct and indirect negative impact caused to human health and the environment due to waste; compiling the standards to be maintained in relation to waste management; establishing an environmentally friendly, safe and sustainable waste management system through an integrated waste management structure; encouraging the public to minimize, reuse, recycle and recover waste; implementing the "polluter pays" principle and introducing extended producer responsibility. This project will conform to this law. The waste produced from the initial site preparation works will be managed according to the waste regulation. The waste generated from the project site will be temporarily stored in a designated area and will be transported to the Thilafushi waste management area for final treatment and disposal.
Protected and Sensitive Areas	Environment	Yes	Under Article 4 of the Environment Protection and Preservation Act, the Ministry of Environment and Energy has vested responsibility for identifying and registering protected areas and natural reserves and for drawing up of rules and regulations for their protection and preservation. As part of the Environmental Regulation, the Maldives EPA has established a list of 'sensitive sites' in the Maldives. Although not formalized as a regulation, the list is mentioned in the Regulation on Dredging and Reclamation (Regulation number 2014/R-13, see Section 5.7, page34). The sensitive sites, according to the Maldives EPA, are sites in the Maldives (islands, reefs, mangroves, inter-tidal areas) where developments ought to be restricted, regulated or controlled. This project does not fall to a boundary of a protected area or an area on the Maldives EPA list of 'sensitive sites'. However, there are MPAs within 10km radius of the project site. These sites are detailed in the existing environment section of the EIA report.
Environmental Liability Regulation (on 2011/R-9)	Environment	Yes	The Environmental Liability Regulation covers a wide range of issues which enable charging of penalties and providing compensation by polluters in accordance with the Maldives EPA. The regulation came into effect in order to ensure that any developmental activities

			conducted will ensure the protection of the environment as well as sustainable development. The regulation also ensures that the surrounding environment is not degraded or deteriorated, and any natural resources are not wasted during said developmental activities. The project activities will be carried out according to the Environment Management Plan with proposed mitigation measures to ensure that the proposed project complies with the Environmental Liability Regulation. Since the EIA forms an integral part of the civil works and operations contracts, the respective parties shall be aware that Environmental Liability Regulation will be applied in instances where damage to the environment is caused.
Guidelines & Action Plans			
Post EIA Monitoring, Auditing and Evaluation	Environment	Yes	The environmental monitoring program has been recommended in the EIA. The monitoring program outlines the objectives of the monitoring; the specific information to be collected; the data collection program and managing the monitoring program. Managing the monitoring program requires assigning institutional responsibility, reporting requirements, enforcement capability, and ensuring that adequate resources are provided in terms of funds, skilled staff, etc. The environmental monitoring program outlined in this report has been developed to comply with the EIA Regulations 2012/R-27.
Waste Incineration Guidelines (Draft 2019)	Environment, Waste Management	Yes (but the guideline is still in draft stage)	This guideline has been drafted by the Environmental Protection Agency (EPA) of the Maldives to facilitate the construction and operation of waste incinerators safely and to mitigate the adverse environmental and health impacts that may arise. This guideline applies to all kinds of waste incinerators and will assist the managers and operators. The guideline discusses four main components (Site selection, emission control, wastewater management and waste management) for the environmental considerations. The site selection for waste incinerators must be selected in a way that would not pose a threat to the surrounding environment and the local community. This guideline sets a minimum buffer distance of 60m from sensitive land uses such as residential use, schools and hospital. It also states that a minimum distance of 30m shall be kept between the vegetation line and the incinerator. The operator of the waste incineration facility must ensure that air emission levels are maintained below the values which is provided in the guidelines covering dust, VOC, HCl, HF, SO2, NOx, CO, Cd and TI, Hg and Dioxins.

			The draft guideline states that Wastewater from the incinerator must be discharged according to the standards set by Maldives EPA. Management of general waste management in the waste incinerator facilities must follow the standards set by Waste Management Regulation 2013/R-58. The guideline sets the procedures for ash management (fly ash and bottom ash) as well as health and safety considerations, monitoring and control systems as well as contingency plans.
National Water and Sewerage Policy (2017)	Environment	Yes	The National Water and Sewerage Policy focuses on providing access to safe water and sewerage services for all. The NWSP has 9 goals: ensure access to safe water supply and adequate sewerage services; adopting cost-effective, environment friendly and appropriate technologies; strengthening legal framework; encouraging private sector investments; building institutional capacity; maintaining financial and environmental sustainability; strengthening advocacy and awareness; promoting research and development; and protection and conservation of water resources. Policy objective 9: calls for adopting a holistic approach to water resources protection, conservation, management, and pollution control. Among the strategies for objective 9 are: establishing an effective research-based monitoring program and information platform for inhabited islands' water resources; developing and implementing evidence-based water resources management plans taking into consideration the sustainability and vulnerability of the island fresh water resources, wastewater reclamation, water reuse and minimization of impacts from pollution.
National Biodiversity Strategy and Action Plan (2016)	Environment	Yes	The National Biodiversity Strategy and Action Plan (NBSAP) 2016-2025 is a 10-year plan and is designed to address the following 6 broad areas of concern by setting a strategy with targets. Strategy 1 – Strengthen governance, policies and strategies for biodiversity Strategy 2 – Enhancing communication and outreach through awareness programs and capacity building Strategy 3 – Work together globally for biodiversity conservation Strategy 4 – Ensure sustainable use of biological resources Strategy 5 – Address threats to conserve biodiversity Strategy 6 – Strengthen information management and resource mobilization The 3 basic principles of the National Biodiversity Strategy and Action Plan 2016-2015 are

			The people of this generation and the generations to come reserves the right to access and share benefits of rich biodiversity and ecosystem service; Responsibility for conserving and sustainable using biodiversity lies on everyone's shoulders and shall be taken as a shared responsibility; Biodiversity shall be mainstreamed into all sectors and in a manner whereby monitoring progress and accountability ensured. The EIA report has considered the six strategies stipulated in the NBSAP. In implementing the proposed project activities, due care should be given to ensure that the national biodiversity strategies are adhered to. The proponent has committed to protection of the environment by minimizing the impact of the natural environment while undertaking the proposed project. More specifically, the coral reef and generally the marine environment have been assessed in order to provide baseline information. Quantitative and qualitative surveys were undertaken to assess the biological diversity of the marine environment, especially in close proximity to the proposed project area. Practical mitigation measures have been identified to protect the marine biodiversity around the proposed project area.
Third National Environment Action Plan (2009)	Environment	Yes	The Third National Environment Action Plan (NEAP 3) is divided into principles, outcomes and goals to achieve the results. Principles prescribed in NEAP 3, which have been incorporated into this EIA exercise include local democracy, informed decision making, continuous learning and improvement, the right to information and participation and most importantly the complementing role of environmental protection in socio-economic development. The proposed project is expected to provide a learning experience in terms of effectiveness of the use of EIA as a planning instrument and appropriate monitoring for which specific focus is laid in Objective 24.1 of NEAP 3 (Ministry of Housing, Transport and Environment, 2009). By undertaking EIA prior to developmental projects, it ensures that environmental impacts from the project activities are minimized or avoided. This project is aiming to address the national waste management issue by facilitating the establishment of Regional Waste Management Facility for Project area covering the islands in the central region of the Maldives.
Maldives Climate Change Policy Framework (2015)	Climate change	Yes	The Maldives Climate Change Policy is a framework to address the climate change issues in the Maldives. It aims to adopt and mitigate the current and future effects of climate change. The policy recognizes climate change as a central player in sustainable development. The

			policy is based on a set of principles to guide related activities that take into account national laws, national development plans, strategies, action plans, policies and relevant documents. The policy has been guided by eight principles: climate leadership, intergenerational equitability, mainstreaming climate change, relevant international commitments, multinational partnerships, transfer of technology and climate resiliency. The proposed project is an adaptation project to improve the resilience of the reef environment through better management of waste in the islands of the Maldives.
Maldives Marine Monitoring Standards issued by EPA.	Marine water quality	Yes	This guideline would be used as a standard to measure the ambient condition to monitor the condition of the marine water quality against the established baseline.
Australian and New Zealand Guidelines for Fresh and Marine Water Quality	Sediments	For comparison purpose	Traces of heavy metals and organometallics in the marine sediments would be compared with the Australian and New Zealand Guidelines for Fresh and Marine Water Quality which quote maximum guideline concentrations for contaminants in freshwater and marine sediments for reference purpose. The traces of heavy metals in the sediments sampled in the post EIA monitoring activities will be compared with that of the baseline which has been established in the EIA process.
Permits			
EIA Decision Statement	Environment	Yes	In order to commence work on the project, the proponent requires to obtain the EIA Decision Statement issued by Maldives EPA following evaluation of this EIA. The EIA Decision Statement is prepared based on the information presented in this EIA report particularly the mitigation measures provided to prevent or reduce the potential environmental impacts. In addition, the monitoring requirements of the project are enforced in the EIA Decision Statement.
Dewatering Permit	Ground water	Yes	A dewatering permit is required for the project during excavation works. A separate application will have to be made to the Maldives EPA to get the permit. Permission can be granted for dewatering at a stretch for a maximum of 28 days, for which a sum of Rf500 should be paid per day. This amount is liable to be increased with the number of days increased.
Dredging and Reclamation Permit	Coastal modification	Yes	Prior to any coastal work that requires dredging or reclamation, a special permit has to be taken from the Maldives EPA. A specific form published by Maldives EPA has to be completed and submitted for the approval. EIA application form will only be accepted when the form is submitted with the costal modification approval given by Maldives EPA in writing.

Registration of Desalination Plants	Desalination plant	Yes	According to Desalination Regulation of the Maldives, all desalination plants operating in the Maldives catering for public water supplies and commercial purposes would have to be registered with Maldives Environmental Protection Agency (EPA) former Maldives Water and Sanitation Authority (MWSA). Therefore, the desalination plants to be installed for the project would have to be registered with Maldives EPA. For this, the Proponent will be required to submit the EIA Decision Note for this EIA report, completed application forms with all details of the plant to be registered. A copy of the relevant section of this EIA may be appended to the forms as justification for the desalination plants.

K. Applicable International Environmental Agreements

157. In addition to national laws, rules and regulations, the government of Maldives is also a signatory to various applicable international conventions. Those applicable to the project as a waste facility in a coastal area, are those relating to environmental pollution and biosafety, as follows:

(i) International Convention for the Prevention of Pollution of the Sea by Oil (1982);
(ii) Vienna Convention for the Protection of the Ozone Layer (1985);
(iii) Montreal Protocol on Substances that Deplete the Ozone Layer (1987);
(iv) Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and their Disposal (1989);
(v) The London Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer (1990);
(vi) Convention on Biological Diversity (1992);
(vii) United Nations Framework Convention on Climate Change (1992);
(viii) The Copenhagen Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer (1992);
(ix) The Montreal Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer (1997);
(x) The Beijing Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer (1999);
(xi) Washington Declaration on Protection of the Marine Environment from Land-Based Activities;
(xii) Kyoto Protocol to the United Nations Framework Convention on Climate Change (1998); and
(xiii) Cartagena Protocol on Biosafety (Maldives acceded on 2 September 2002).

IV. ANALYSIS OF ALTERNATIVES

158. ADB SPS requires projects with potential significant adverse environmental impacts to undertake analysis of alternatives. This step will ensure all reasonable alternatives or options are taken into account, including the effect of a no project option scenario, and that these are examined with an eye towards minimizing impacts to the environment and allowing decision makers to choose the best alternatives to protect and enhance environmental quality. Alternatives include project redesign, alternative sites, and alternative technologies and construction techniques.

159. This section presents all the alternatives considered under the project that led to the selection of design as discussed in Section III. As the project will be implemented under a DBO arrangement, specific details of project components are expected to be decided upon by the contractor during the detailed design stage. However, alternatives assessed and recommended or selected in this EIA shall be used and will be made binding to the contractor through relevant provisions in the DBO contract documents.

A. No Project Option

160. It should be noted that the **"no project" option** cannot be excluded without proper evaluation. In this report this alternative was considered as the baseline against which to evaluate the other options. The no project option takes the following into consideration:

(i) Continue current dumping of waste as a method to manage waste in Thilafushi;
(ii) Cost related to the project activities will be avoided;
(iii) Further environmental damage to the proposed area will be avoided; and
(iv) Existing public frustration will continue to worsen due to lack of proper waste management system in Thilafushi.

161. The main advantages and disadvantages of the no-project option are given in **Table 14**.

Table 14: Advantages and disadvantages of the no project option

Strategy	Advantages	Disadvantages
Carrying out the waste management practice in Thilafushi without establishment of a Regional Waste Management Facility for Project area	Costs related to improving the situation may be avoided in the short term. Environmental problems related to development can be avoided	Long term social problems may arise due to unacceptable manner of waste management in the island. Higher long-term costs to fix and maintain the existing waste dump site in Thilafushi, especially if the island will continue to accept and manage wastes generated in Project area.
Improving waste management using existing land in Thilafushi	Short term costs associated with the project may be avoided	Existing site does not have infrastructure to develop a proper waste management and disposal facility. The existing problems for the management of waste may worsen. Option will not address current concerns adequately, and public frustrations and anger may prevail in time.

162. In view of the current status of the waste issue in Thilafushi, it is evident that the waste management practice in the island needs urgent actions. The small islands in Project area are now suffering from serious environmental and human health impacts due to inefficient waste disposal system. Apart from being a priority of the government, the option to develop a better waste management system in Project area is highly justified in order to address the worsening waste management scheme in the region, more particularly in the small island communities. On this basis, the positive benefits of establishing a proper waste management facility that will cater to the atolls or islands in the central region of the Maldives clearly outweighs the financial, environmental and social implications. Therefore, the “no project” option is not recommended.

163. According to the findings and recommendations of the site selection and technology selection processes, including the construction and operation requirements, the scope of the project in Thilafushi has been developed. It should be noted that in addition to the consideration of alternative site and technology for the development of the WTE Plant, the following alternatives have been considered in the study in arriving at the preferred scope of the project.

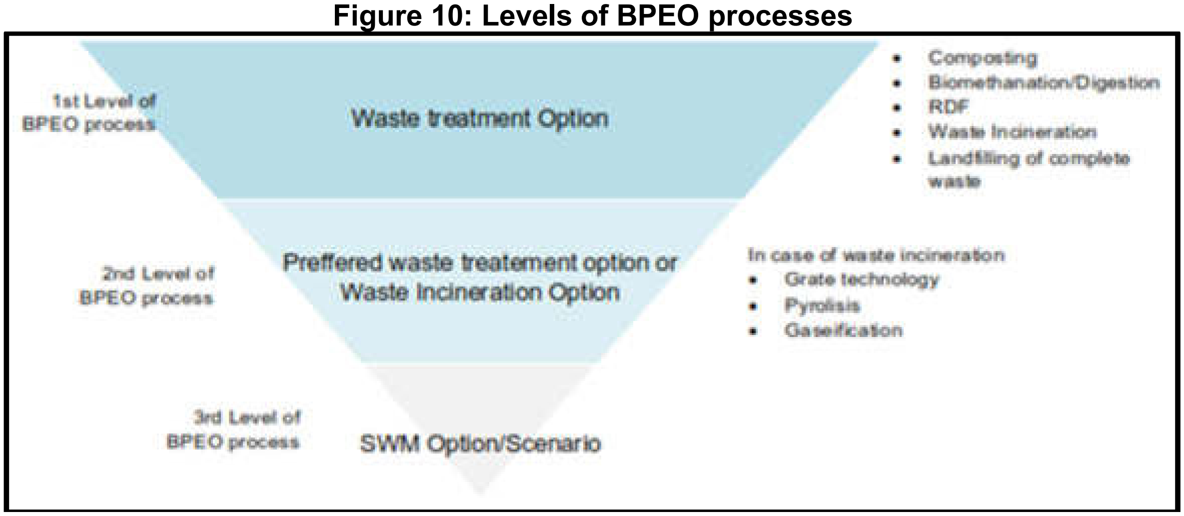
B. Alternative Options for the Management of Waste

164. Feasibility Study for an Integrated Solid Waste Management System for Project area (including Greater Malé) and Design of the Regional Waste Management Facility at Thilafushi (2018) for selection of the most appropriate waste management option has been conducted using a screening and selection process known as the Best Practicable Environmental Option (BPEO).

165. BPEO entails a systematic and balanced assessment of different waste disposal options, to identify the option which provides maximum environment, economic and social benefit. A BPEO process involves a process of identifying viable scenarios for waste management, followed by a process of performance assessing against a number of decision criteria such as technical, environment, social and financial/economic to determine which scenario is the preferred option. The BPEO concept has been outlined in the "National Solid Waste Management Policy for the Republic of Maldives" and has been identified as "one of the strategic principles for development of waste management systems in the country".

166. BPEO is a strategic rather than site-specific tool, hence it does not address the site-specific issues associated with individual locations and it cannot justify the selection of particular site for individual facilities. The BPEO approach implicitly recognizes that the preferred option may differ from location to location because of variation in the local needs, resources and impact and in relative significance of criteria. Nevertheless, because of the nature of analysis required, the concept is not sufficiently precise to be used to justify the selection of specific sites, but is appropriate to use in conjunction with the broad area of research. The geographical, social and cultural context in the Maldives makes the search for options and scenarios more complex while due to its unicity there is not similar cases which could be transferred from other countries in the region.

Figure 10: Levels of BPEO processes



167. The first level is focused on the different treatment technologies in the SWM. Objective is to reduce the number of technologies to a reasonable level in order to develop a minimum number of scenarios through the BPEO process (3 level). Initially 8 options were developed in a series of consultative workshops with key stakeholders in the process of identifying and finalizing a BPEO for a technology that will be used in RWMP. The identified options included: windrow composting, in-vessel composting, Mechanical biological treatment (MBT), Bio-methanation, Refuse Derived Fuel (RDF), Incineration, Integrated system of composting with RDF, Integrated system of Sanitary landfill (of complete MSW).

168. The study (Financial Feasibility report for the RWMP; SENES & CDE 2011) for selection of the most appropriate waste management option has been conducted using a screening and selection process known as the Best Practicable Environmental Option (BPEO). BPEO entails a systematic and balanced assessment of different waste disposal options, to identify the option

which provides maximum environment, economic and social benefit. A BPEO process involves a process of identifying viable scenarios for waste management, followed by a process of performance assessing against a number of decision criteria such as technical, environment, social and financial/economic to determine which scenario is the preferred option.

169. A series of consultative workshops with key stakeholders were held in the process of identifying and finalizing a BPEO for a technology that will be used in RWMF and for selection of most appropriate site to locate this facility. The identified options were assessed against each decision criteria (environmental, technical, economic and social) during the BPEO exercise and the assessment resulted in three options, here ranked according to their initial priority:

(i) Composting of organic waste at the island level, simple incineration of remaining waste and land reclamation with rejects at RWMF;
(ii) Composting of organic waste at the island, transportation of rejects to RWMF for landfill; and
(iii) Composting of organic waste at the island level, simple incineration of remaining waste and landfilling of rejects at RWMF.

170. The Incineration technology has been finally selected though the BPEO exercise.

C. Alternative Incineration Technologies

1. Grate technology

171. Grate incinerators are widely applied for the incineration of mixed municipal wastes and can be used for untreated, non- homogenous, and low calorific municipal waste. An overhead crane feeds waste into the hopper, where it is transported via the chute to the grate in the furnace. On the grate, the waste is dried and then burned at high temperature with supply of air. The ash, including non-combustible fractions of waste, leaves the grate as slag or bottom ash through the ash chute.

172. Different grate systems can be distinguished by the way the waste is conveyed through the different zones in the combustion chamber. The type of grate system determines the efficacy of primary air feeding, conveying velocity and raking, as well as mixing of the waste.

173. Reciprocating grates: Many modern MSWM incinerator facilities use reciprocating grates. The quality of burnout achieved is generally good. Reciprocating grates consist of sections that span the width of the furnace but are stacked above each other. Alternate grate sections slide back and forth, while the adjacent sections remain fixed. Waste tumbles off the fixed portion and is agitated and mixed as it moves along the grate.

174. There are essentially two main reciprocating grate variations:

(i) Reverse reciprocating grate: The grate bars oscillate back and forth in the reverse direction to the flow of the waste. The grate is sloped from the feed end to the ash discharge end and is comprised of fixed and moving grate steps.
(ii) Push forward grate: The grate bars form a series of many steps that oscillate horizontally and push the waste in the direction of the ash discharge. Other grate types that have been in use include rocking grates, travelling grates, roller grates, and cooled grates.

175. Grate incinerators are of two types:

(i) Moving grate furnace system: waste enters from one end while ash is discharged at other
(ii) Fixed grates: series of steps with drying stage and initial combustion phase, complete combustion and final carbon burn- out

176. Advantages of Grate Incinerators:

(i) There is no need for prior sorting or shredding.
(ii) Technology is widely tested and meets the standards of technical performance.
(iii) It accommodates large variations in waste composition and calorific value.
(iv) It allows for an overall thermal efficiency of up to 85%.

177. Disadvantage of grate incinerators:

(i) Capital and maintenance costs are relatively high.

178. The viability of grate incinerators in the Maldives context is high. The advantages of this technology clearly fit to address the challenges being encountered in Maldives, particularly on the large variations in waste composition collected from sources that is very common in developing countries.

2. Pyrolysis

179. Pyrolysis involves an irreversible chemical change brought about by the action of heat in an atmosphere devoid of oxygen. Synonymous terms are thermal decomposition, destructive distillation, and carbonization. Pyrolysis, unlike incineration, is an endothermic reaction and heat must be applied to waste to distil volatile components. The converting of plastic to fuels through pyrolysis is possible, but it is yet to be proven to be a commercially viable venture.

180. Pyrolysis is carried out at 500°C – 1,000°C and produces three component streams:

(i) Gas: a mixture of combustible gases such as hydrogen, carbon monoxide, methane, carbon dioxide, and some hydrocarbons.
(ii) Liquid: consisting of tar, pitch, light oil, and low boiling organic chemicals like acetic acid, acetone, methanol, etc.
(iii) Char: consisting of elemental carbon along with the inert material in the waste feed.

181. The gas and liquid fractions and the char are useful because of their high calorific value. Part of the heat obtained by combustion of either char or gas is often used as process heat for the endothermic pyrolysis reaction. It has been observed that even after utilizing the heat necessary for pyrolysis, extra heat still remains which can be commercially exploited.

182. Although a number of laboratory and pilot investigations have been made, only a few have led to full scale plants. German experience also indicates that while several small-scale pyrolysis and gasification plants for MSW were set up a few decades ago, almost all have been shut down due to operational and commercial issues.

183. **Feed stock for pyrolysis**. Feedstock for pyrolysis should have high calorific value with very limited moisture content and should be homogenous in nature. Many plastics, particularly

the polyolefins, which have high calorific values and simple chemical constitutions of primarily carbon and hydrogen, are usually used as a feedstock in pyrolysis. More recently, pyrolysis plants are being tested to degrade carbon-rich organic material such as MSW. For mixed MSW pre-processing is necessary to bring homogeneity to increase efficiency.

184. **Municipal solid waste pyrolysis**. Sorted and pre-treated feedstock is supplied to pyrolysis reactor-rotary kilns, rotary hearth furnaces, and fluidized bed furnaces which are commonly used as MSW pyrolysis reactors where partial combustion of material occurs at 500°C-800°C.

185. As a result of combustion of organic matter in an oxygen-deficient environment, various products such as char (ash), pyrolysis oil, and syngas are produced. Production of these is dependent on the organic component of MSW, temperature, pressure, and time of retention in the reactor. Char or solid residue is a combination of non-combustible material and carbon. The syngas is a mixture of gases (combustible constituents include carbon monoxide, hydrogen, methane, and a broad range of other volatile organic compounds). Syngas is further refined to remove particulates, hydrocarbons, and soluble matter, and is then combusted to generate electricity. The syngas typically has a net calorific value (NCV) of 2,800-4,800 kilocalories per normal cubic meter (kcal/Nm^3) or 10 – 20 mega joules per normal cubic meter (MJ/Nm^3). If required, the condensable fraction can be collected by cooling the syngas, potentially for use as a liquid fuel (oils, waxes, and tars).

186. One key issue for use of syngas in energy recovery is tarring. The deposition of tars can cause blockages and other operational challenges and has been associated with plant failures and inefficiencies at some pilot and commercial scale facilities. Tarring issues may be overcome by higher temperature secondary processing.

187. In order to recover the energy content of syngas, it should be further processed in the following ways:

- (i) Syngas can be burned in a boiler to generate steam, which may be used for power generation or industrial heating;
- (ii) Syngas can be used as a fuel in a dedicated gas engine;
- (iii) Syngas, after reforming, may be suitable for use in a gas turbine; and
- (iv) Syngas can also be used as a chemical feedstock.

188. For plasma pyrolysis of MSW, it should be noted that, along with pre- sorted MSW as feedstock, additional inputs, such as flux material and carbonaceous material (e.g. coke) are required.

189. **Plasma pyrolysis vitrification**. This is a modified pyrolysis technology aiming at energy or resource recovery from organic waste. The system uses a plasma reactor, which generates, by application of high voltage between two electrodes, an extremely high temperature (5,000°C-14,000°C). This hot plasma zone dissociates the molecules in any organic material into the individual elemental atoms, while all the inorganic materials are simultaneously melted into a molten lava. This process is still far away from any proven practical and sustainable application in MSWM.

3. Gasification

190. Gasification is a partial combustion of organic or fossil based carbonaceous material, plastics, etc. into carbon monoxide, hydrogen, carbon dioxide, and methane. This is achieved at high temperature (650°C and above), with a controlled amount of air, oxygen, or steam. The process is largely exothermic, but some heat may be required to initialize and sustain the gasification process.

191. The main product is syngas, which contains carbon monoxide, hydrogen, and methane. Typically, the gas generated from gasification will have an NCV of 4–10 MJ/Nm^3. The other main product produced by gasification is a solid residue of non-combustible material (ash), which contains a relatively low level of carbon.

192. **Gasification of municipal solid waste**. Feedstock Preparation: MSW should be pre-processed before it can be used as feedstock for the gasification process. The pre-processing comprises of manual and mechanical sorting, grinding, blending with other material, drying, and pelletization. The purpose of pre-processing is to produce a feed material with consistent physical characteristics and chemical properties. Carbonaceous material of municipal waste stream is most important feedstock for gasification.

193. **Gasifiers for municipal solid waste treatment**. Gasification technology is selected on the basis of available fuel quality, capacity range, and gas quality conditions. The main reactors used for gasification of MSW are fixed beds and fluidized beds. Larger capacity gasifiers are preferable for treatment of MSW because they allow for variable fuel feed, uniform process temperatures due to highly turbulent flow through the bed, good interaction between gases and solids, and high levels of carbon conversion.

194. **Fixed Beds**. Fixed bed gasifiers typically have a grate to support the feed material and maintain a stationary reaction zone. They are relatively easy to design and operate, and are therefore useful for small and medium scale power and thermal energy uses. The two primary types of fixed bed gasifiers are updraft and downdraft.

195. In an updraft gasifier, the fuel is also fed at the top of the gasifier, but the airflow is in the upward direction. As the fuel flows downward through the vessel, it dries, pyrolyzes, gasifies, and combusts. The main use of updraft gasifiers has been with direct use of the gas in a closely coupled boiler or furnace. Because the gas leaves this gasifier at relatively low temperatures, the process has a high thermal efficiency and, as a result, wet MSW containing 50% moisture can be gasified without any pre- drying of the waste.

196. In a downdraft gasifier, air is introduced into a downward flowing packed bed or solid fuel stream and gas is drawn off at the bottom. The air or oxygen and fuel enter the reaction zone from the top, decomposing the combustion gases and burning most of the tars. Downdraft gasifiers are not ideal for waste treatment because they typically require a low ash fuel such as wood to avoid clogging.

197. **Fluidized Beds**. Fluidized beds are an attractive proposition for the gasification of MSW. In a fluidized bed boiler, a stream of gas (typically air or steam) is passed upward through a bed of solid fuel and material (such as coarse sand or limestone). The gas acts as the fluidizing medium and also provides the oxidant for combustion and tar cracking. Waste is introduced either on top of the bed through a feed chute or into the bed through an auger. Fluidized beds have the advantage of extremely good mixing and high heat transfer, resulting in very uniform bed

conditions and efficient reactions. Fluidized bed technology is more suitable for generators with capacities greater than 10 MW because it can be used with different fuels, requires relatively compact combustion chambers, and allows for good operational control. The two main types of fluidized beds for power generation are bubbling and circulating fluidized beds.

198. In a bubbling fluidized bed (BFB), the gas velocity must be high enough so that the solid particles, comprising the bed material, are lifted, thus expanding the bed and causing it to bubble like liquid. A bubbling fluidized bed reactor typically has a cylindrical or rectangular chamber designed so that contact between the gas and solids facilitates drying and size reduction (attrition). As waste is introduced into the bed, most of the organics vaporize pyrolytically and are partially combusted in the bed. Typical desired operating temperatures range from 900°C to 1,000°C.

199. A circulating fluidized bed (CFB) is differentiated from a bubbling fluid bed in that there is no distinct separation between the dense solids zone and the dilute solids zone. The capacity to process different feedstock with varying compositions and moisture contents is a major advantage in such systems.

200. **Integrated gasification with power generating equipment**. MSW gasification can be integrated with power turbines, steam cycle, and other power generating equipment to provide thermal energy. Combination of MSW gasification with power turbines and fuel cells increases overall efficiency of the system. Development is happening on the following lines:

(i) Integrated gasification combined cycle (IGCC) is based on the concept of integrating MSW gasification with gas turbines and steam cycle.
(ii) Fuel cells are integrated with MSW gasifier. Tubular solid oxide fuel cells have been found to be most effective for these applications.

201. **General challenges of operating gasification plants**. Gasification takes place in low oxygen environment that limits the emission of pollutants. It also generates fuel gas that can be further used in a number of ways, as suggested in the section on pyrolysis. During gasification, tars, heavy metals, halogens, and alkaline compounds are released within the product gas and can cause environmental and operational problems. Tars are high molecular weight organic gases that ruin reforming catalysts, sulfur removal systems, and ceramic filters and increase the occurrence of slagging in boilers, on other metal and refractory surfaces. Alkalis can increase agglomeration in fluidized beds that are used in some gasification systems and can also ruin gas turbines during combustion. Heavy metals are toxic and accumulate, if released into the environment. Halogens are corrosive and a cause of acid rain, if emitted to the environment. The key to achieving cost efficient, clean energy recovery from MSW gasification will be overcoming problems associated with the release and formation of these contaminants.

202. **Challenges of Utilizing Pyrolysis and Gasification Technologies in Maldives**. High calorific value waste, which may otherwise be processed in more sustainable processes, is required as feedstock. Organics can be converted into compost in a much more cost effective and environmentally safe process, as against using them as feedstock for these processes.

203. Pyrolysis and gasification processes require specific feedstock quality, which has a direct impact on the efficiency and commercial viability of the product. Pre-treatment of waste is a must for pyrolysis but is not practical in the context of Maldives as source separation has not been possible due many factors and on-site separation is not possible due to the unavailability of land at transfer stations proposed and at the Thilafushi RWMF. Specified size and consistency of solid

waste should be achieved before MSW can be used as feed. Therefore, pyrolysis and gasification processes are not viable options under the project.

D. Alternatives on Discharge Locations for WTE Cooling Water

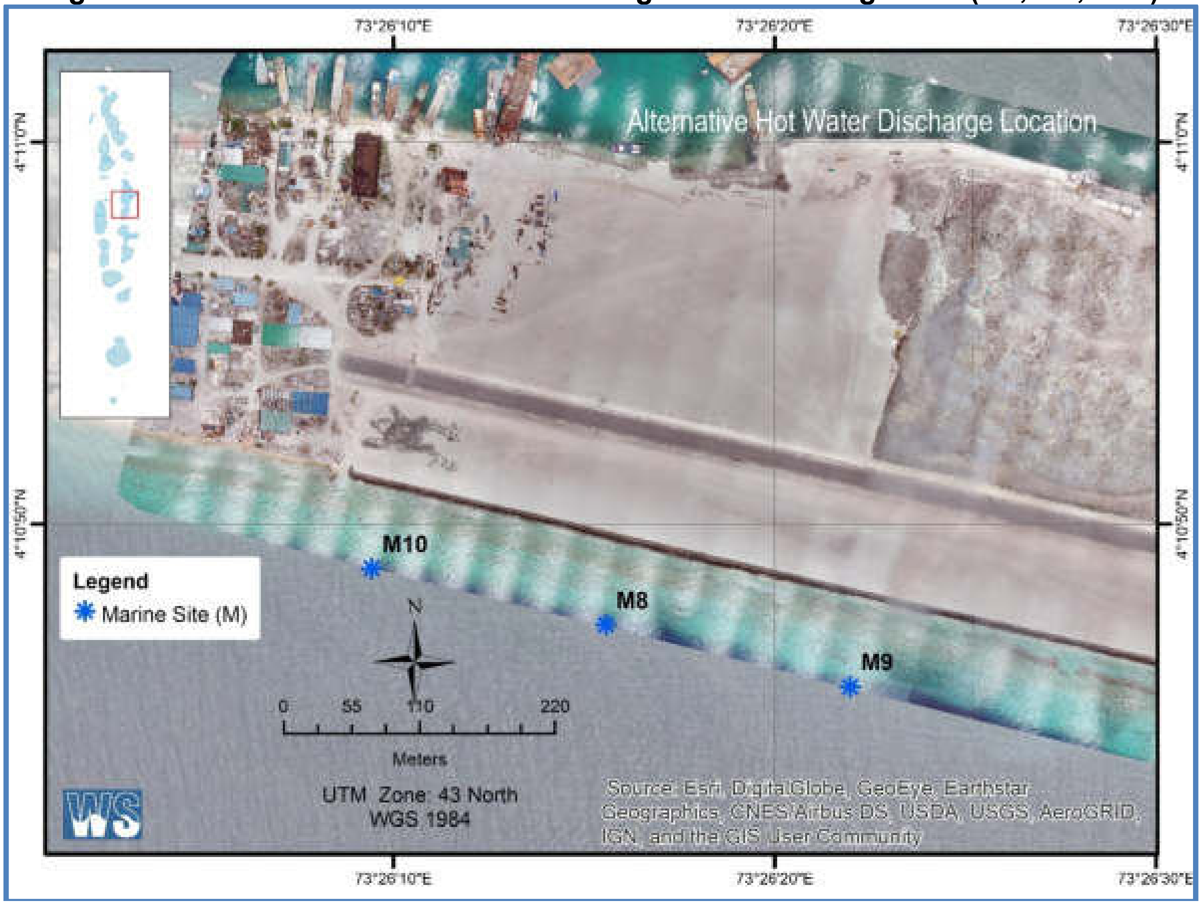
204. The proposed WTE plant will use sea water as the coolant and discharge cooling water back to the sea. Inevitably, the temperature of water discharged is above the ambient. As temperature is one of the most important environmental variables, discharging water of elevated temperature will have significant impact to aquatic organisms and to the local biological and biogeochemistry of the ocean. Potential impacts of elevated water temperature discharge are such as:

(i) Coral bleaching;
(ii) Reduction of dissolved oxygen level;
(iii) Stimulation of phytoplankton and benthic algal growth;
(iv) Alteration in ecosystem which affects the mortality and reproduction; and
(v) Alteration of thermal structure of the ocean, current patterns, surface wave patterns.

205. The most practical location of the discharge pipe and outfall of the cooling water from the condenser is the southern side of the project site (and of the island) that is facing the open sea. In order to identify the best section through which the discharge pipe should be positioned, underwater marine life survey including a reef profile survey was conducted along the 500-meter stretch of the southern coastal boundary of the project site. Initially in 2018, two underwater marine survey was conducted at this stretch and found no significant marine life in the area. See tagged locations M1 and M2 in Figure 89 in Section V. However, information describes the description of the underwater ecosystem up to a depth of 10 meters only. In order to gain robust understanding of the underwater ecology in the area, additional underwater survey was conducted in September 2019. Three specific sections were identified for this additional survey which are tagged as M8, M9 and M10 in

Figure 11 below.

Figure 11: Alternative Locations for Cooling Water Discharge Line (M8, M9, M10)



206. Results show that at these three alternative sections, underwater characteristics and profiles are the same wherein fish life, fish abundance and coral reef system have been rated as "very poor". The rating of "very poor" means that the entire stretch of the study area has uniform characteristics of mostly dead corals, very rare pelagic life and diversity as very low. At the depth of more than 20 meters, results also show that the seabed is generally characterized by large expanse of rocks with no live corals. The figures below summarize the findings related to underwater marine life at these alternative sections studied. A complete report on this underwater survey is attached as Appendix 7.

207. The underwater study findings confirm that the extent of marine biota is too low in the survey area. The impact of discharge of cooling water to marine ecology in this area is not significant regardless of where the outfall is positioned at any of these three alternative sections considered. Given this scenario, the deciding factor for choosing the best section to locate the discharge pipe has been on the selection on which section has the best reef slope to anchor the discharge pipe effectively and efficiently. Comparison among the alternatives indicates that M8 section is the best alternative because of its gradual slope and least geographical characteristics compared to M9 and M10 sections. M9 section is considered too steep, while M10 section has relatively uneven slope with small cave feature at depth of around 7 – 10 meters. Slope characteristics and profiles at these three sections considered are illustrated in Figure 12 to Figure 14 below.

Figure 12: Reef Slope Characteristics at Section M8

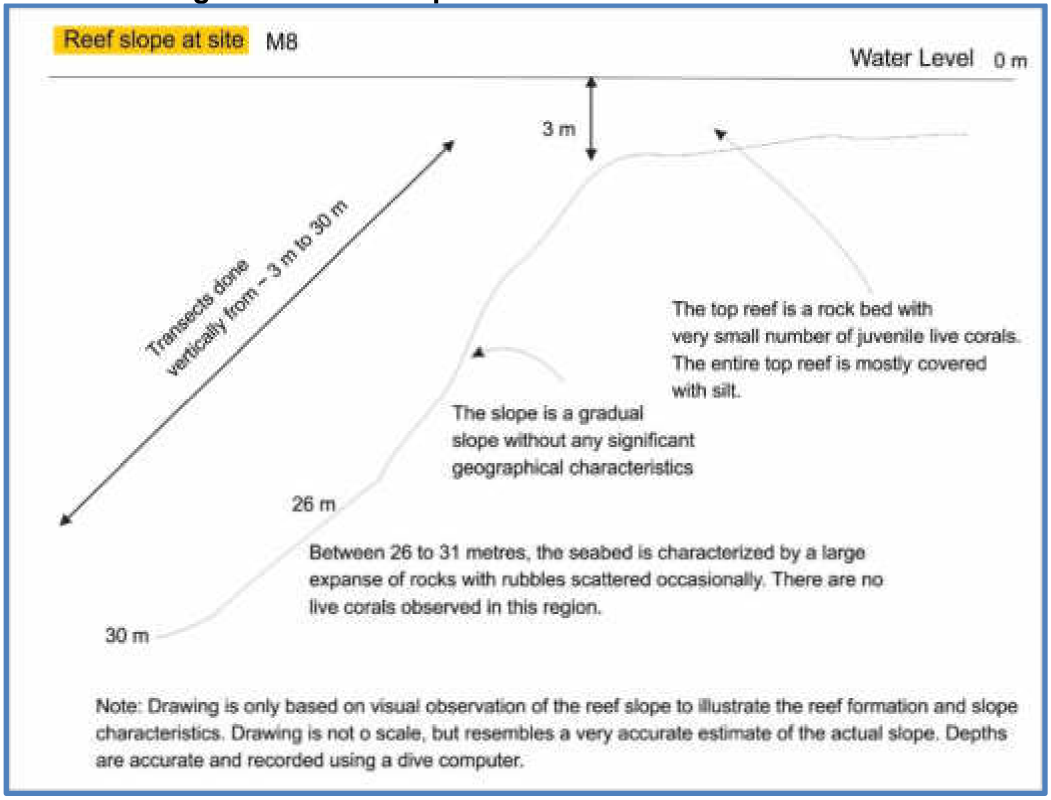


Figure 13: Reef Slope Characteristics at Section M9

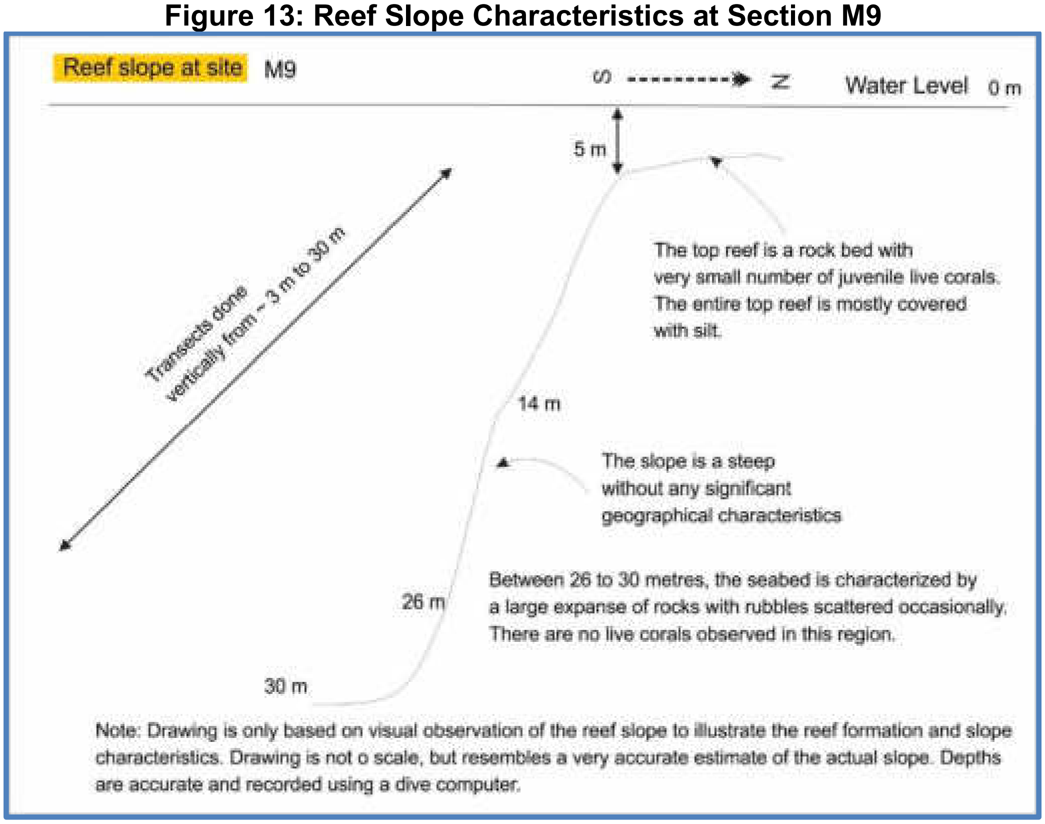
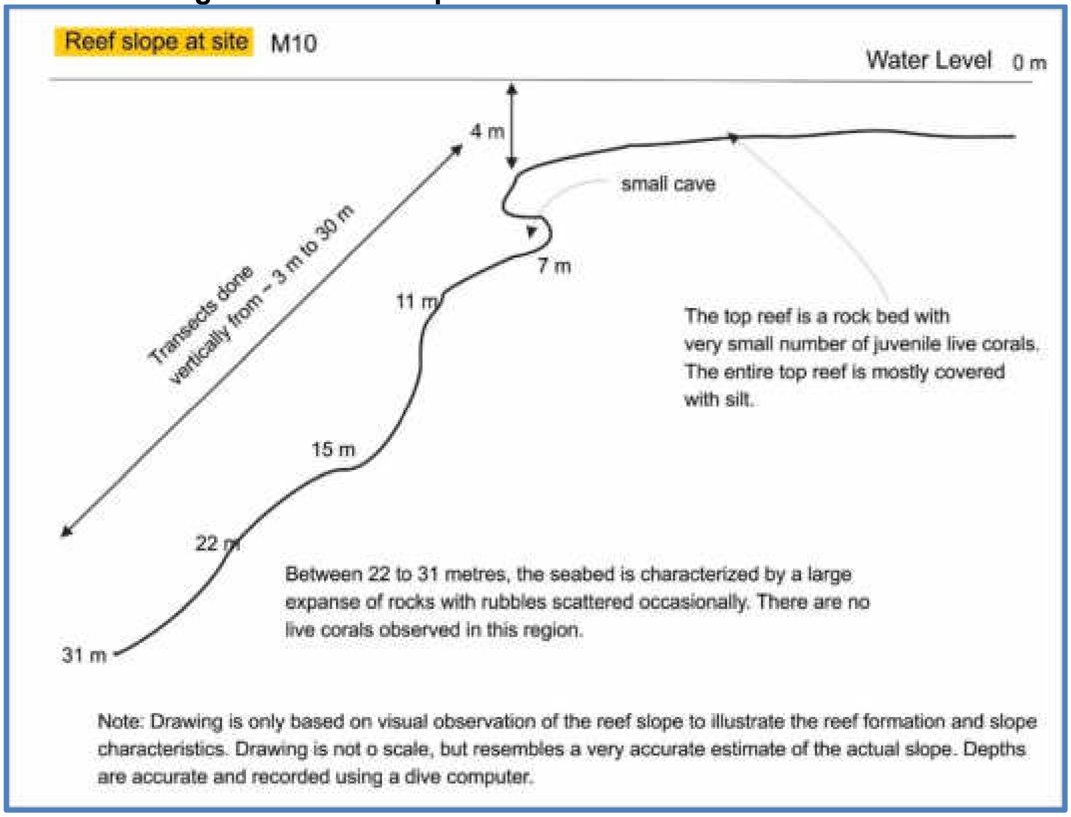


Figure 14: Reef Slope Characteristics at Section M10

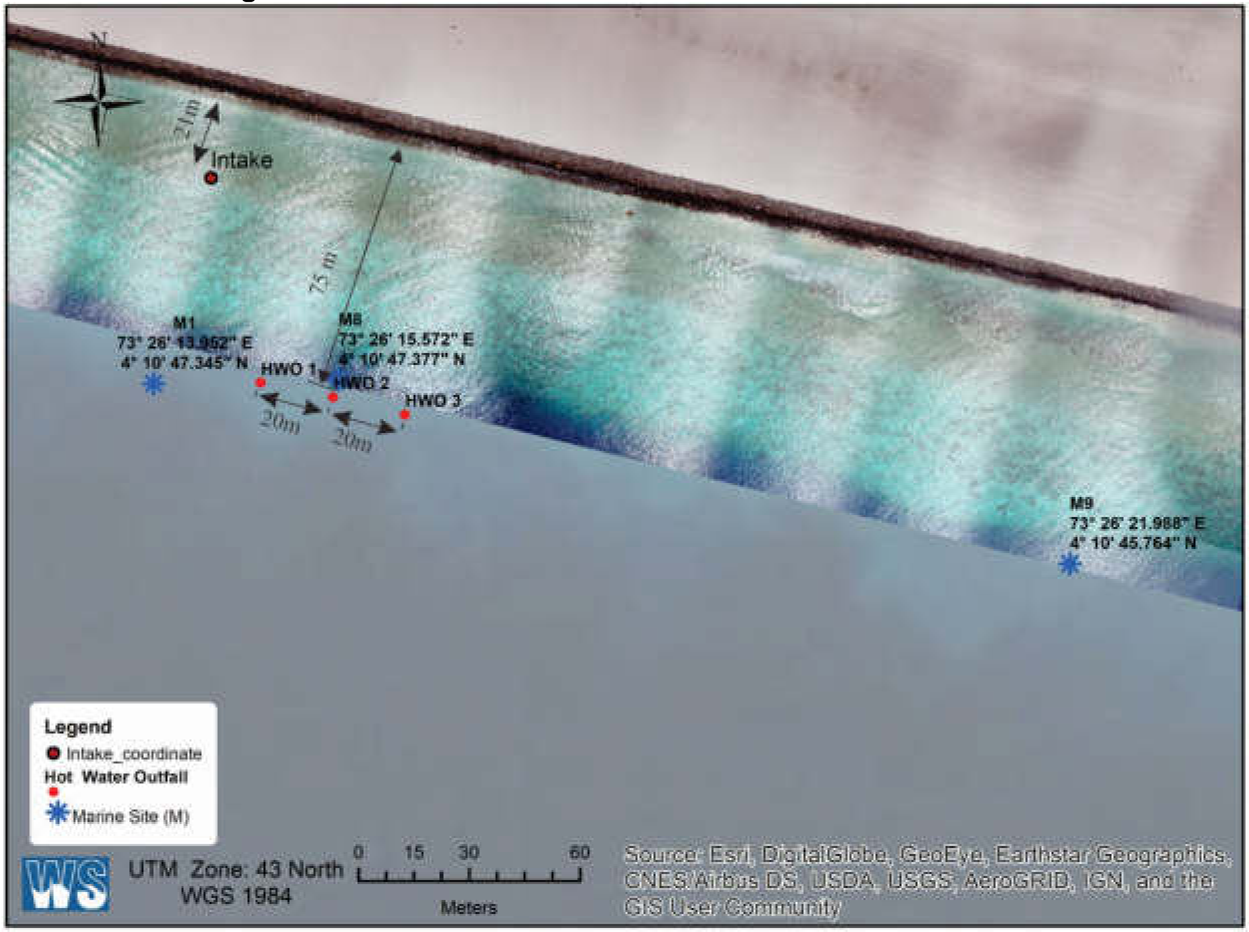


1. Outfall Position of the Cooling Water Discharge Pipe

208. At the chosen M8 section, pelagic life such as fishes may roam the upper layer of the underwater study area (potential pelagic zone). Therefore, the outfalls or tips of the discharge pipes should be positioned at a certain depth that will not cause any thermal impact to the potential pelagic zone.

Figure 15 below shows the position of the outfalls and its distance of 75 m from the shoreline.

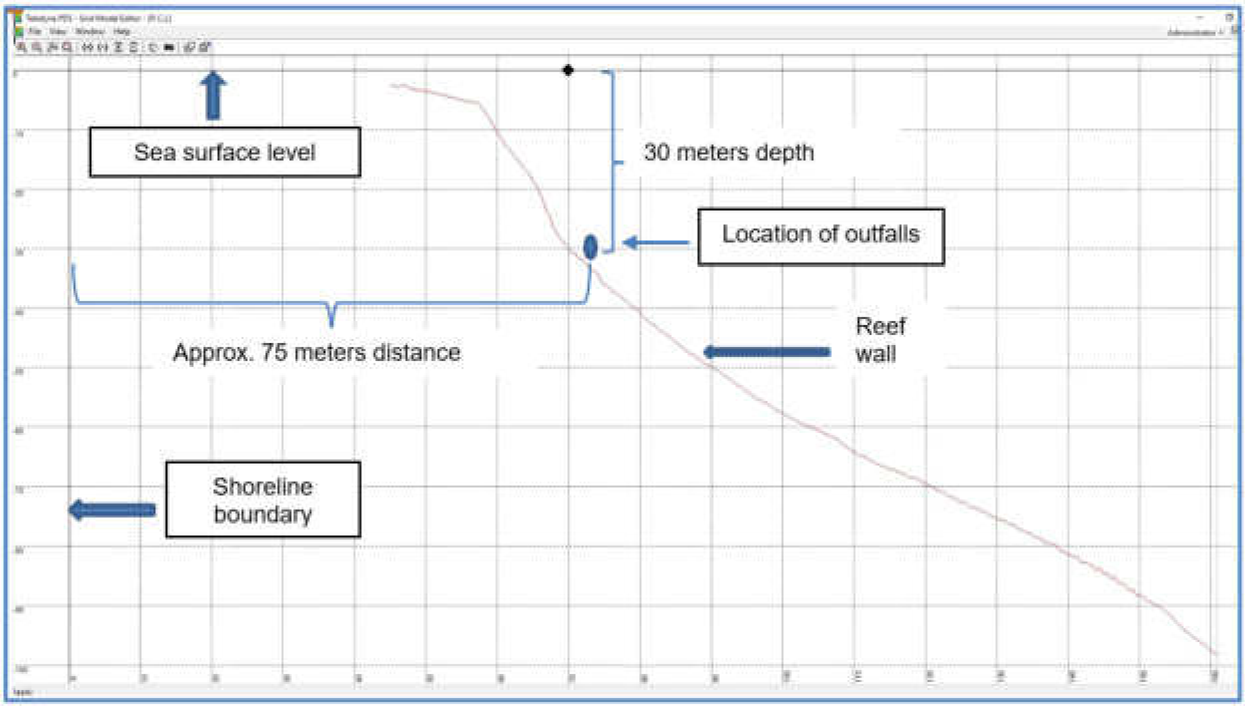
Figure 15: Recommended Location of Outfall at M8 Section



209. **Cooling Water Dispersion Modeling**. A dispersion modeling has been conducted to simulate the heat dissipation of cooling water as it is discharged undersea via two alternative configurations – three outfalls (as primary alternative) and single outfall (as second alternative for comparison). For each configuration, the pipes will have diameters that will result to discharge velocity of 2 m/s. In this modeling process, initial dilution is estimated using a near field model (CORMIX). Using its results, the depth average diluted thermal factors are obtained and fed them to a far field model (MIKE 21 HD Thermal Dispersion). Finally spreading of thermal plume in 2D plain can be obtained.

210. The hot water discharge will have an exit temperature of not more than 3°C from ambient temperature of receiving water. Based on the underwater survey and as a precautionary measure, the outfalls shall be positioned at a depth of 30m where no corals and fishes exists. This depth of the outfall and temperature of the discharge were used as inputs to the modeling. See Figure **16** for the layout that shows the depth of the outfall considered in the modeling relative to the bathymetry.

Figure 16: Depth of Outfalls Analyzed in Cooling Water Dispersion Modeling



211. In addition, two different monsoon and tidal conditions are also considered. Therefore, all together, four number of scenarios were simulated. All simulation scenarios are given in the following table.

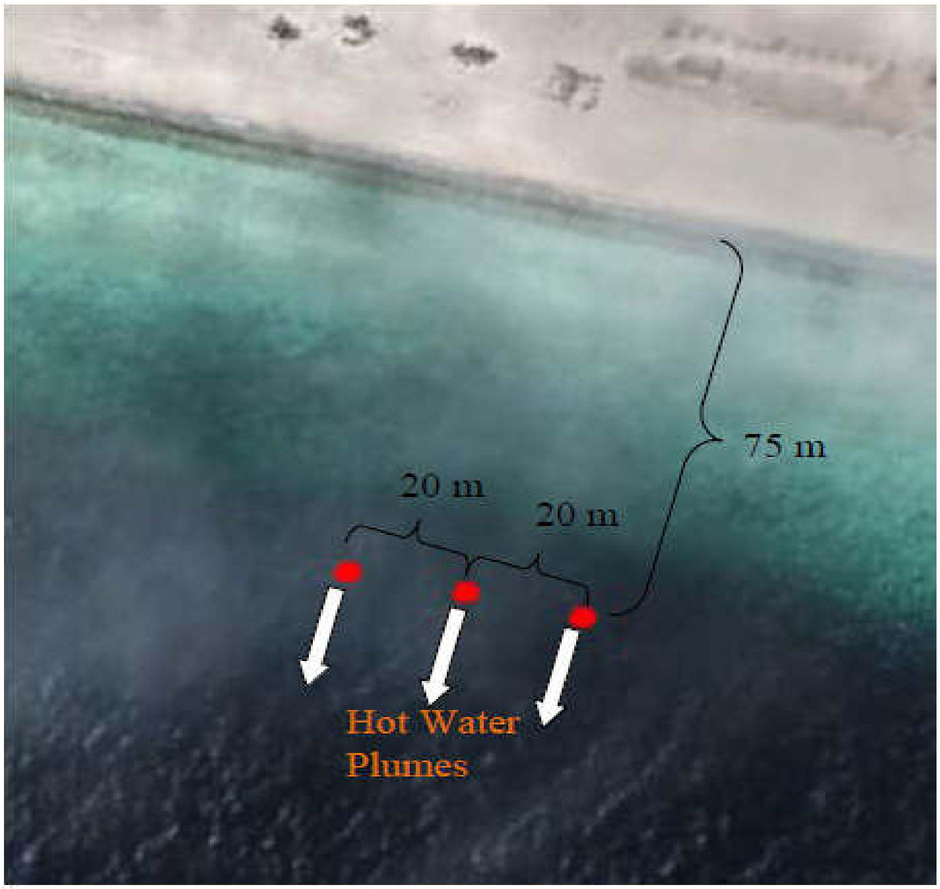
Table 15: Summary of Simulation Scenarios for Three Outfalls

Scenario ID	**Monsoon**	**Tide**	**Excess Temp.** (ºC)	**Flow Rate** (m^3/h)	**Depth at Discharge** (m)	**Current Condition**	
						Speed (m/s)	**Direction (Deg.)**
NE_S_01	Northeast	Spring	3	6,626.67 x 3	30	0.20	271
NE_N_01		Neap	3	6,626.67 x 3	30	0.10	280
SW_S_01	Southwest	Spring	3	6,626.67 x 3	30	0.22	280
SW_N_01		Neap	3	6,626.67 x 3	30	0.10	277

212. **Near Field Modeling**. For the three outfalls configuration, the given pipe diameter is 1,100 mm for each outfall and discharge velocity of 2 m/s. Three outfalls place in a 20m interval distance to each other in a straight line. This outfall line is parallel to the shoreline and around 75m away from the shore as shown in **Figure 16**. The outfalls are set perpendicular to the shore in which the outlets are arranged to release the hot water jet parallel to the center line of their ports at a depth of 30 m towards the deep sea as shown in **Figure 17**. Since the density of the heated plume is less it will act as negatively buoyant discharges and tends to move upwards. The initial momentum of the discharge will lead to a very turbulent flow that will attempt to mix the fluid over the full depth available. This mixing will be resisted by the fact that the discharge is buoyant. The mixing will also cause ambient fluid to be entrained into the jet, reducing its momentum and temperature. This initial momentum is very important and generally reduces the excess temperature by a factor of 2 to 3 over a distance of a few meters. Once the discharge momentum

has been reduced below a certain limit due to the dilution, the mixing will cease to be the dominant factor and the discharge will transform into what is generally known as a plume. After this the discharge enters the far field. To examine the near field behavior of the heated plume CORMIX mixing zone model is used.

Figure 17: Outfall Locations and Direction of Plume



213. **Cormix Modeling System for the Near Field Modeling**. The CORMIX is a mixing zone model and decision support system for environmental impact assessment of regulatory mixing zones resulting from continuous point source discharges (Doneker & Jirka 2007). It is a computer-aided-design (CAD) developed by the Defrees Hydraulic Laboratory at Cornell University, Ithaca, New York, in cooperation of USEPA for studying aqueous pollutant discharges into a range of water bodies, design and mixing zone analysis (Doneker & Jirka 2007). The role of boundary interaction is the emphasis of the system for predicting steady-state mixing behavior and plume geometry (Doneker & Jirka 2007).

214. Simulation model selection in CORMIX is controlled by the graphical user interface (GUI) and mixing zone rule-based expert systems technology. Description of discharge and ambient conditions are specified as input data in the GUI. Based on the inputs, the most appropriate hydrodynamic simulation model is determined. CORMIX employs the length-scaled rule-based system for classification of flow regimes and uses the length scale for predicting the initial dilution. CORMIX simplifies the characteristics of each stage in the steady-state condition and predicts the plume dilution by using some empirical equations (Etemad-Shahidi & Azimi 2007).

215. CORMIX is applicable to wide range of problems from a simple single submerge pipe discharge into a small stream with rapid cross-sectional mixing to a complicated multiport diffuser installation in deeply stratified coastal water. However, there is lack of applicability in highly unsteady ambient flow conditions that are prone to locally recirculating flows (Doneker & Jirka 2007).

216. The main aim is to obtain an estimation of spreading of heated plume around the discharge. The model set up used the excess temperature as a tool to access the change in temperature level. Based on the requirement, three different water depths were considered for outfall and simulations were carried out accordingly for considering all the relative environmental conditions.

217. **Model Simulations**. As discussed earlier, dilution process can be divided into a primary jet dilution in the so-called **near-field** and a subsequent natural dilution in the **far-field**. The natural dilution (far field) is influenced by waves, currents and environment conditions.

218. In general, near field of an outfall is governed by the initial jet characteristics of the plume and outfall geometry. In this case, horizontal single port discharge is considered in the modeling simulations. The density of effluent was varied from 1017kg/m^3 to 1020 kg/m^3 according to the excess temperature and the ambient density of the sea water is considered as 1025kg/m^3. Ambient temperature level is assumed as 28°C. Simulations were carried out for list of scenarios given in
Table 15.

219. **Near Field Modeling Results for Three Outfall Alternative**. Visualization of the effluent discharged from the port and rising to the surface in a cross flow at near-field region is given below for the simulation of the four scenarios. Complete report of the modeling is in Appendix 8.

Figure 18: Visualization of the Cooling Water Discharge from One Port and Rising to the Surface at Near-Field Region (3-D View for NE Monsoon – Spring Tide)

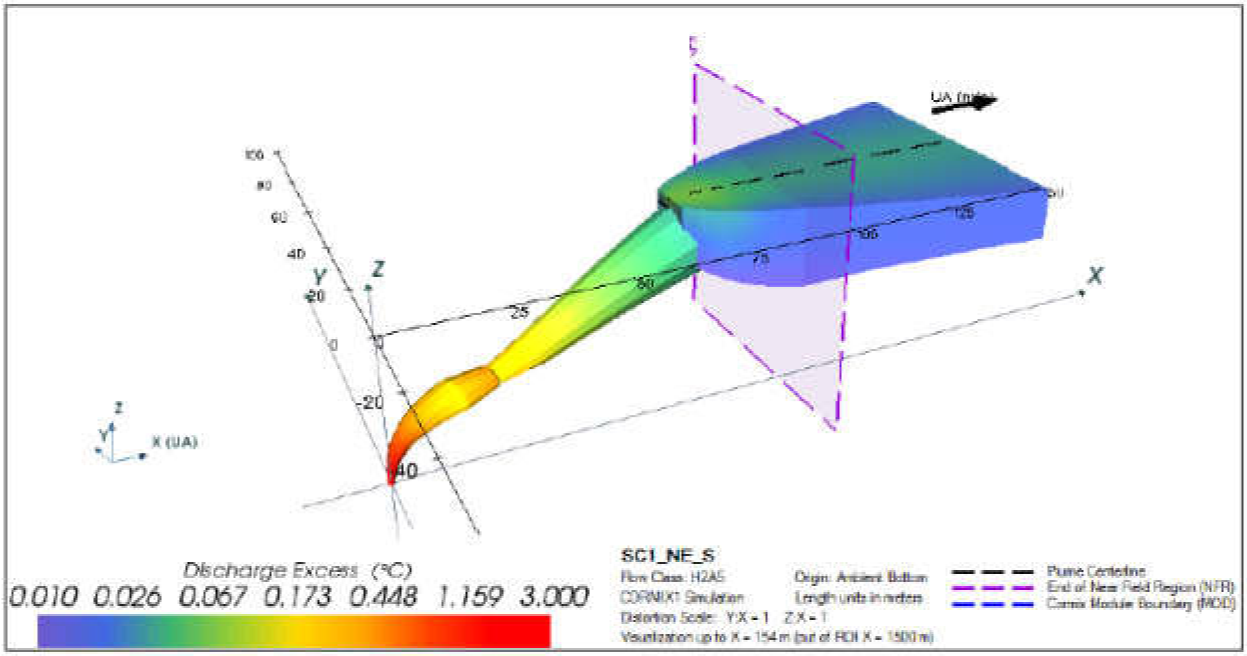


Figure 19: Visualization of the Cooling Water Discharge from One Port and Rising to the Surface at Near-Field Region (Plan View for NE Monsoon – Spring Tide)

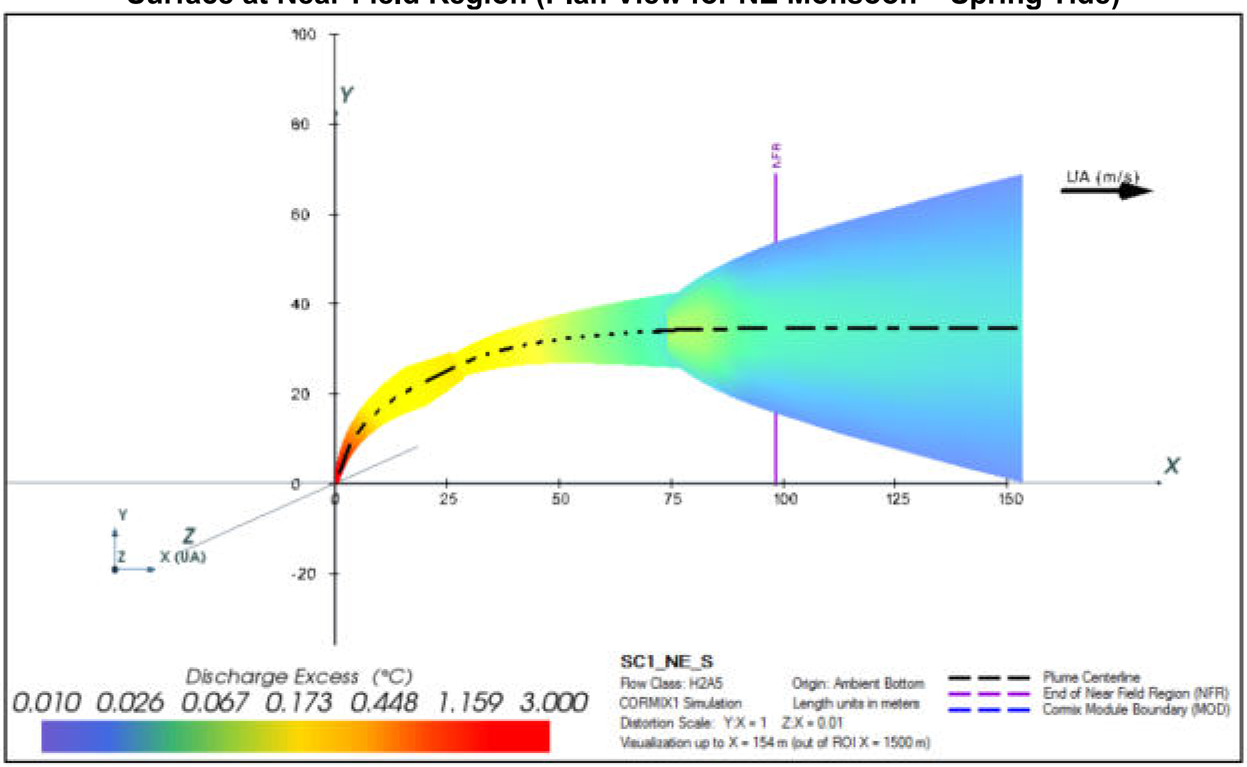


Figure 20: Visualization of the Cooling Water Discharge from One Port and Rising to the Surface at Near-Field Region. (Elevation View for NE Monsoon – Spring Tide)

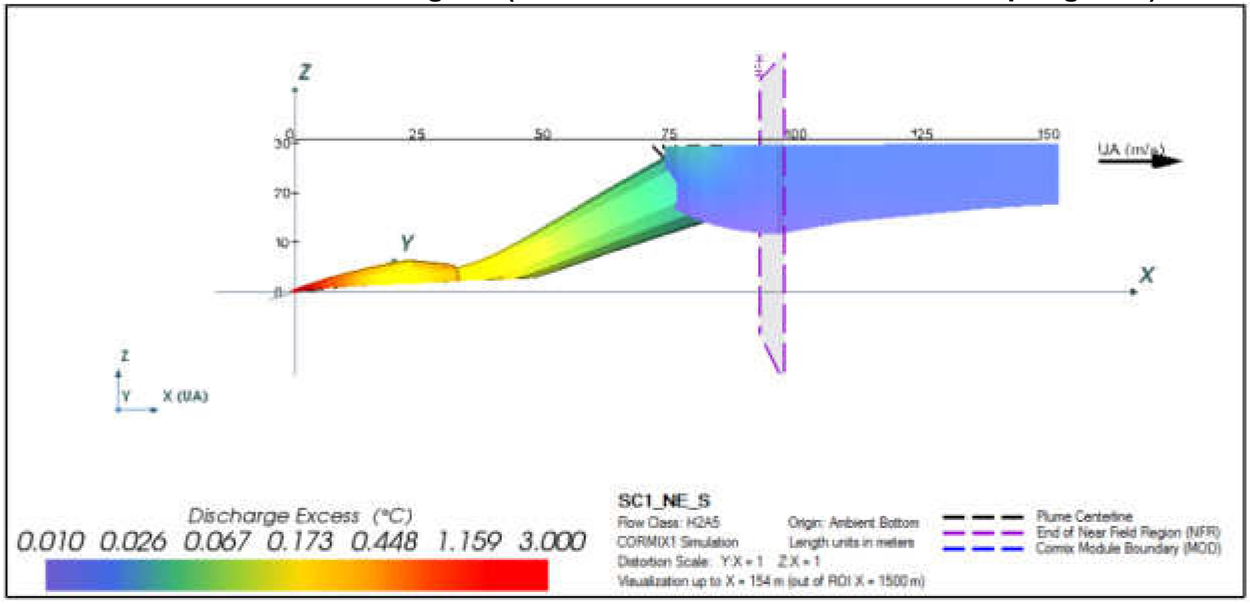


Figure 21: Visualization of the Cooling Water Discharge from One Port and Rising to the Surface at Near-Field Region (3-D View for NE Monsoon – Neap Tide)

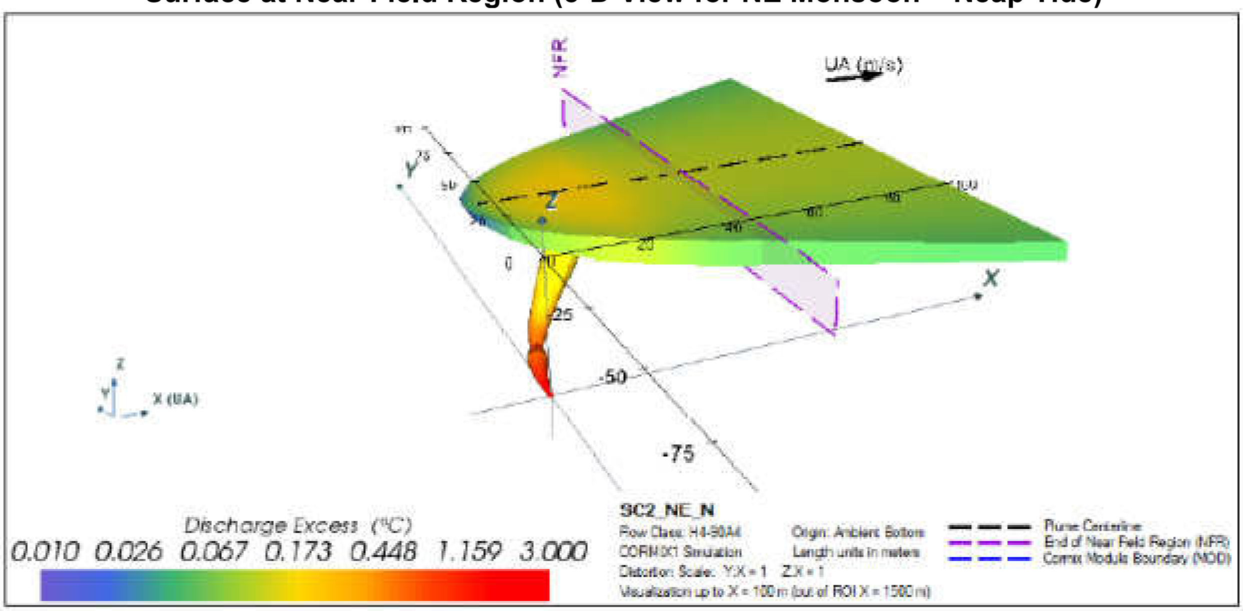


Figure 22: Visualization of the Cooling Water Discharge from One Port and Rising to the Surface at Near-Field Region (Plan View for NE Monsoon – Neap Tide)

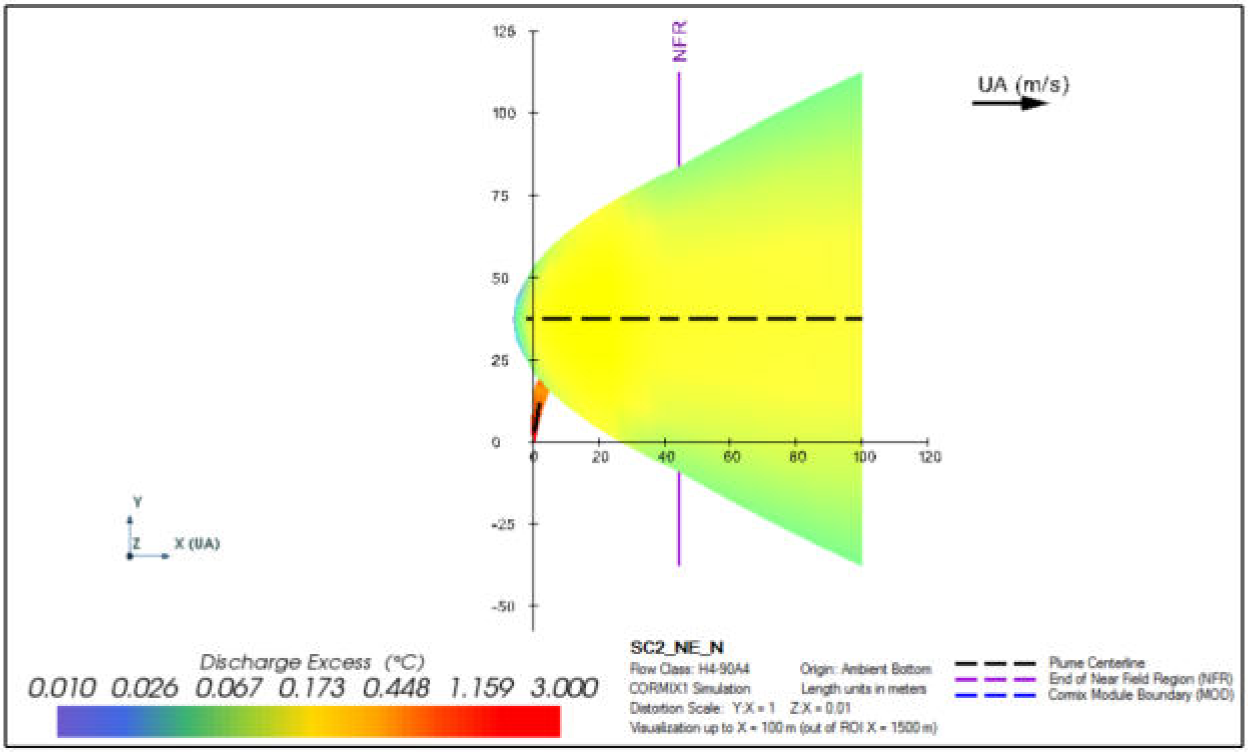


Figure 23: Visualization of the Cooling Water Discharge from One Port and Rising to the Surface at Near-Field Region. (Elevation View for NE Monsoon – Neap Tide)

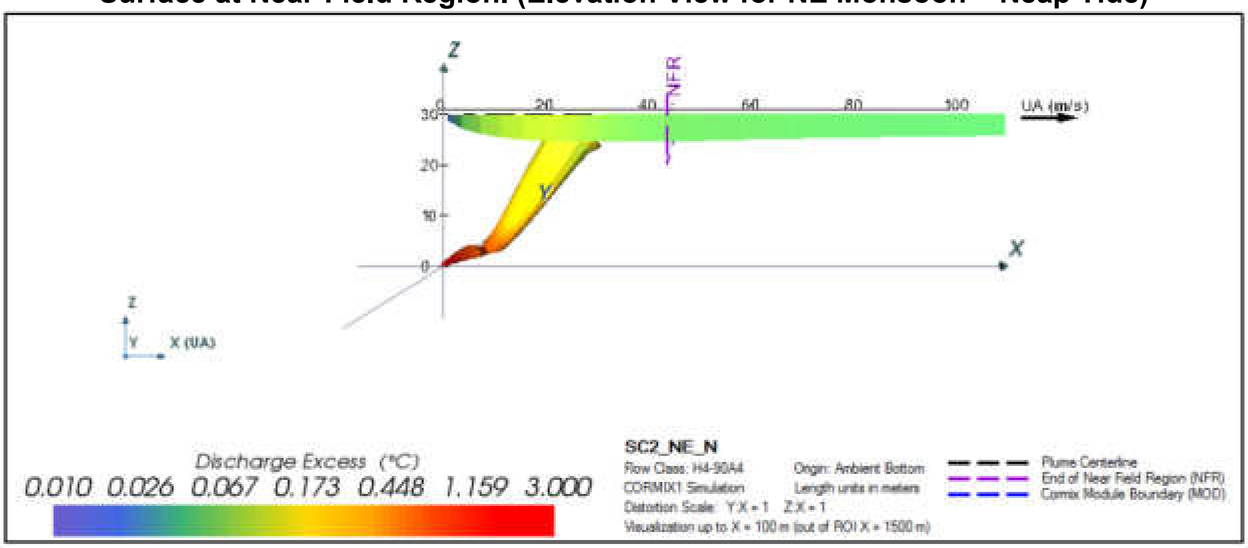


Figure 24: Visualization of the Cooling Water Discharge from One Port and Rising to the Surface at Near-Field Region (3-D View for SW Monsoon – Spring Tide)

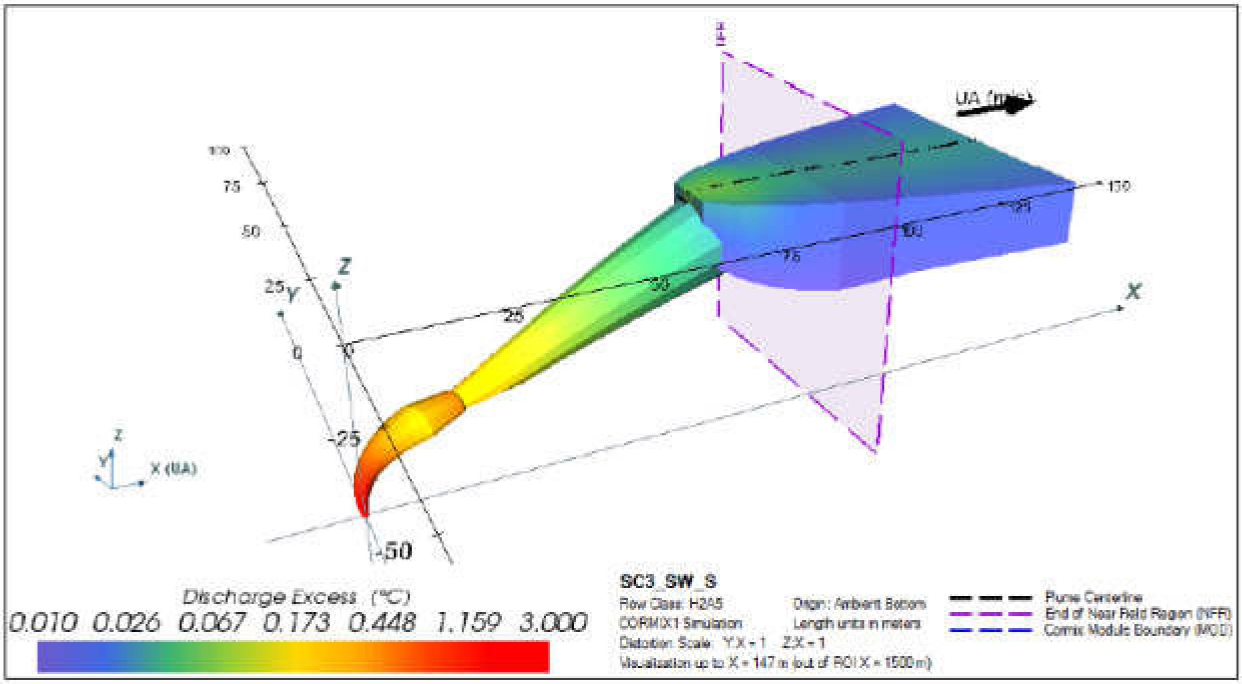


Figure 25: Visualization of the Cooling Water Discharge from One Port and Rising to the Surface at Near-Field Region (Plan View for SW Monsoon – Spring Tide)

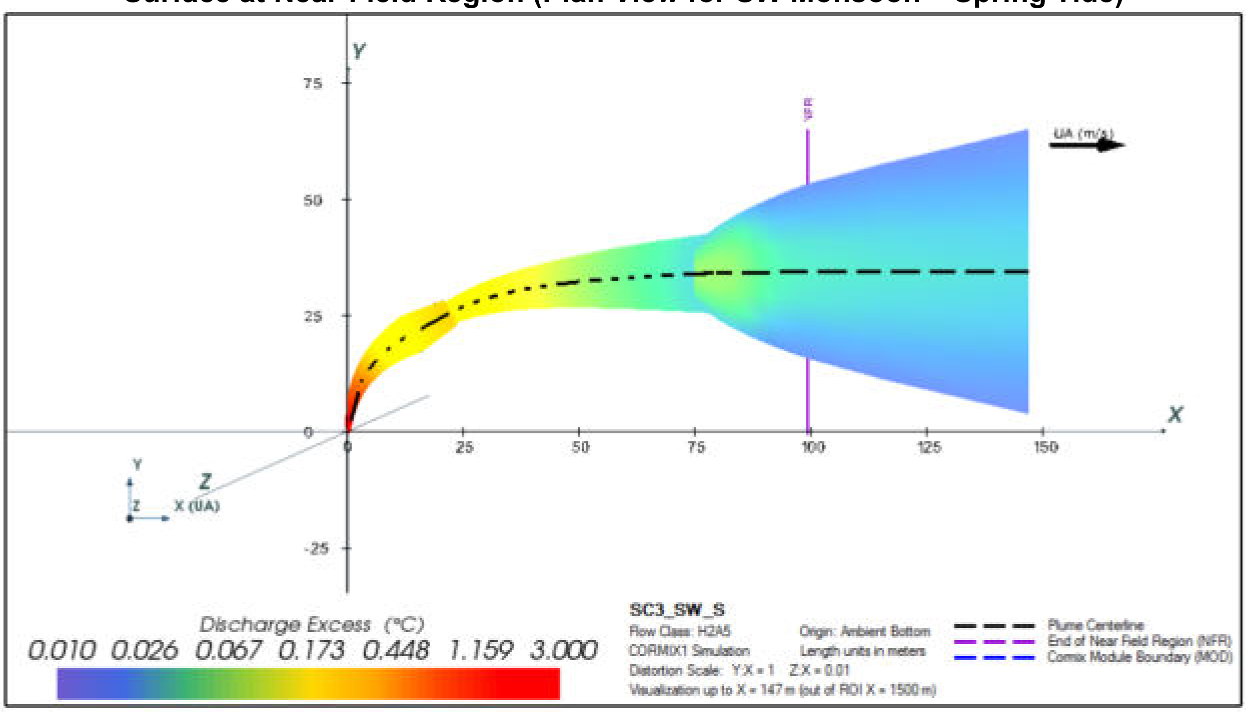


Figure 26: Visualization of the Cooling Water Discharge from One Port and Rising to the Surface at Near-Field Region. (Elevation View for SW Monsoon – Spring Tide)

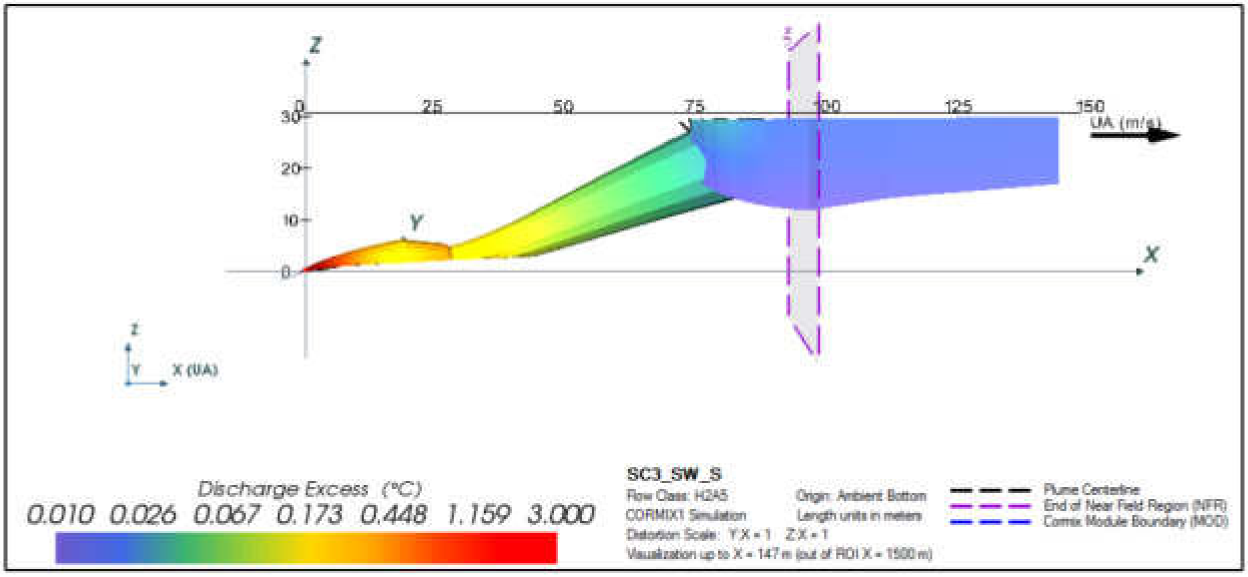


Figure 27: Visualization of the Cooling Water Discharge from One Port and Rising to the Surface at Near-Field Region. (3-D View for SW Monsoon – Neap Tide)

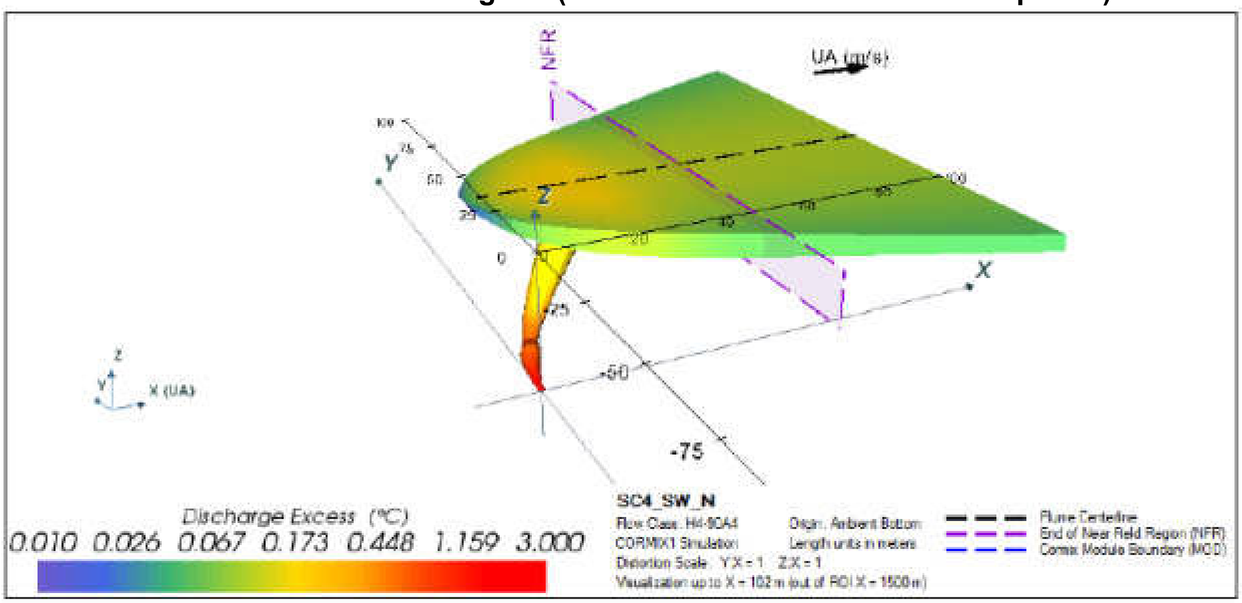


Figure 28: Visualization of the Cooling Water Discharge from One Port and Rising to the Surface at Near-Field Region. (Plan View for SW Monsoon – Neap Tide)

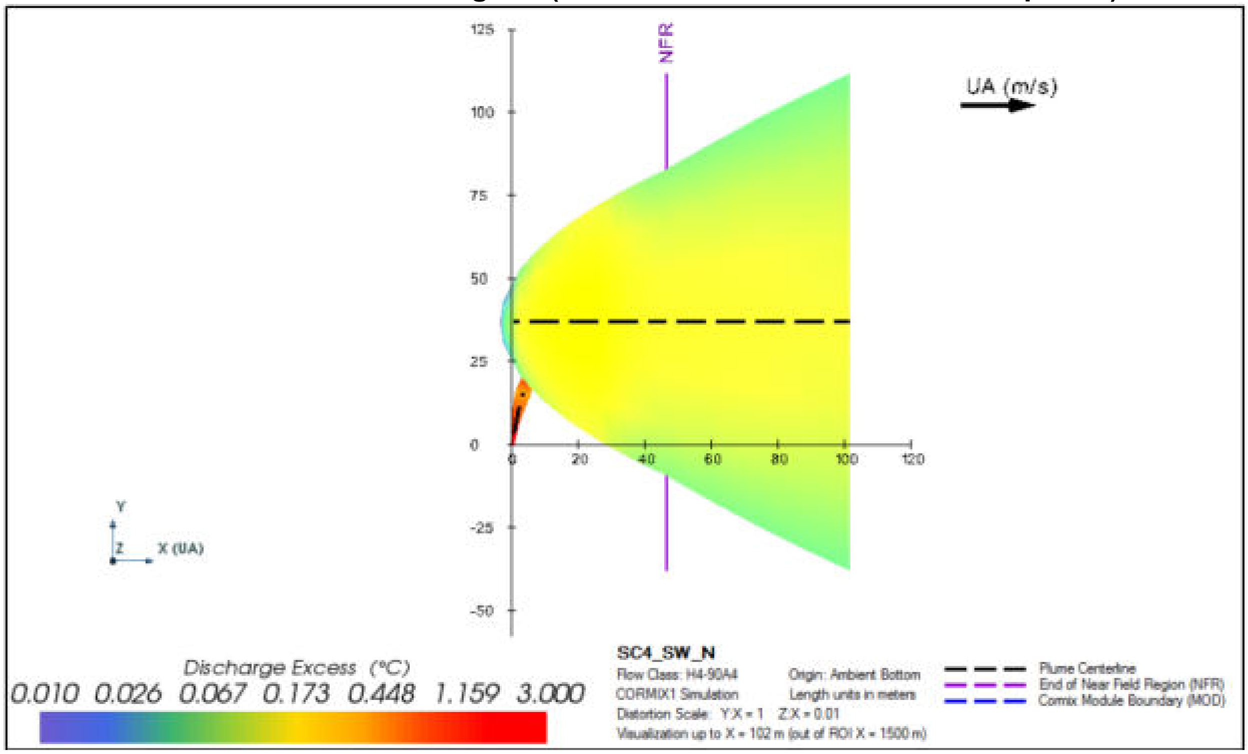
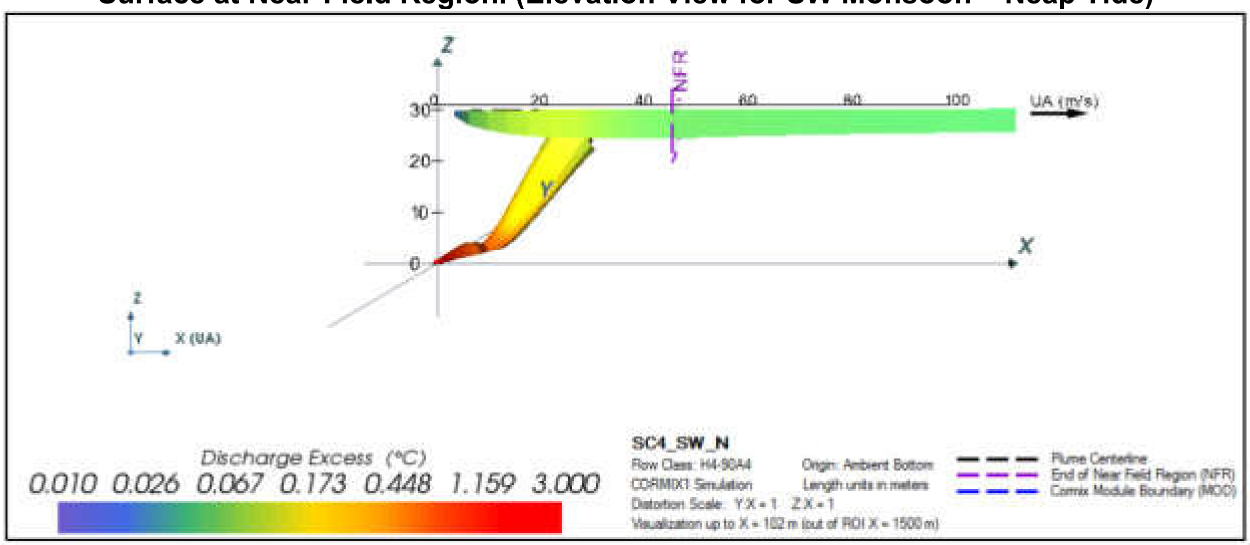


Figure 29: Visualization of the Cooling Water Discharge from One Port and Rising to the Surface at Near-Field Region. (Elevation View for SW Monsoon – Neap Tide)



220. Based on the simulation and consistent with the visualization figures above, the excess temperatures have been plotted versus the downstream distance for each of the scenarios. Figures below show the graphical presentations.

Figure 30: Excess Temperature vs. Downstream Distance
(NE Monsoon – Spring Tide)

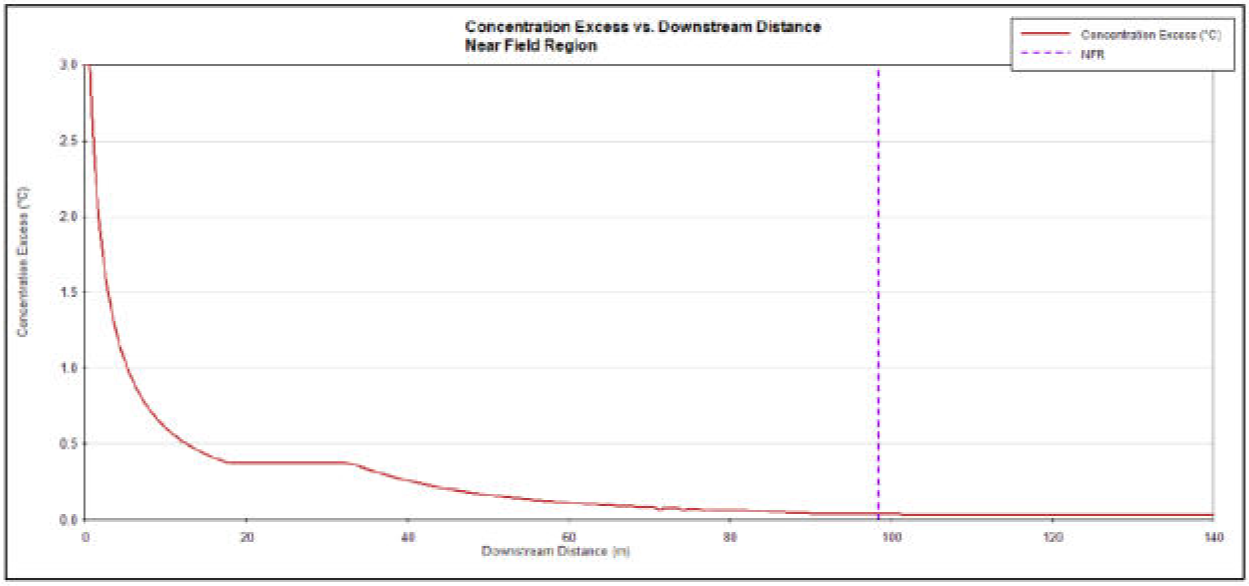


Figure 31: Excess Temperature vs. Downstream Distance
(NE Monsoon – Neap Tide)

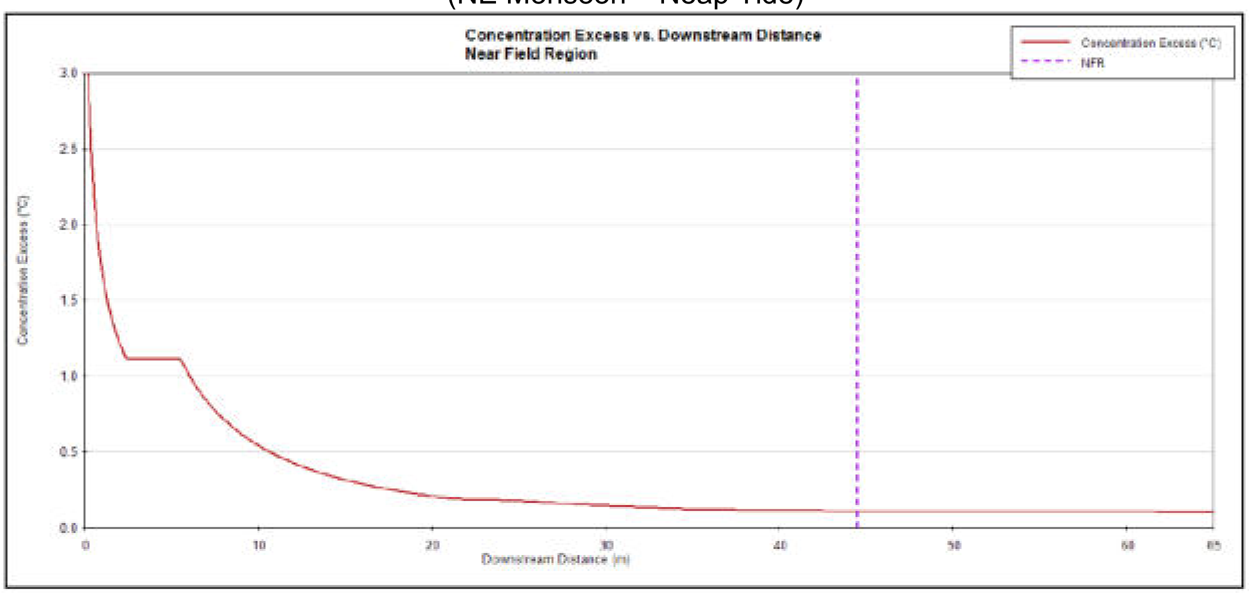


Figure 32: Excess Temperature vs. Downstream Distance
(SW Monsoon – Spring Tide)

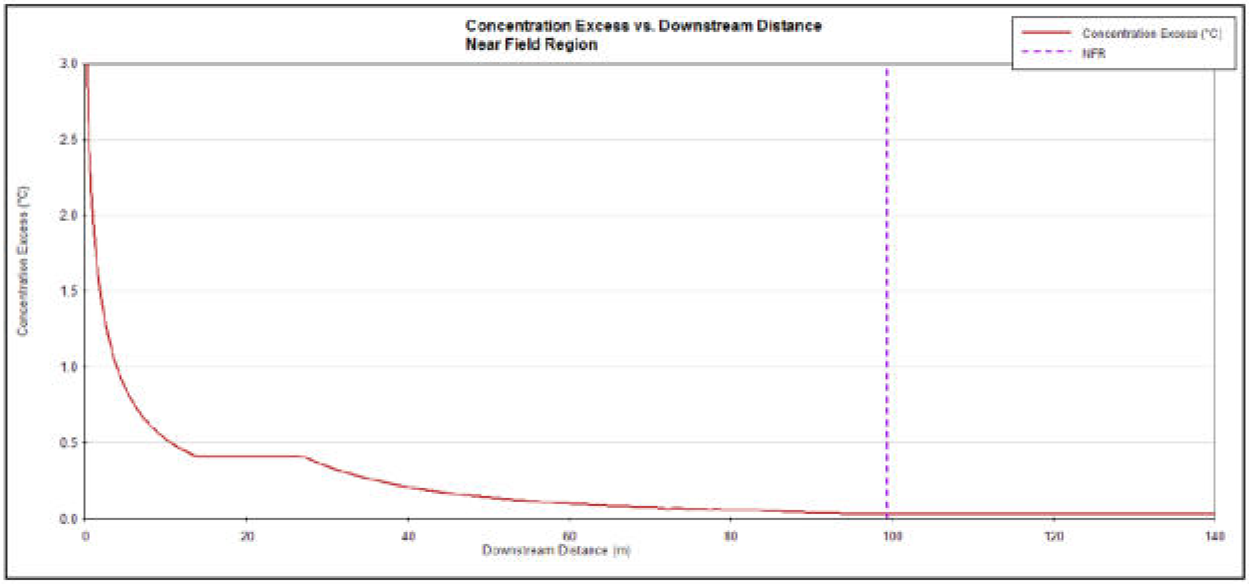
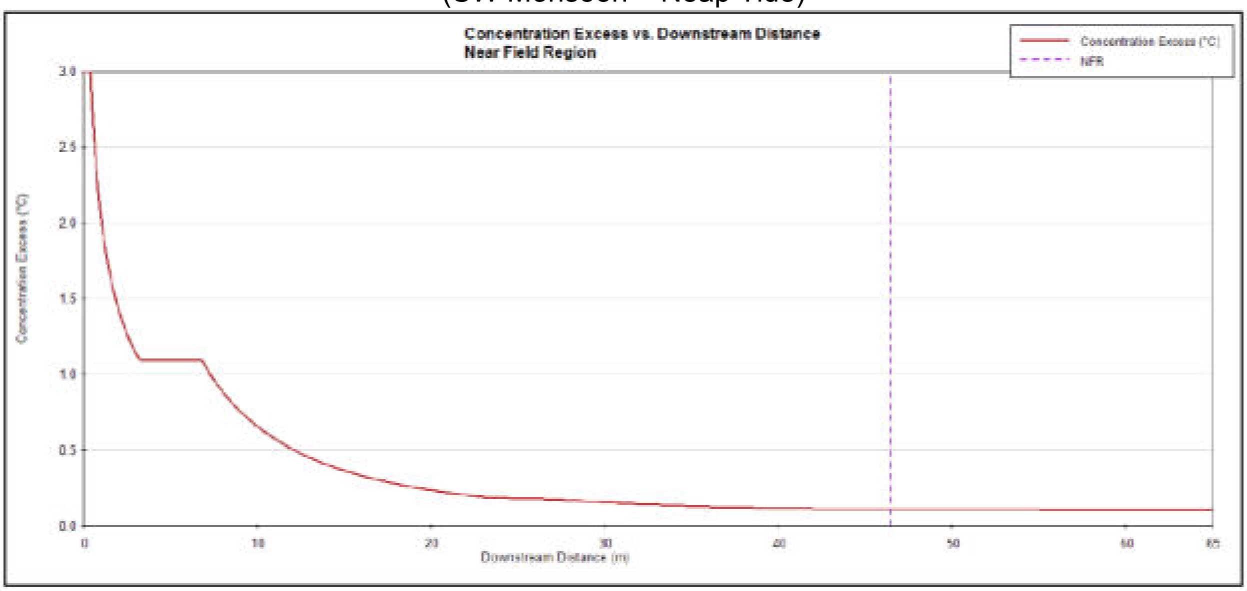


Figure 33: Excess Temperature vs. Downstream Distance
(SW Monsoon – Neap Tide)



221. The apparent 'discontinuity' effects in the Excess temperature vs. Downstream distance in the above graphs are due to a transition in the plume profile that were assumed to cover highly complex flow characteristics in that distance of the discharge point. Owing to the so called "Coanda effect" in the near field, the bottom of the sea limits ambient entrainment into the jet. Most of the near field mixing is due to the buoyancy differences between ambient water and discharge. Though the CORMIX model visualization may appear as a discontinuity, the results of the model rather indicate the user of the presence of these highly complex flow conditions whose

tendency is in line with the expected results, i.e. the neap tide conditions reveal that the Coanda effect occurs closer to the discharge point.

222. If the Coanda effect occurs, it reduces the initial dilution and causes to reduce the dissipation of excess temperature. However, the existing bathymetry at the vicinity of proposed outfall locations indicates a steep sloping bed profile and heat plume releases towards slope further into the deep sea. Hence heat plume tends to flow without having a bottom attachment (Coanda effect), then high initial dispersion and further reduction of excess temperature could be expected. Therefore, this considered case is more conservative.

223. The excess temperatures at the boundary of the near field were extracted from the model results for every scenario and they are presented in the table below. It can be gleaned from all these simulation scenarios that the excess temperatures at the near field boundary are low in the range of 0.036°C to 0.114°C.

Table 16: Excess Temperature at the Edge of Near Field of Simulation Scenarios (Three Outfalls)

Scenario ID	**Monsoon**	**Tide**	**Excess Temp.** (°C)	**Flow Rate** (m^3/h)	**Depth at Discharge** (m)	**Current Condition**		**Excess Temp. at the Edge of Near Field** (°C)
						Speed (m/s)	**Direction (Deg.)**	
NE_S_01	Northeast	Spring	3	6,626.67 x 3	30	0.20	271	0.039
NE_N_01		Neap	3	6,626.67 x 3	30	0.10	280	0.114
SW_S_01	Southwest	Spring	3	6,626.67 x 3	30	0.22	280	0.036
SW_N_01		Neap	3	6,626.67 x 3	30	0.10	277	0.112

224. **Effect of Three Outfalls.** The heat plume discharge was simulated for one outfall in the near field as presented above. In view of the three outfalls alternative, the modeling subsequently presented a visualization of the combined effect of three outfalls within the near field region. The same result obtained for the single outfall for a particular scenario was repeated considering the geographical locations of the outfalls in terms of the downstream distances. Since the outfalls are located in 20 m interval in general downstream direction, the same result was overlaid by 20 m interval.

225. The figures below show the overall results of the elevation or vertical profile and plan view of heat plume dispersion in the near field region. In this case, the results were interpreted using excess temperature isolines.

Figure 34: Interpreted Overall Results for Vertical Profile of Heat Plume for NE Monsoon – Spring Tide

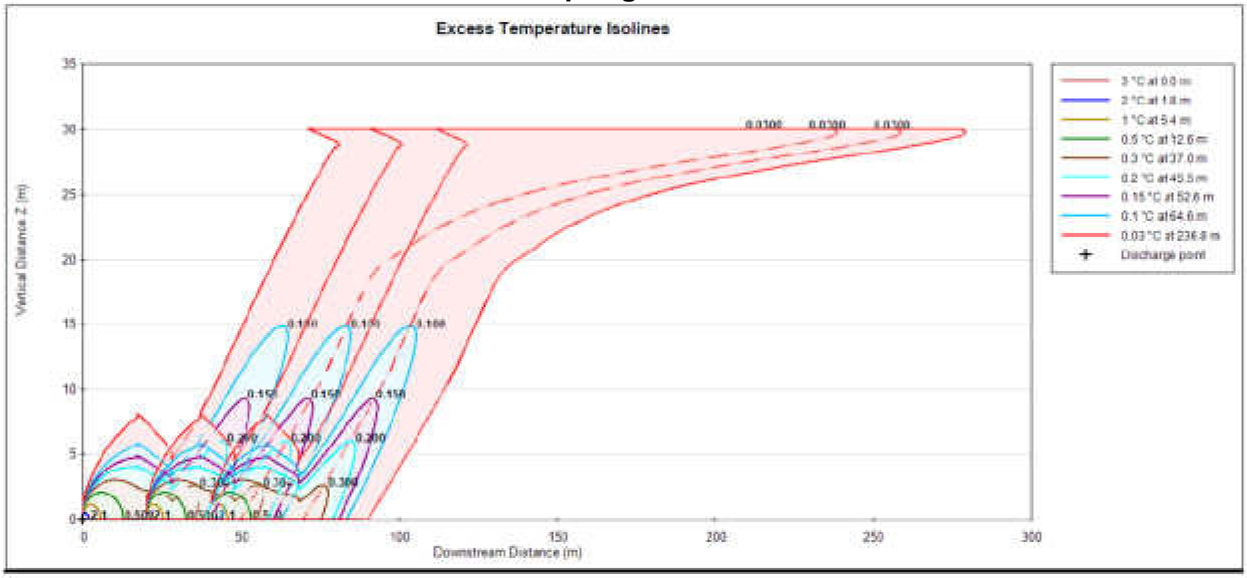


Figure 35: Interpreted Overall Results for Vertical Profile of Heat Plume for NE Monsoon – Neap Tide

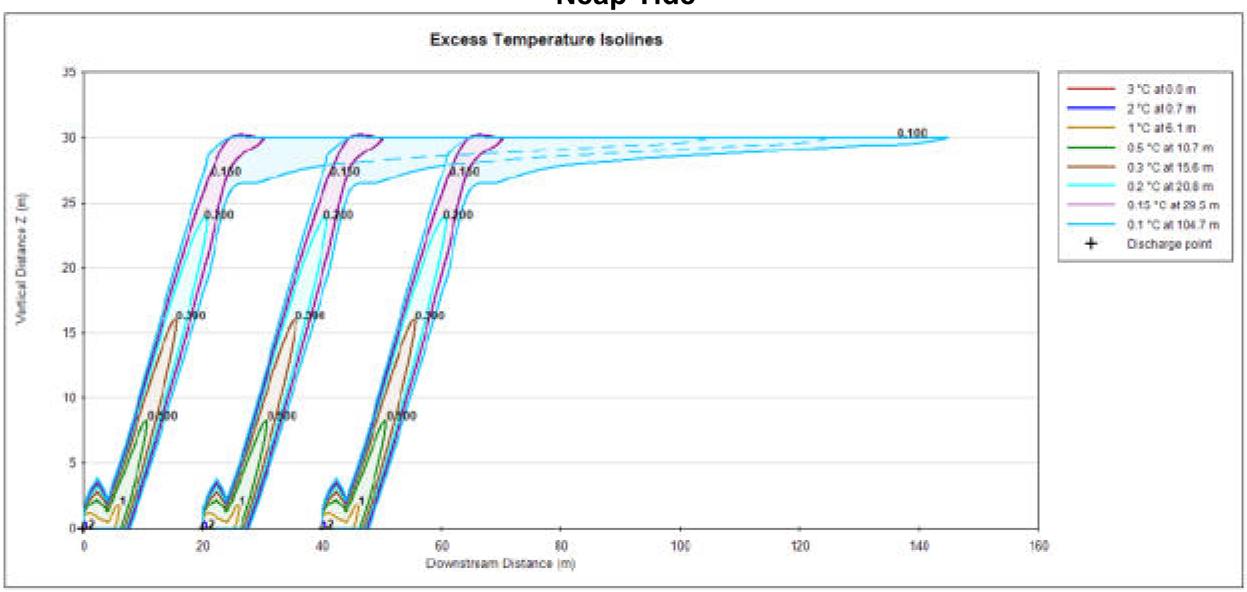


Figure 36: Interpreted Overall Results for Vertical Profile of Heat Plume for SW Monsoon – Spring Tide

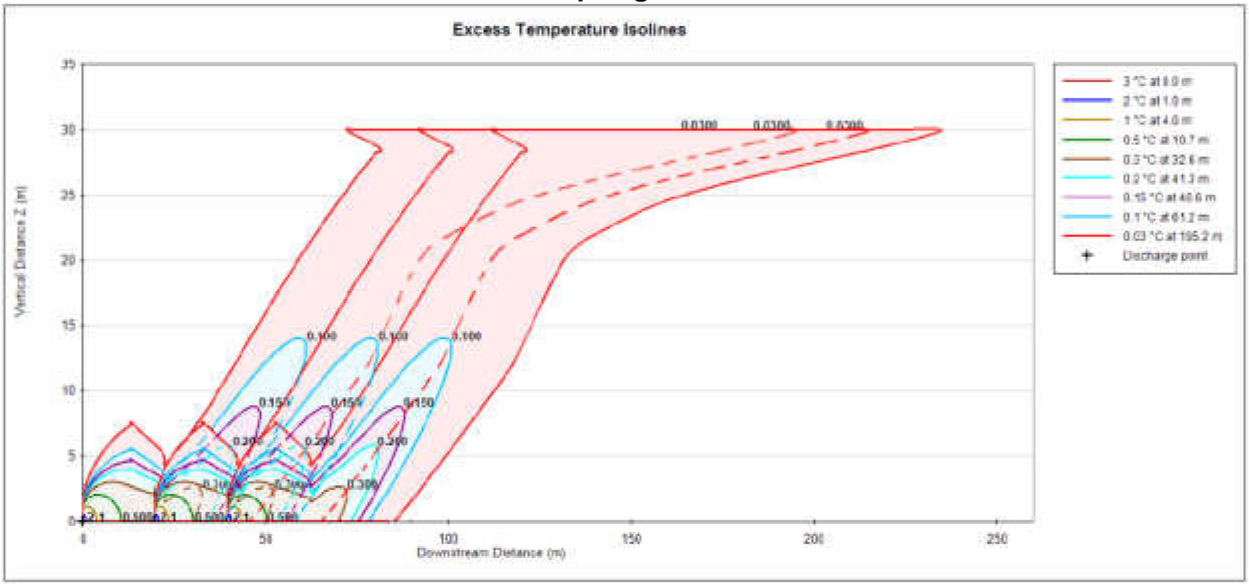


Figure 37: Interpreted Overall Results for Vertical Profile of Heat Plume for SW Monsoon – Neap Tide

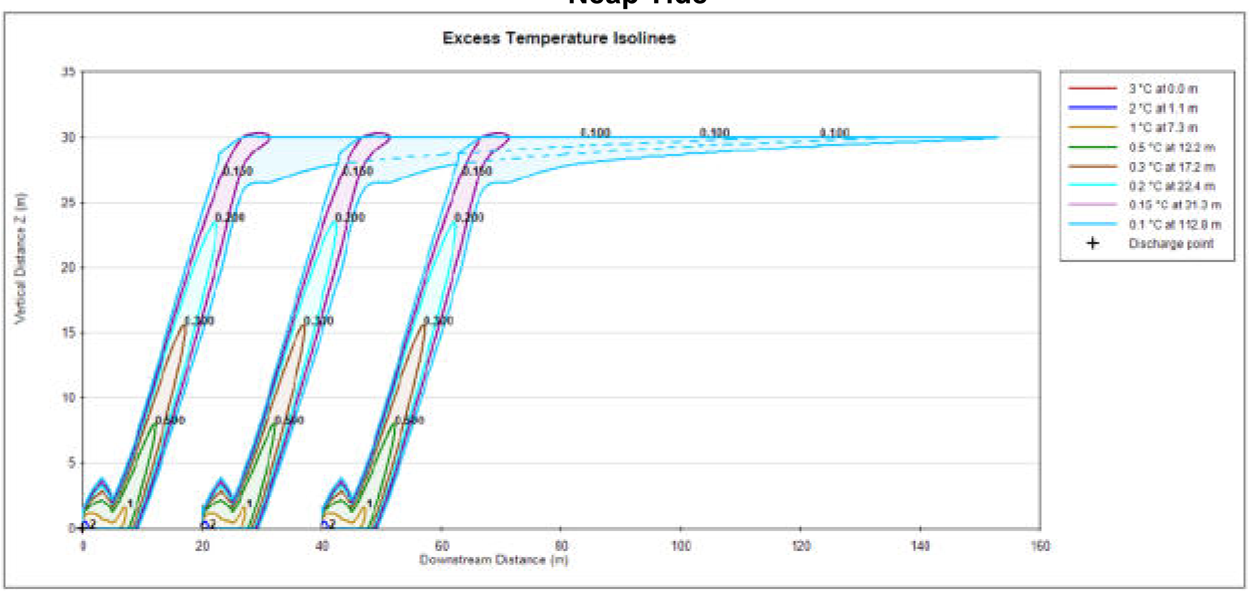


Figure 38: Interpreted Overall Results for Plan View of Heat Plume for NE Monsoon – Spring Tide

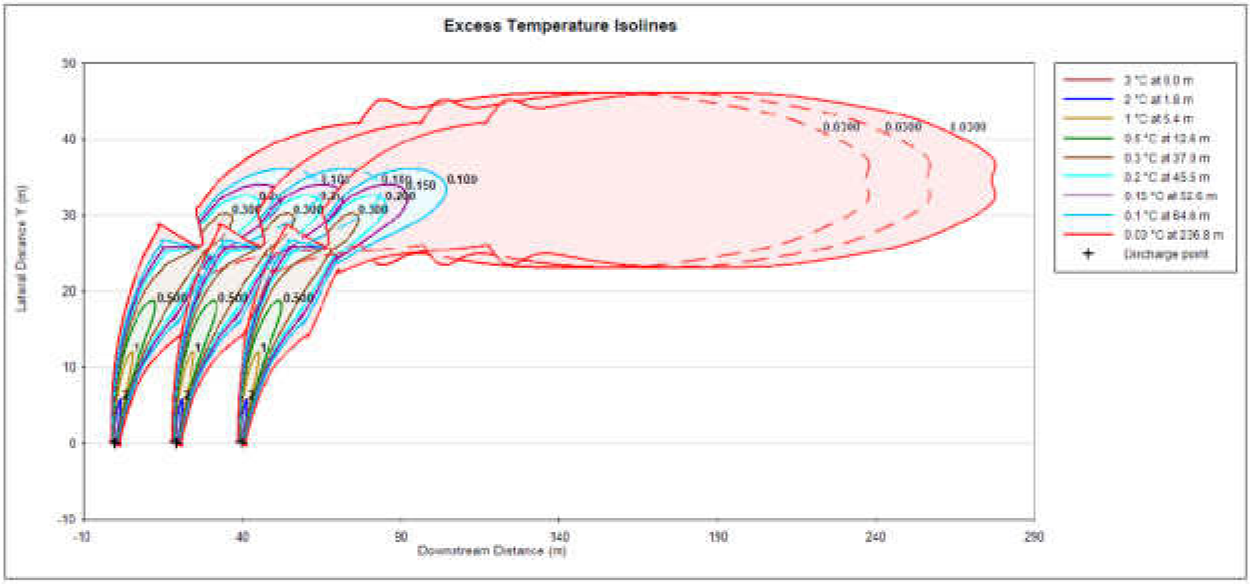


Figure 39: Interpreted Overall Results for Plan View of Heat Plume for NE Monsoon – Neap Tide

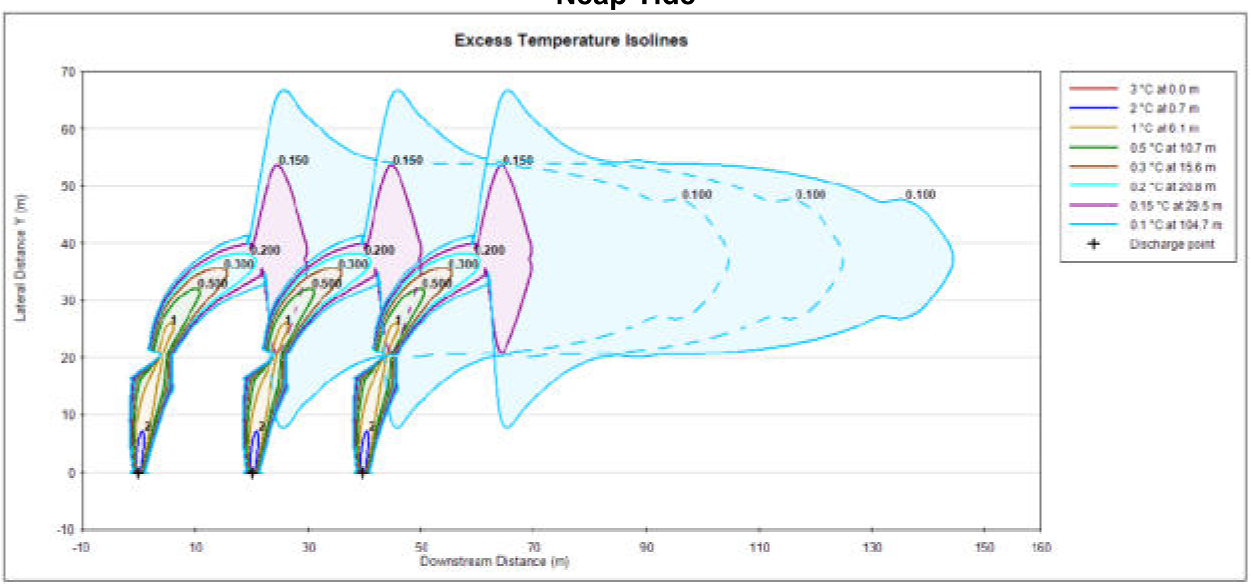


Figure 40: Interpreted Overall Results for Plan View of Heat Plume for SW Monsoon – Spring Tide

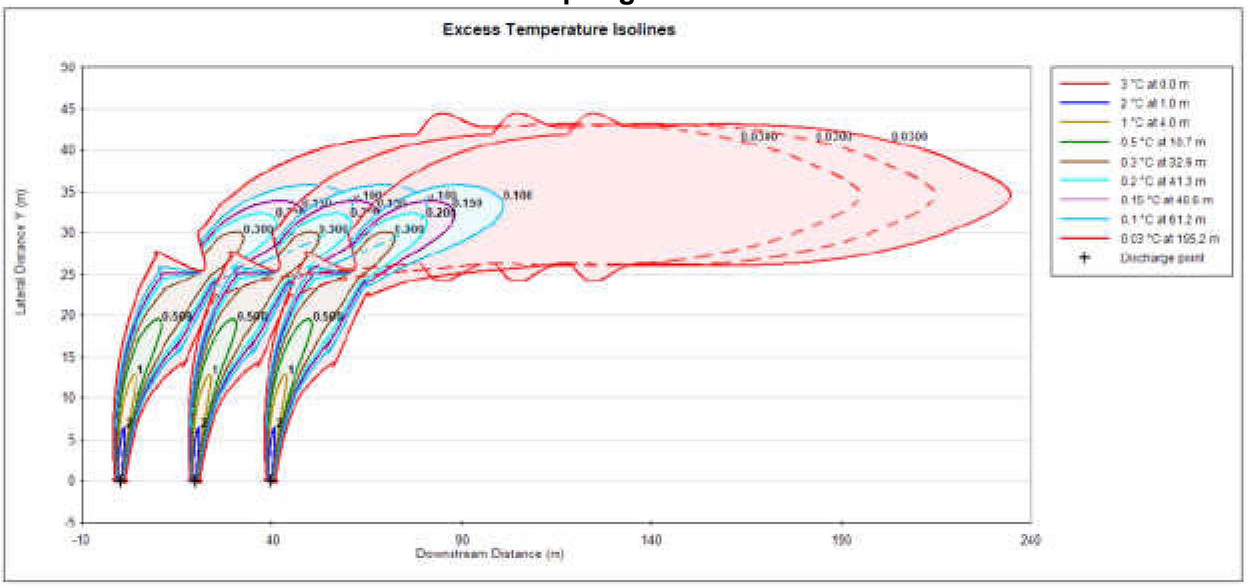
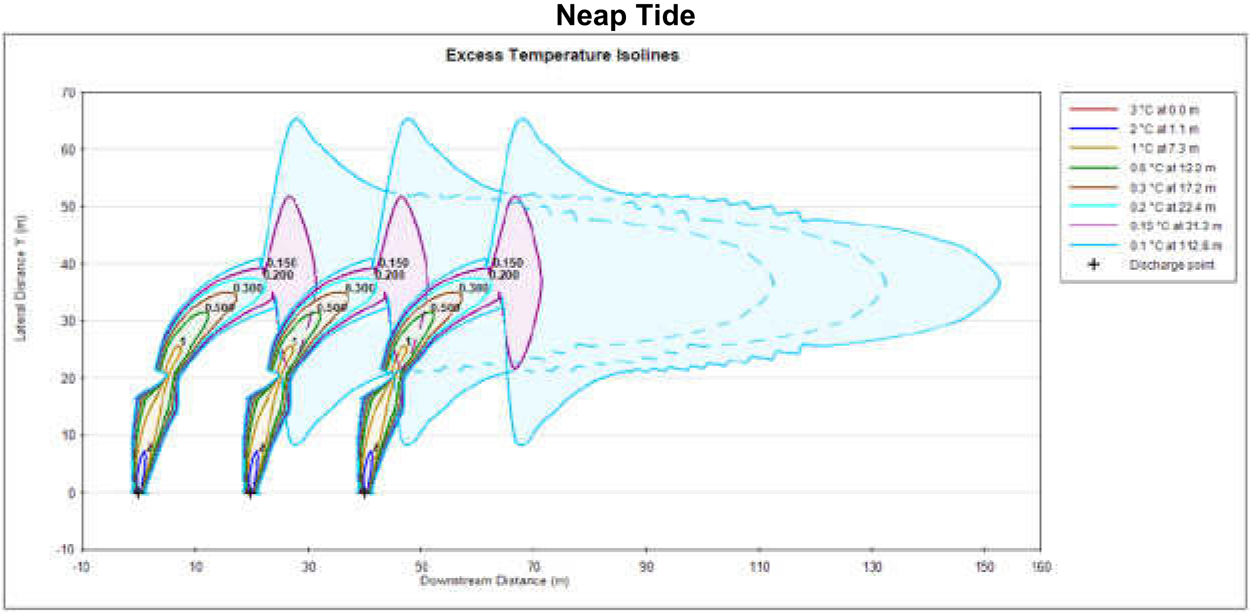


Figure 41: Interpreted Overall Results for Plan View of Heat Plume for SW Monsoon – Neap Tide



226. Based on the above excess temperature isolines representing the effect of the three outfalls, results show that for the near-field model, the temperature difference of the cooling water over ambient drops to around 1ºC in less the 10 meters from the outfalls, and reduces further to 0.5ºC and less as the plume spreads farther beyond 10 meters from the outfalls.

227. **Single Outfall Alternative**. Another alternative of using single outfall was also simulated to determine the excess temperature in the near-field. For this alternative, the discharge pipe will have diameter of 1.9m to maintain the discharge velocity of 2 m/s

228. Same as the previous simulations, four scenarios, (i.e. two monsoon conditions and two tidal conditions) were also considered in this simulation. Accordingly, graphical presentation of heat plume dispersion for different scenarios are presented in the figures below.

Figure 42: 3-D View - Cooling Water Discharge at Near-Field Region for Combined Single Outfall (NE Monsoon – Spring Tide)

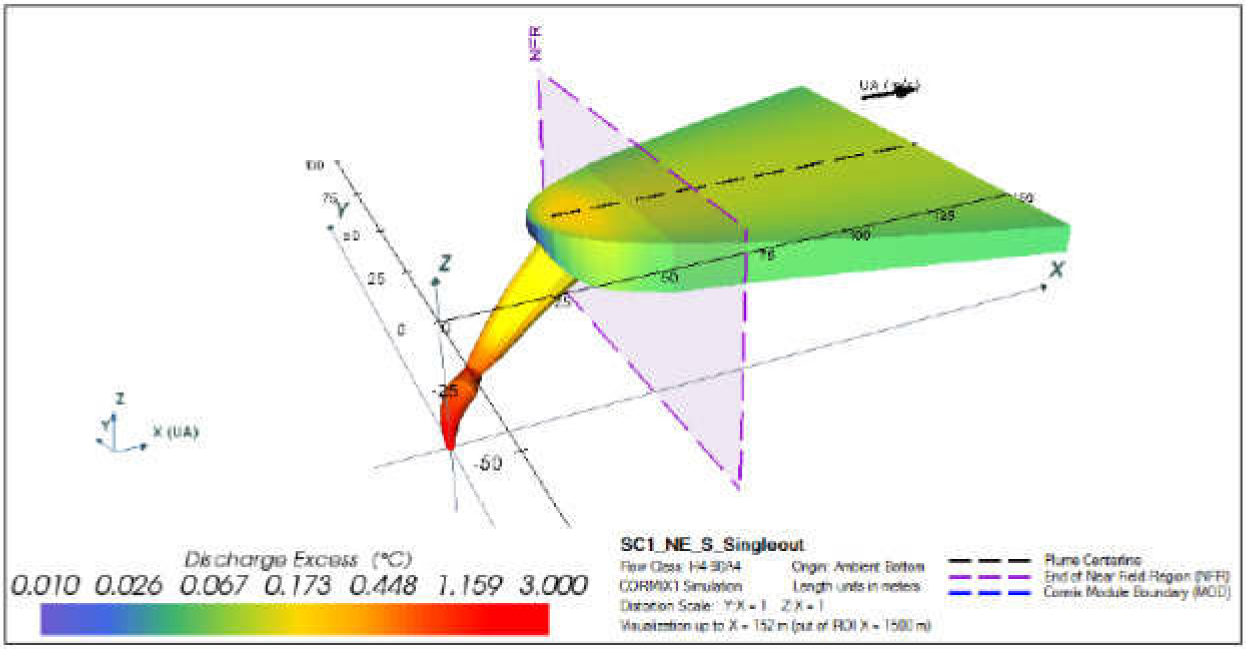


Figure 43: Plan View – Cooling Water Discharge at Near-Field Region for Combine Single Outfall (NE Monsoon – Spring Tide)

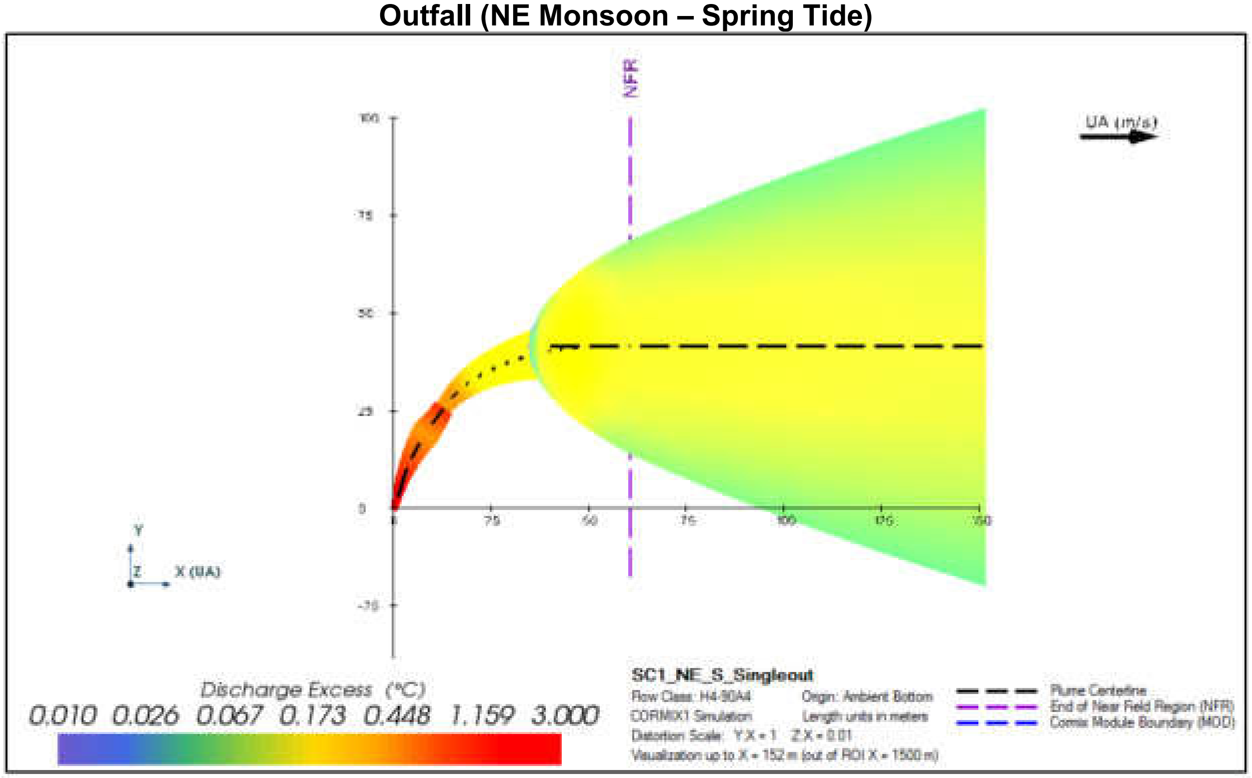


Figure 44: Elevation View – Cooling Water Discharge at Near-Field Region for Combine Single Outfall (NE Monsoon – Spring Tide)

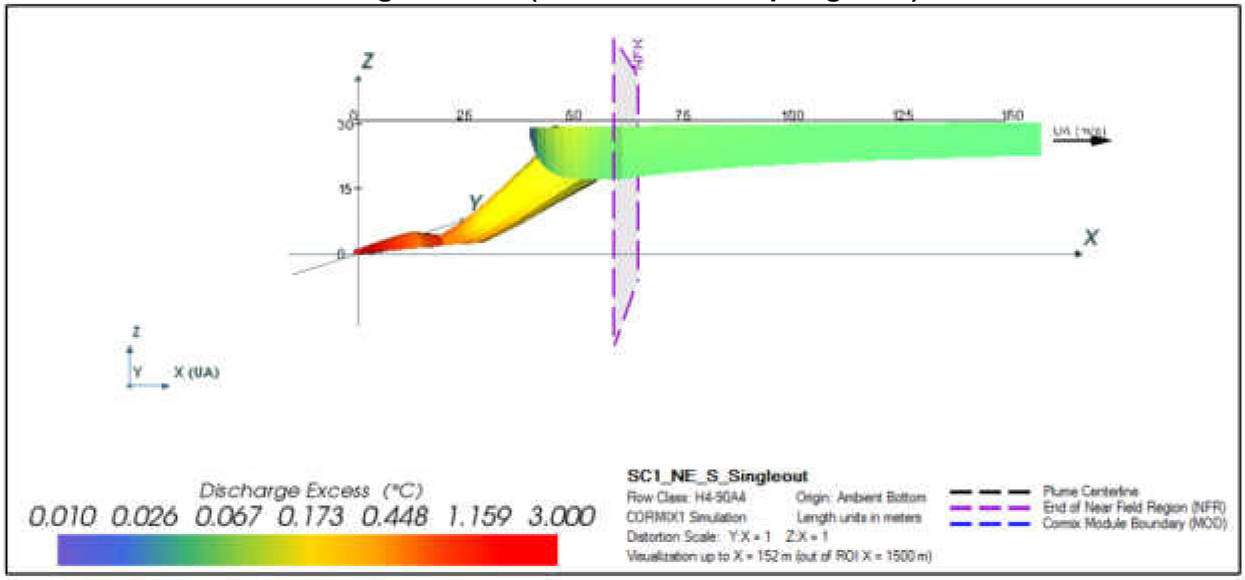


Figure 45: 3-D View – Cooling Water Discharge at Near-Field Region for Combined Single Outfall (NE Monsoon – Neap Tide)

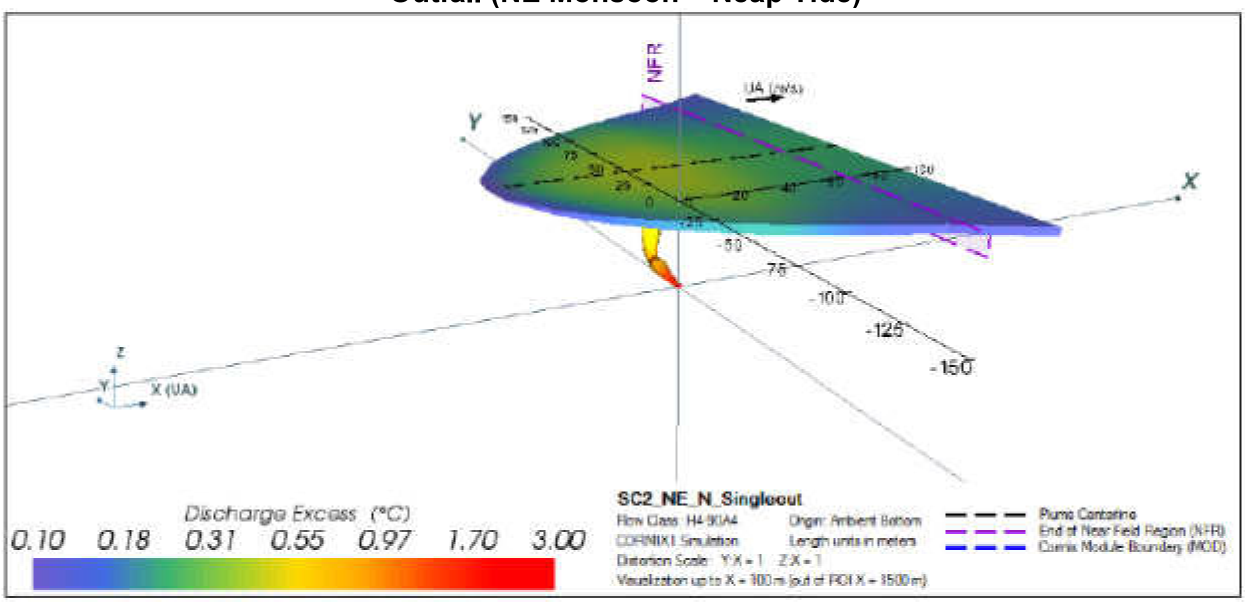


Figure 46: Plan View – Cooling Water Discharge at Near-Field Region for Combine Single Outfall (NE Monsoon – Neap Tide)

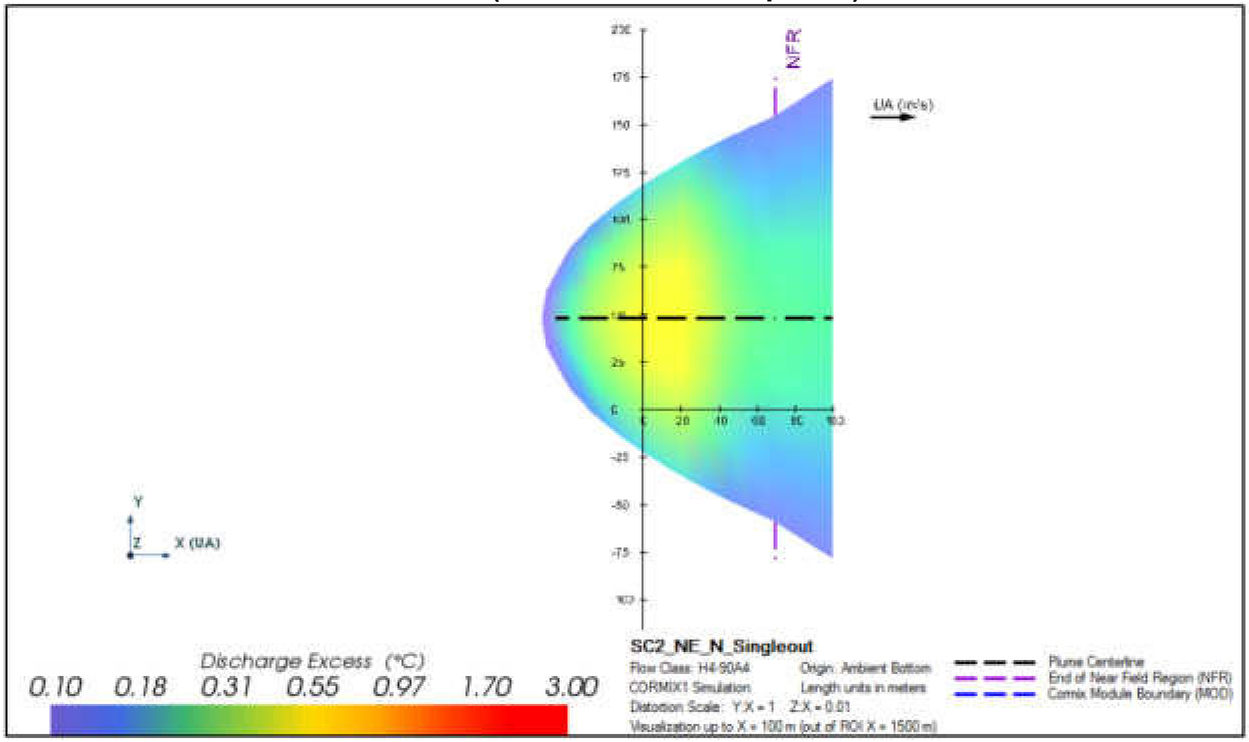


Figure 47: Elevation View – Cooling Water Discharge at Near-Field Region for Combine Single Outfall (NE Monsoon – Neap Tide)

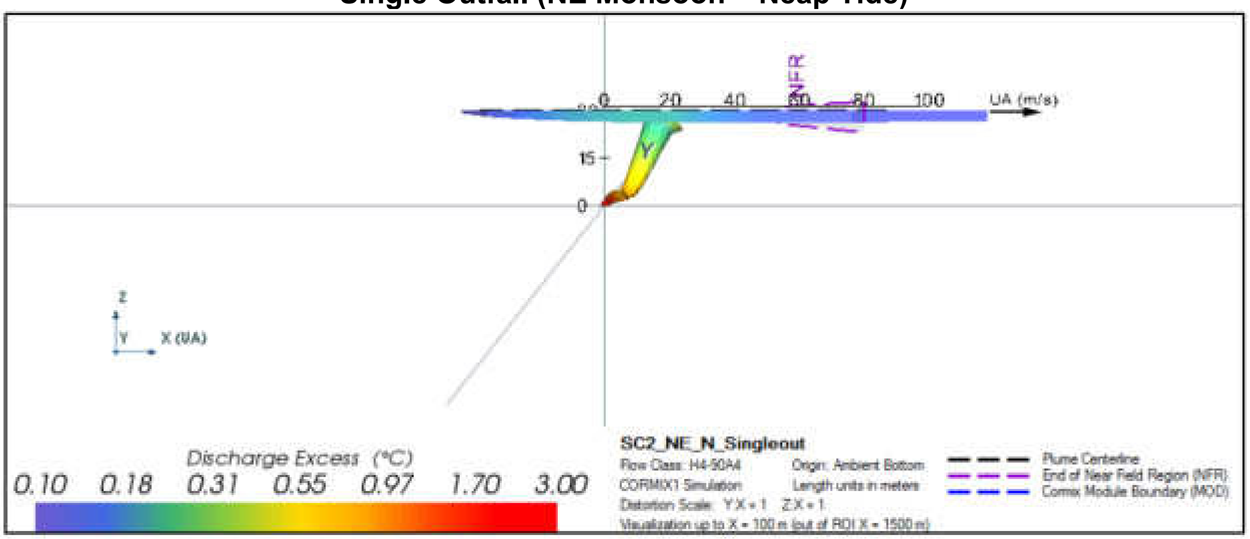


Figure 48: 3D View – Cooling Water Discharge at Near-Field Region for Combined Single Outfall (SW Monsoon – Spring Tide)

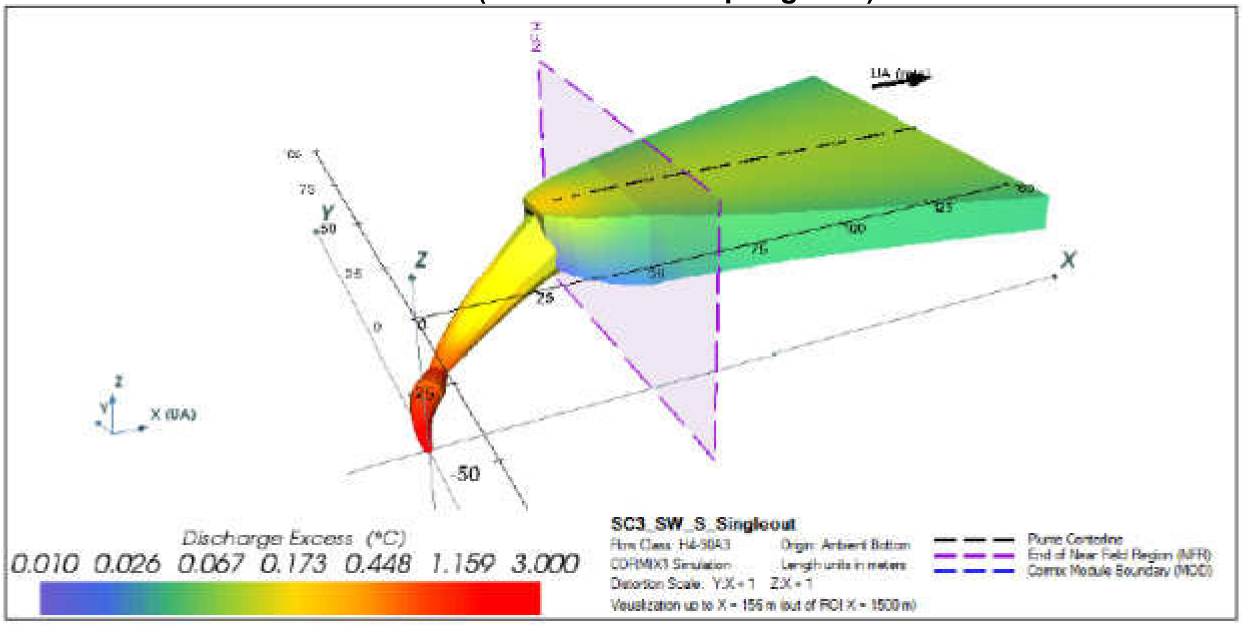


Figure 49: Plan View – Cooling Water Discharge at Near-Field Region for Combine Single Outfall (SW Monsoon – Spring Tide)

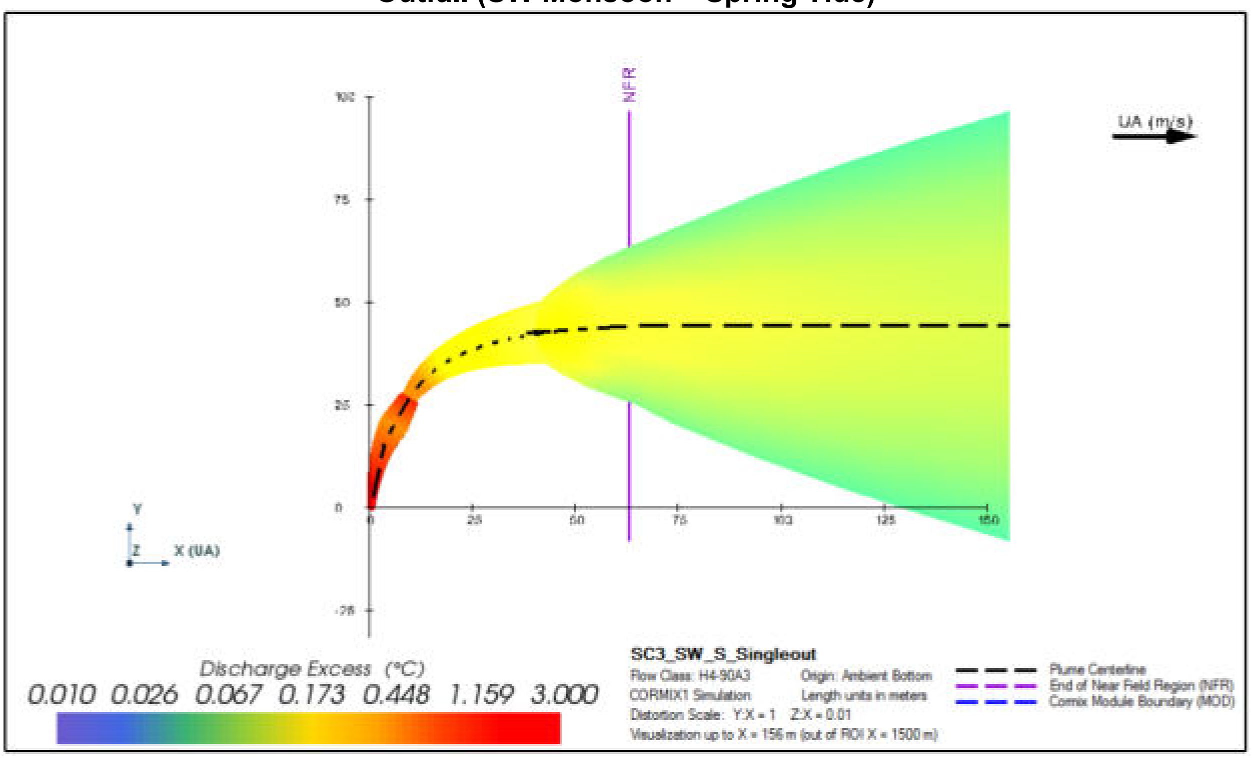


Figure 50: Elevation View – Cooling Water Discharge at Near-Field Region for Combine Single Outfall (SW Monsoon – Spring Tide)

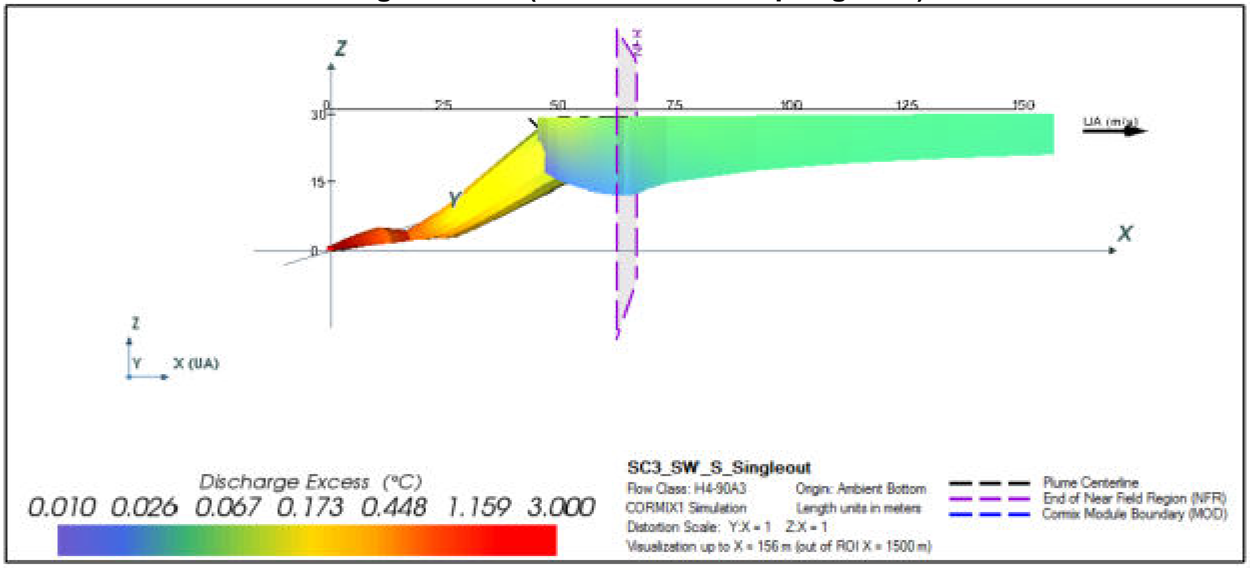


Figure 51: 3D View – Cooling Water Discharged at Near-Field Region for Combined Single Outfall (SW Monsoon – Neap Tide)

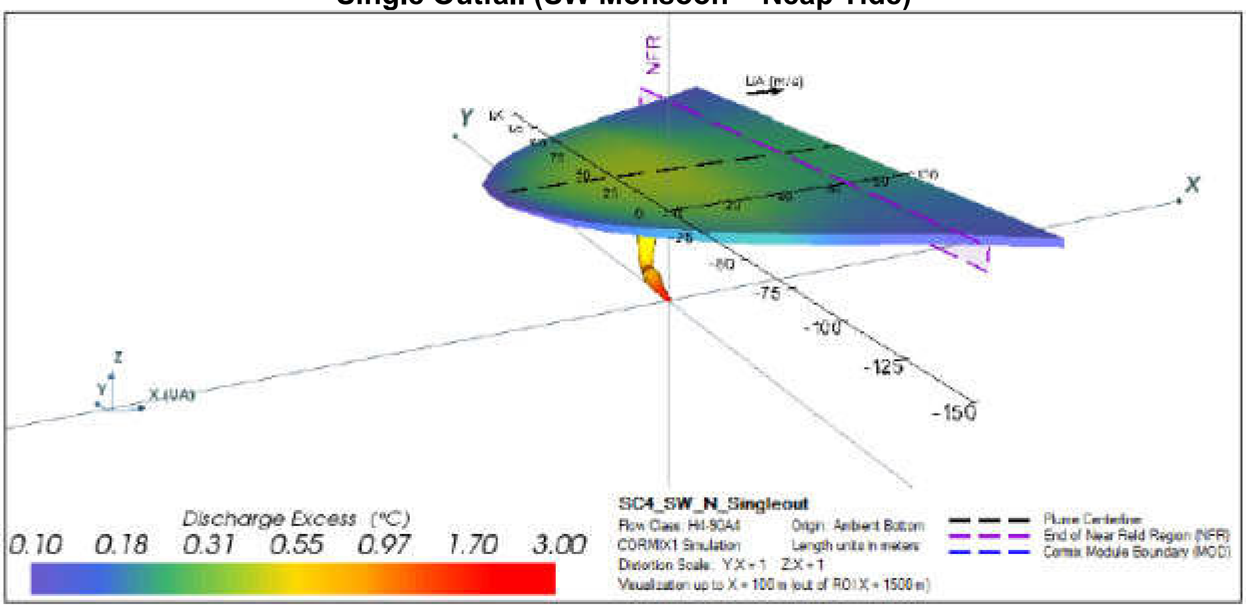


Figure 52: Plan View – Cooling Water Discharge at Near-Field Region for Combine Single Outfall (SW Monsoon – Neap Tide)

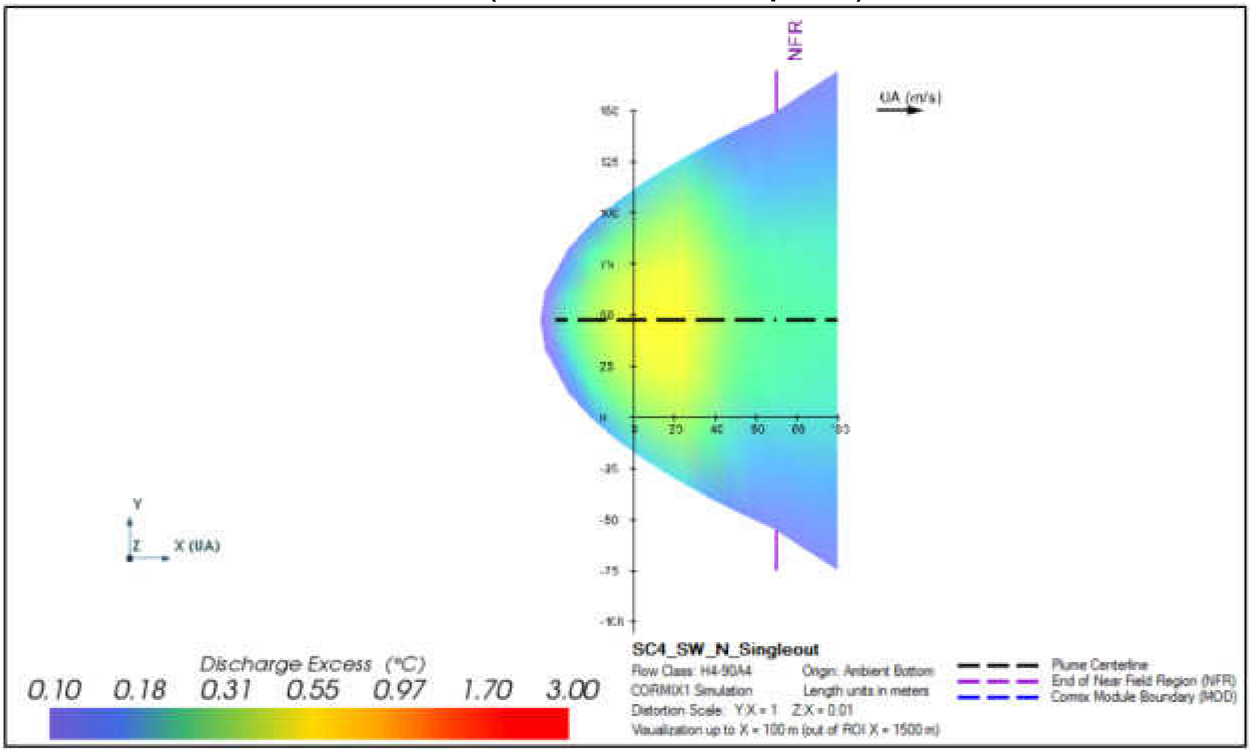
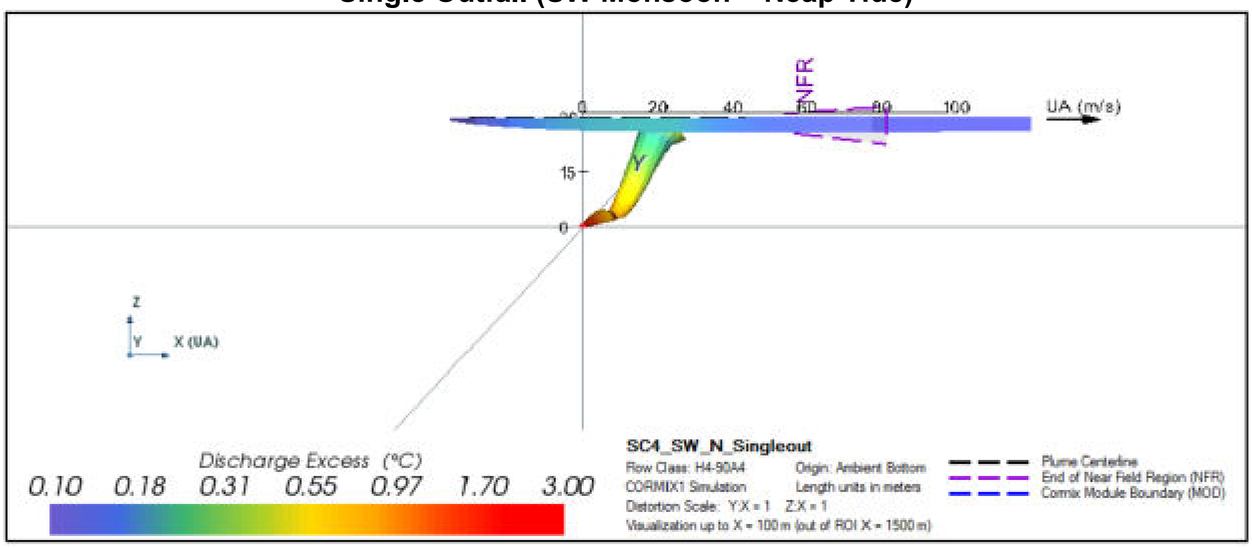


Figure 53: Elevation View – Cooling Water Discharge at Near-Field Region for Combine Single Outfall (SW Monsoon – Neap Tide)



229. Based on the simulation and consistent with the visualization figures above for the single outfall alternative, the excess temperatures have been plotted versus the downstream distance for each of the scenarios. Figures below show the graphical presentations.

Figure 54: Excess Temperature vs Downstream Distance for Combine Single Outfall (NE Monsoon – Spring Tide)

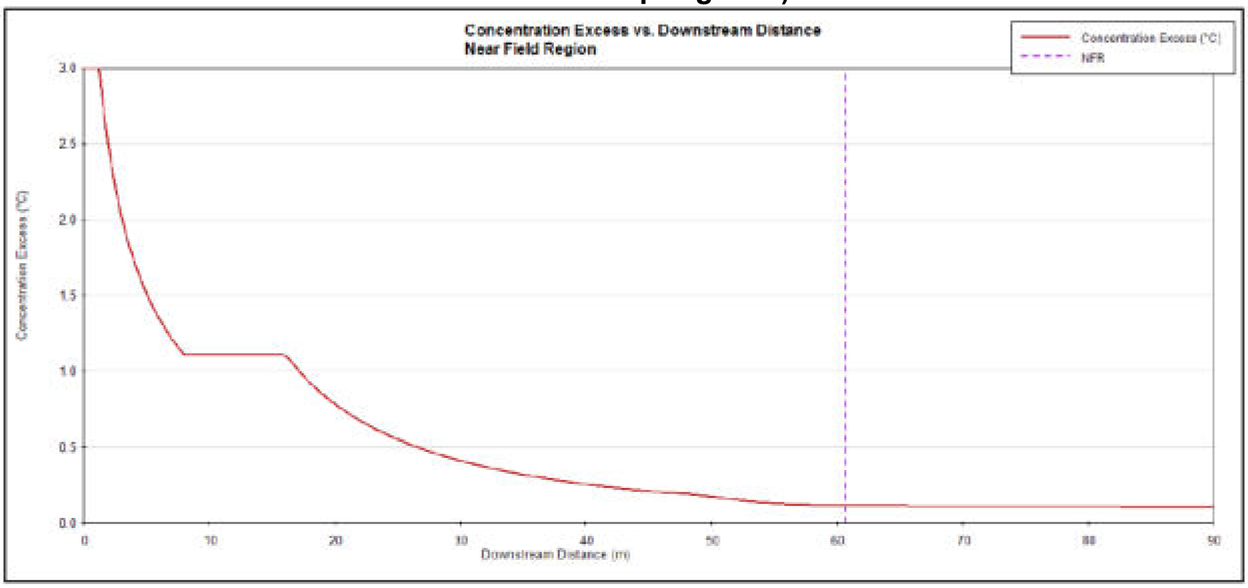


Figure 55: Excess Temperature vs Downstream Distance for Combine Single Outfall (NE Monsoon – Neap Tide)

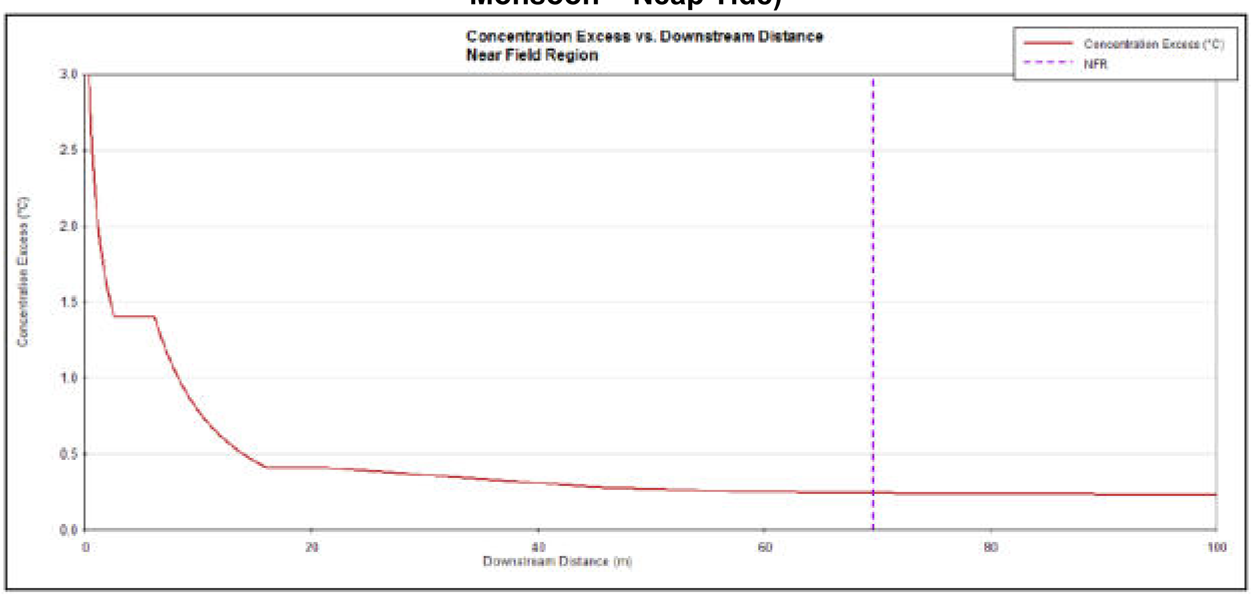


Figure 56: Excess Temperature vs Downstream Distance for Combine Single Outfall (SW Monsoon – Spring Tide)

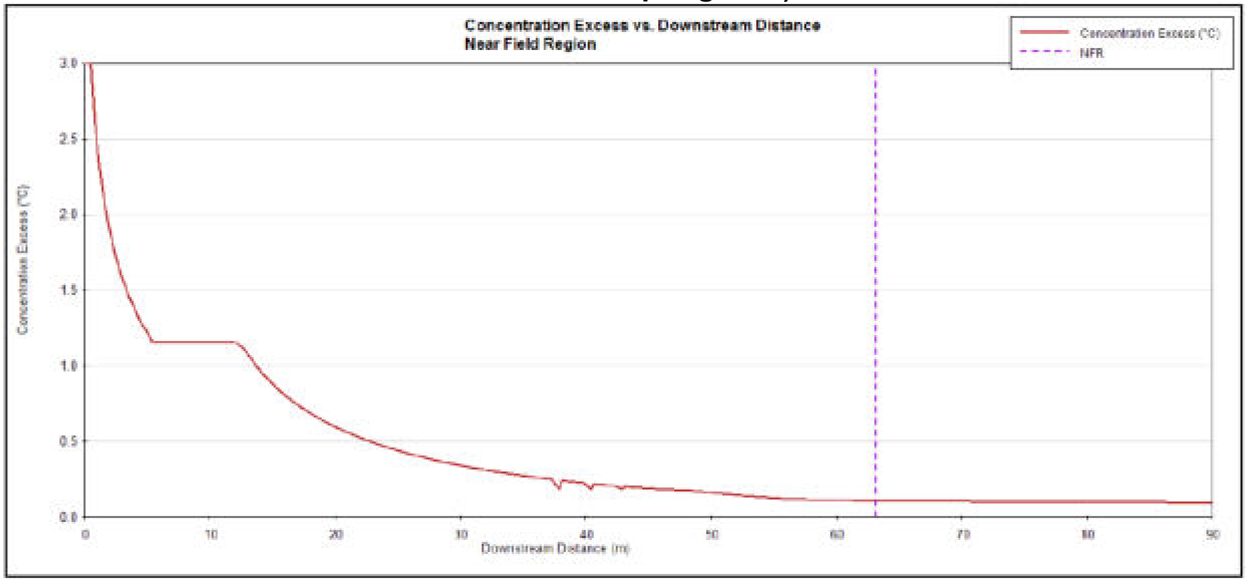
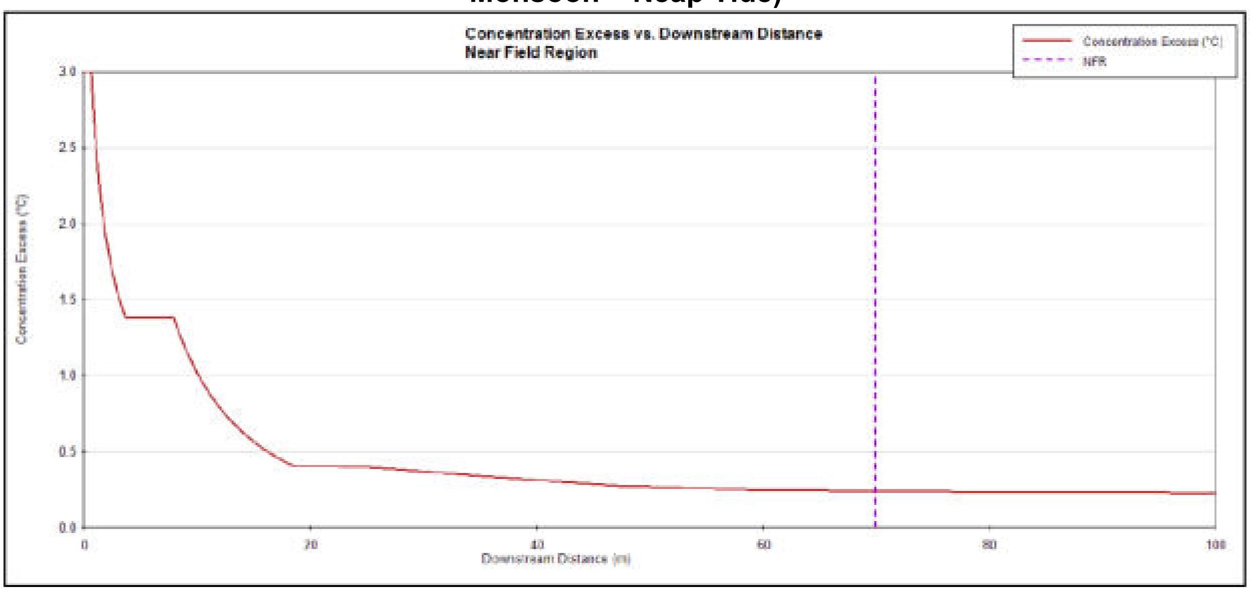


Figure 57: Excess Temperature vs Downstream Distance for Combine Single Outfall (SW Monsoon – Neap Tide)



230. The excess temperatures at the boundary of the near field were extracted from the model results for every scenario and they are presented in the table below. It can be gleaned from all these simulation scenarios that the temperatures at the near field are relatively higher than the temperatures taken from the three-outfall scenario. However, these temperatures are still considered low in the range of 0.107ºC to 0.244ºC. The apparent discontinuity in these graphs are known as the “Coanda effect” as described and explained above.

Table 17: Excess Temperature at the Edge of Near Field of Simulation Scenarios (Single Outfall)

Scenario ID	Monsoon	Tide	Excess Temp. (ºC)	Flow Rate (m^3/h)	Depth at Discharge (m)	Current Condition		Excess Temp. at the Edge of Near Field (ºC)
						Speed (m/s)	Direction (Deg.)	
NE_S_01	Northeast	Spring	3	19,880	30	0.20	271	0.118
NE_N_01		Neap	3	19,880	30	0.10	280	0.244
SW_S_01	Southwest	Spring	3	19,880	30	0.22	280	0.107
SW_N_01		Neap	3	19,880	30	0.10	277	0.240

231. **Conclusion on Heat Dispersion for the Near Field Scenarios**. According to the results of the scenarios for the three outfalls alternative, the excess temperature of 3ºC at the outlet is decreased significantly down to 1ºC within the first few meters for both the neap and spring tide conditions. As the outfalls release the hot water plume perpendicular to the shoreline, the excess temperature in the vertical direction and along the shoreline is uncritical (1ºC to 2ºC) in the direct vicinity of the outfall. Current speeds are high during spring tide which results in a higher initial dilution, i.e. in lower temperatures in the near field, but in a more extended mixing zone of the heat plume which yet reveals lower excess temperatures compared to the neap tide.

232. The interpretations of isolines overlaying (representing the effects of three outfalls) show that mixing of heat plume in near field region is very low for neap tide condition. According to the results of vertical profiles, the mixing takes place only after the excess temperature reduces to 0.1ºC. However, temperature isolines overlap at less than 0.5ºC for spring tide condition, and the comparatively high current at outfall would be the reason for that mixing. But the plume reduces its temperature within a short distance, and when it reaches the near field boundary the excess temperature reduces up to 0.03ºC.

233. Whereas, according to the results of the scenarios for the single outfall alternative, there are higher excess temperature at near field boundary compared to the three outfalls system. The higher flow rate for a single outfall would be the reason for these higher excess temperatures.

234. **Far Field Modeling**. The discussions above are the results of modeling done for the near field scenarios using the semi-empirical length scale model, CORMIX. Another modeling has been done to describe the heat dispersion or dissipation as the plume travels beyond the near field boundaries, known as far field region. As turbulent plume travels further away from the discharge location, the jet characteristics become less important and three-dimensional treatment of thermal dispersion is nearly changed to two dimensional treatments. In order to simulate the current phenomena, it is possible to use two-dimensional models. MIKE 21 Hydrodynamic Model combined with Thermal Dispersion Tool has been used for hydrodynamic and thermal dispersion simulation in far field region.

235. **Input Data**. All input parameters used in local hydrodynamic model were used for thermal dispersion modelling. Therefore, two different monsoonal conditions (South-West and North-East) and two different tidal conditions (Spring and Neap) were taken into consideration in the simulation. In addition, heat plume discharge boundary for far-field simulation was established using the near-field model (CORMIX) results. The excess temperature was extracted in near field boundary from CORMIX model and given as an input data for MIKE 21 HD thermal dispersion model. Even though single outfall was simulated in the near field model, effect of all three outfalls

were taken in to far field model. The excess temperature extracted for different scenarios are given in **Error! Reference source not found.**.

Table 18: Input Excess Temperature for Far-Field Model

Scenario ID	Monsoon	Tide	Current Condition		Excess Temp. at the Edge of Near Field (ºC)
			Speed (m/s)	Direction (Deg.)	
NE_S_01	Northeast	Spring	0.20	271	0.039
NE_N_01		Neap	0.10	280	0.114
SW_S_01	Southwest	Spring	0.22	280	0.036
SW_N_01		Neap	0.10	277	0.112

236. **Model Results for the Far Field**. Scenarios with neap tidal condition shows higher influence with their high input temperatures at near-field boundary and low current speed relative to the spring tide. As an example, Scenario ID: NE_N has been used for further discussion which resulted in the highest excess temperature at the near field boundary among considered four scenarios. **Figure 58** and **Figure 59** show the temperature variation in 2D plain for this high influence scenario when current directed westward and eastward respectively. According to the results, 0.03ºC excess temperature at around 1km range from the discharge point for both cases. However, 0.03ºC excess temperature is a very low temperature and negligible in coastal environment. Therefore, thermal dispersion is very high even in a high influence scenario and its effect to the costal environment is very low. The thermal dispersion plots for all the other scenarios are included in Appendix 8.

Figure 58: Thermal Dispersion towards West at Scenario NE_N

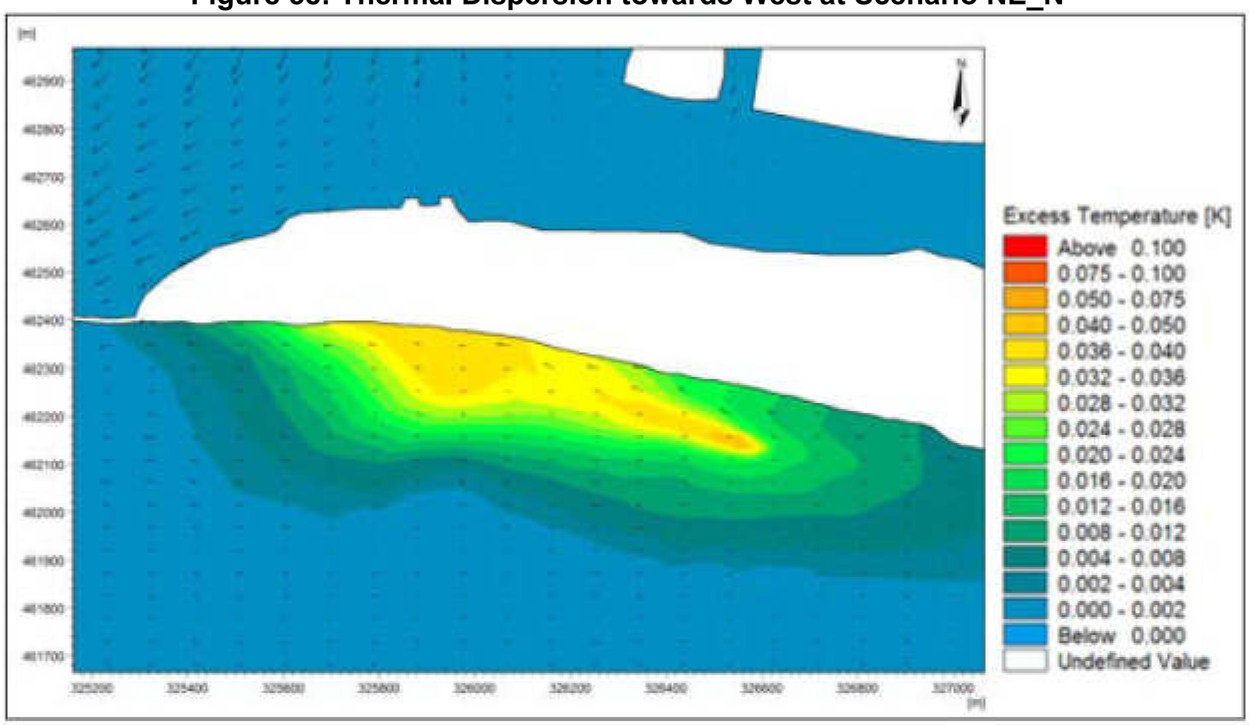
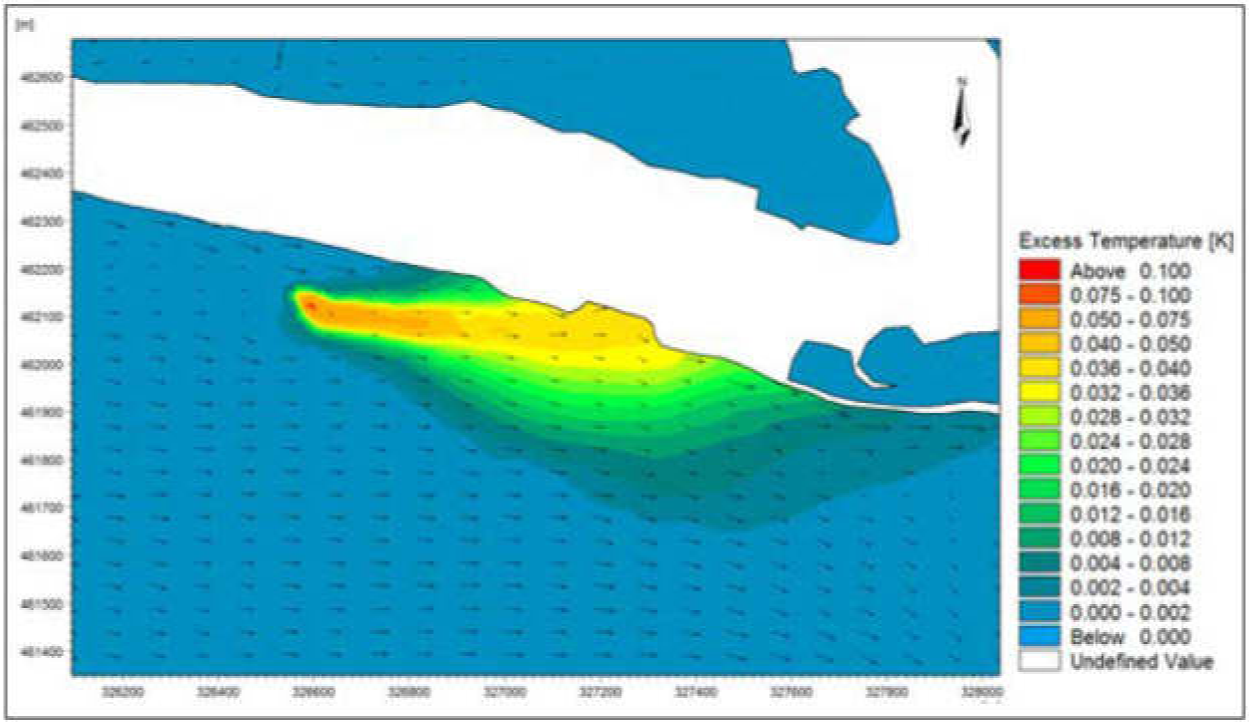


Figure 59: Thermal Dispersion towards East at Scenario NE_N



237. From the far field model results, the temperatures at 10m and 20m depths next to the middle outfall location (for the three outfalls configuration) were extracted. The locations and coordinates of the extracted points are given below.

Table 19: Coordinates for Extracted Locations at 10m and 20m Depth

Location	Coordinates	
	Latitude	Longitude
10 m depth	4°10'47.56"N	73°26'15.58"E
20 m depth	4°10'47.37"N	73°26'15.55"E

238. The maximum temperatures obtained through extracted results for different scenarios are given in **Table 20**. Even though extracted points are very close to the middle outfall, excess temperature values are not significantly high. The maximum values are even less than the near field boundary excess temperatures for every scenario. Heat plume projections are directed seaward, but the extracted points are located at the other way towards the shoreline. Hence, high temperatures would not be expected to transfer northward to the shoreline. The direction of heat plume projections (which is seaward or away from the shoreline) would be the reason for low maximum temperatures in the north side of the outfalls.

Table 20: Maximum Excess Temperature at Extracted Points (10m and 20m Depths)

Scenario ID	Monsoon	Tide	Maximum Excess Temperature	
			10 m depth	20 m depth
NE_S_01	Northeast	Spring	0.020	0.021
NE_N_01		Neap	0.036	0.038
SW_S_01	Southwest	Spring	0.016	0.017
SW_N_01		Neap	0.065	0.073

239. **Summary and Conclusion**. Based on the above results of modeling, summary and conclusion are as follows:

(i) In order to find out thermal dispersion of hot water plume from the outfall of cooling water from the WTE plant, a set of numerical model simulation was carried out for different monsoon and tidal conditions.

(ii) Measured data as well as reliable predicted data were utilized as model inputs, and analyzed them before applied to the model.

(iii) MIKE 21 SW model was used to establish the wave condition at site for different monsoon periods (South-West and North-East) and MIKE 21 HD model was used to obtain the current condition at discharge point at M8 location. Further, both spring and neap tidal conditions were simulated separately, and about 0.2m/s and 0.1m/s average current speed were obtained at the discharge point for spring and neap tide, respectively. Wave condition was not significantly affected on current condition at discharge point.

(iv) Two modeling system were used thermal dispersion modeling, namely CORMIX model for near field dispersion and MIKE 21 HD coupled with thermal dispersion tool for far field dispersion.

(v) According to the near-field model results,

a. Excess temperatures at the near field boundary for the neap tidal conditions (around 0.11°C) were higher than for the spring tidal conditions (0.03 °C)

b. A high temperature reduction was observed within a few meters from the released point.

c. Heat plume mixing of three outfalls shows the overlay interpretation for spring tidal condition, but it happens within a short distance from the release point and eventually, the excess temperature reduces up to 0.03°C at near field boundary.

d. Higher excess temperatures (0.11°C to 0.24°C) at the near field boundary were observed in a single outfall alternative compared to the three separate outfalls system. The high flow rate for the single outfall case would be the reason for the result.

(ii) Results obtained from near-field model were used as input parameter for far-field model.

(iii) Far-field model results represent the temperature spreading in 2D plain for different scenarios.

(iv) According to far-field model results,

a. Same as the near-field model, scenarios with the neap tidal condition show some influence compared to the spring tidal situations.

b. High spreading of heat is also observed in the neap tidal condition but the excess temperature values are small, which would not significantly impact coastal environment.

c. Maximum excess temperatures extracted shoreward from the outfall locations at 30m depth are low. Even though extracted points are very close to the middle outfall (both points are located around within 10m distance from HWO2), heat plume projections are directed to opposite way (towards the deep sea). Therefore, the direction of heat plume projections would be the reason for low maximum temperatures in the north side of the outfalls.

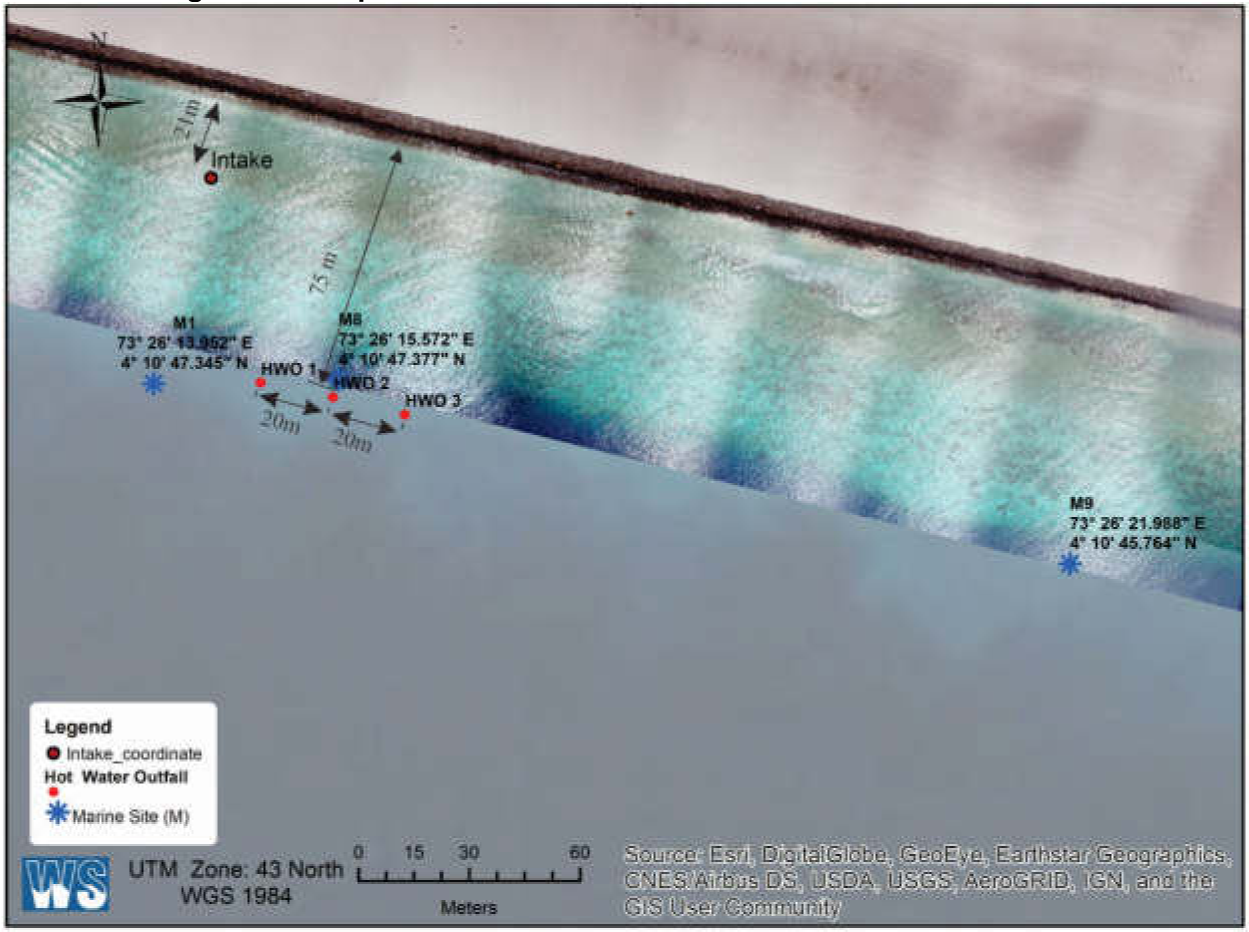
240. In view of the above findings and conclusions, positioning the outfall at a depth of 30 meters could already reduce the excess temperature from 3°C to less than 0.5°C at a distance of 10 meters from the outfall for the worst case scenario (high influence scenario). As the water disperses farther to 20 meters, the excess temperature reduces to less the 0.1°C, which is already considered negligible as far as the vast coastal environment is concerned. From this findings of the modeling, it can be concluded that for both alternatives (three outfalls and one outfall), the hot water will disperse without impacting any marine life such as corals or pelagic marine life that may be present at the upper strata and reef wall.

241. **Selection of Best-Case Alternative**. From the findings, the best-case scenario is obviously the use of three outfalls which showed faster heat dissipation rate and lower excess temperatures at the boundaries of the respective near field models. Use of the three outfalls will provide faster dispersion of heat at a shorter distance that will better ensure lower excess temperatures as the hot water disperses farther from the outfalls.

E. Alternatives on Intake Location for WTE Cooling Water

242. The results of the underwater survey at the southern coastal section of the project site (M1, M8, M9, and M10) reveals no significant underwater marine life at these locations. This provides greater flexibility for the DBO Contractor to position the intake location of cooling water at any of these locations. However, in order to reduce impacts on the shoreline during construction phase, intake location will be positioned at the vicinity of Sections M1 and M8. This will ensure that construction of intake and discharge line structures, will be integrated and undertaken coherently at the same or close alignment and location. See Figure 60 for recommended position of the inlet structure.

Figure 60: Proposed Location of Intake Relative to Outfall Location



243. The DBO Contractor shall include in its final detailed design the condition that the inlet opening of its sub-surface intake line is positioned at considerable distance from the outfall and away from the direction of the cooling water jet plume. The location should have seawater temperature at ambient level.

V. DESCRIPTION OF THE ENVIRONMENT

A. Geology and Topography

244. Thilafushi is located in North Malé atoll, 9.5km from Malé. In terms of geographic coordinates, it is located at 04° 11' 00" N and 73° 26' 44" E. The nearest inhabited island is Villingili, approximately 7.1 km east of Thilafushi. Thilafushi Island has been developed as a solid waste landfill since December 1992. The island was initially developed as a sand bank using dredged material from the Thilafushi Reef. Since then, land has been reclaimed by placing solid waste in dredged holes on the reef flat and later topping it up with fresh lagoon sand. The island referred to as Thilafushi-1 was and is being reclaimed using this method. A second island, zoned as Thilafushi-2 (where the project will be located), was reclaimed from lagoon sand. Subsequently a third island, Thilafushi-3, was initiated to reclaim 167 Ha of land from the remaining reef areas of Thilafushi.

245. The islands of the Maldives occupy the central 700 km – long portion of the 3000 km – long Lacadive-Chagos submarine ridge, where they form a double chain of north-south orientated parallel atolls separated by an inner sea. The atolls rest on a submarine plateau that is 275 to 700 m deep, 700 km long and up to 130 km wide. There is several east-west trending deep (~1000 m) channels separating atoll groups.

246. The islands are low-lying Holocene features that began forming between 3000 and 5500 years ago (Woodroffe, 1992). The islands represent the most recent deposition along a submarine plateau that is underlain by approximately 2100 meters of mostly shallow-water carbonates resting on a slowly subsiding Eocene volcanic foundation (Purdy, 1981).

247. All islands of the Maldives are very low lying; more than 80% of the land area is less than 1 m above mean high tide level (MEEW, 2005).

B. Reclaimed Land for the Development of the WTE plant

248. The proposed site for the establishment of the WTE plant was reclaimed in 2018. Fifteen hectares of land was reclaimed from the shallow lagoon which was located on either side of the link road that was constructed at Thilafushi. The materials for the reclamation was burrowed from North Malé Atoll with a distance of 10 km from Thilafushi using a Trailing Suction Hopper Dredger (TSHD). The dredger burrowed the material for the reclamation from burrow sites were within a depth range of 40-50m. The material from the dredger was discharged to the reclamation area via a floating pipeline which ran from the sea floor to the reclamation area, which was bunded with sand bunds from southern side of the reclamation area.

249. The site has been reclaimed to a height of +1.5 m from MSL from an average depth of -1.5 m above the sea floor. The sand grains are angular to sub-angular in shape with gravel size varies from 20 – 30 mm in diameter and fairly uniformly graded. It can be described as loosely packed, silty, coral sand with pieces of corals and shells. Since the area had been recently reclaimed, the site does not have humus topsoil which is found on typical tropical islands. The soils have very high permeability for water. Much of the rainfall occurs as intense storms but no signs of erosion are observed, confirming high infiltration capacity.

250. The reclaimed land is similar to Hulhumale' second phase that was reclaimed in 2014. In this Hulhumale location, plate bearing tests found the soil bearing capacity with 150 Kpa bearing with maximum settlement of up to 5.52mm. The degree of compaction and maximum settlement achieved by 150Kpa bearing seems applicable to meet the requirement for the designed reclamation area (DI, 2015).

Figure 61: Aerial Photograph of Proposed WTE plant Location at Thilafushi

C. Terrestrial Environment

1. Climate and Meteorology

251. Regular meteorological observations and measurements in Maldives are limited to airports. A total of 12 airports are in operation, however meteorological observation takes place only on 5 airports. They are Hanimaadhoo in the north, Velana International Airport in the center, Kahdhdhoo, in the south center, Kaadehdhoo, in the south, and Gan Island in the south. Observation routinely monitored and measured include, wind speed and direction, daily minimum and maximum temperature, humidity, cloud cover. Monitoring of sea-level height takes place only in Hulhulhe (center) and in Gan Island (south).

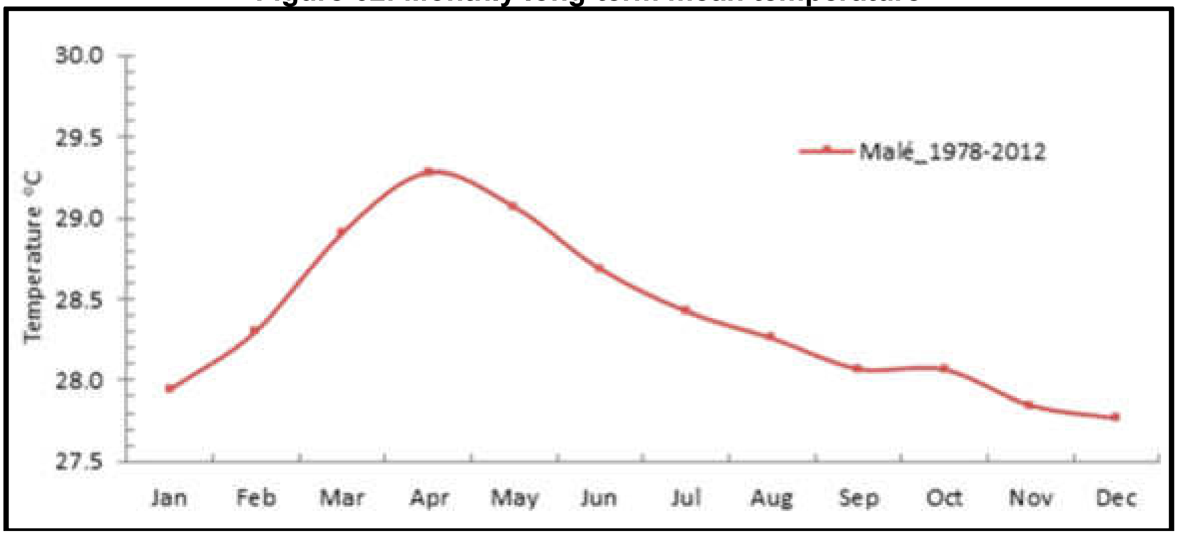
252. It is a fair and reasonable to assume that average climate conditions do not show much variation between different islands. For the purposes of this EIA observations from the Velana International Airport at Hulhulhe, which is closest to the project site, will be used to describe the climate condition around the project area.

253. The climate in Maldives is warm and humid, typical of the tropics. The average temperature ranges between 25°C to 30°C and relative humidity varies from 73 – 85%. The annual average rainfall is approximately 1,950mm. As the Maldives lie on or close to the equator, the islands of the Maldives receive plenty of sunshine throughout the year. Significant variation is observed in the climate between the northern and the southern atolls. The annual average rainfall

in the southern atolls is higher than the northern atolls. In addition, greater extremes of temperature are also recorded in the southern atolls. On average, the southern atolls receive 2,704 hours of sunshine each year.

254. **Temperature**. Central region of the Maldives experiences a warm and humid climate throughout the year. Temperature is moderated by the presence of vast sea and oceans surrounding the small islands. The long-term average temperature ranges from 25°C to 31°C. With the influence of the monsoon, seasonal fluctuations are observed throughout the year. The warmest period is observed during March, April and May with higher temperatures in the north Figure 62 depicts the monthly variation in Malé.

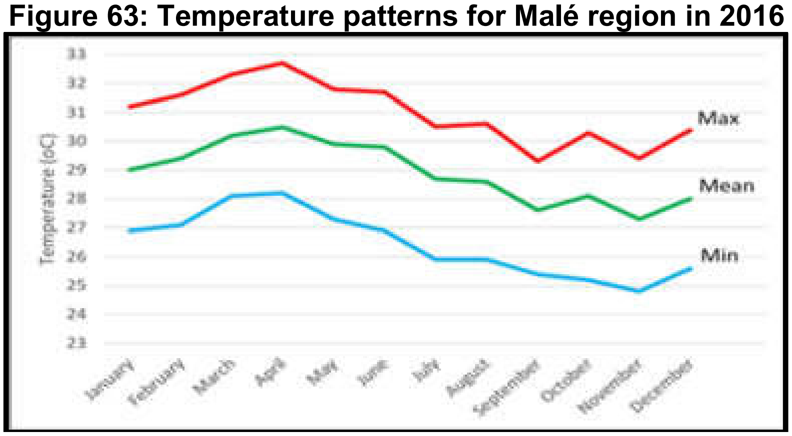
Figure 62: Monthly long-term mean temperature



Source: MEE, 2015

255. The highest temperature recorded in the Greater Malé region last year was on April 2016. The temperature recorded was 32.7 degree Celsius. The minimum temperature recorded in this region last year was on November 2016. The temperature recorded was 24.8 degree Celsius. Figure 63 below shows the monthly maximum, minimum and mean temperature for the year 2016. Data was obtained from Maldives Meteorological Service.

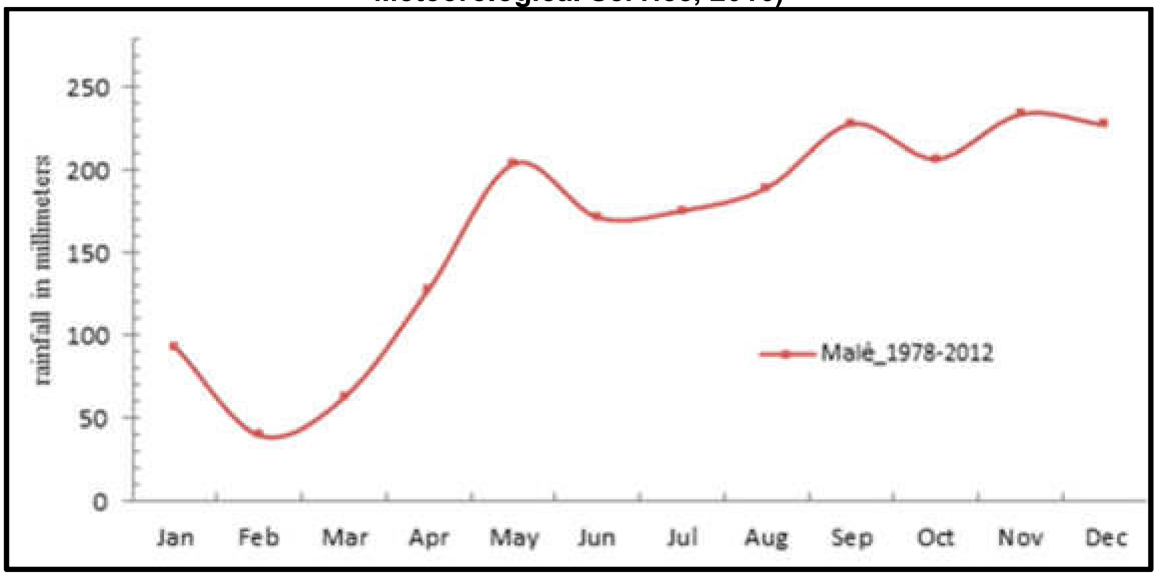
Figure 63: Temperature patterns for Malé region in 2016



256. **Rainfall.** The rainfall over the Maldives varies during the two monsoon periods with more rainfall during the southwest monsoon. These seasonal characteristics can be seen from Figure 64, which shows the mean monthly rainfall observed for central atolls.

257. The average annual rainfall for the archipelago is 2,124 mm. There are regional variations in average annual rainfall: southern atolls receive approximately 2,280 mm, and northern atolls receive approximately 1,790 mm annually (MEE, 2015). Mean monthly rainfall also varies substantially throughout the year with the dry season getting considerably less rainfall. This pattern is less prominent in the southern half, however. The proportions of flood and drought years are relatively small throughout the archipelago, and the southern half is less prone to drought (UNDP, 2006).

Figure 64: Long term average rainfall for the central atolls (Source: Maldives Meteorological Service, 2016)



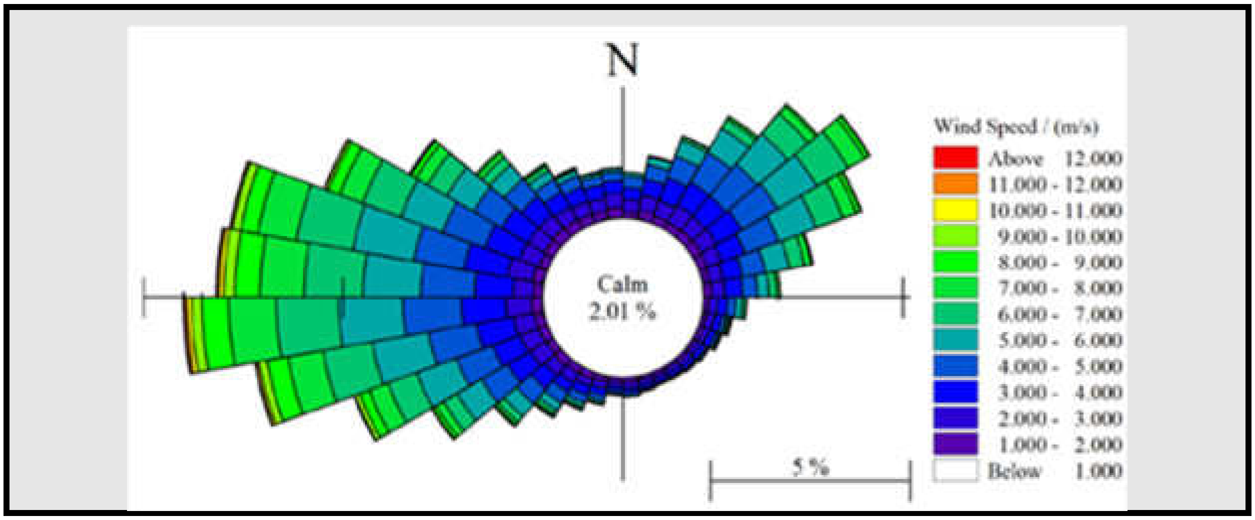
258. For Malé region the highest rainfall recorded is 310.3mm during August and lowest rainfall recorded is 4.3mm during March 2016.

259. **Monsoon.** Monsoons of Indian Ocean govern the climatology of the Maldives. Monsoon wind reversal plays a significant role in weather patterns. Two monsoon seasons are observed in Maldives: the Northeast (Iruvai) and the Southwest (Hulhangu) monsoon. Monsoons can be best characterized by wind and rainfall patterns. The southwest monsoon lasts from May to September and the northeast monsoon occurs from December to February. The transition period of southwest monsoon, which is the driest part of the year, occurs between March and April while that of northeast monsoon occurs between October and November.

260. **Wind.** The prevailing wind over the Maldives represents typical Asian monsoonal characteristics. It follows the traditional definition of monsoon as seasonal reversal of wind direction by more than 120° between the months January and July. Looking at annual variations, westerly winds are predominant throughout the country, varying between west-southwest and west-northwest. Figure 65 shows the annual wind pattern. More specific to monthly variations, easterly winds are predominant for December to February. The month of March is a combination of easterly and NW winds, while westerly winds are predominant for the rest of the year. Figure 66 shows the monthly wind patterns.

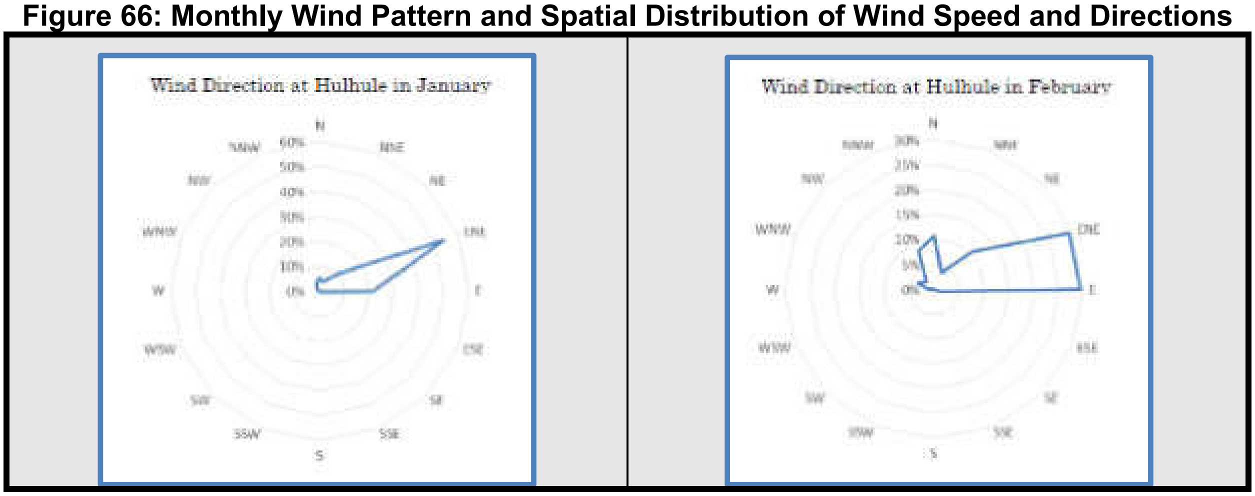
261. The southwest monsoon, with winds predominantly between SW and NW, lasts from May to October. In May and June, winds are mainly from WSW to WNW, and in July to October, winds between W and NW predominate. The northeast monsoon, with winds predominantly from NE to E, lasts from December to February. During March and April, winds are variable. During November, winds are primarily from the west, becoming variable and can occasionally exceed 30 knots from the NE sector. However, yearly wind speed in the northeast and southwest monsoons are observed to be between 9-13 knots.

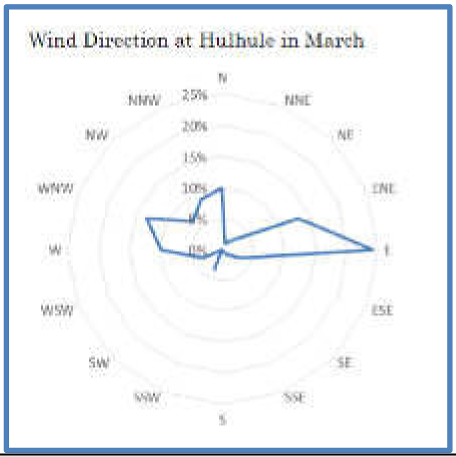
Figure 65: Seasonal Wind Pattern and Spatial Distribution of Wind Speed and Directions from 1986-2016

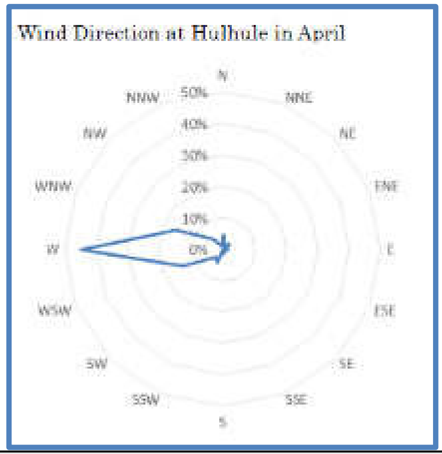


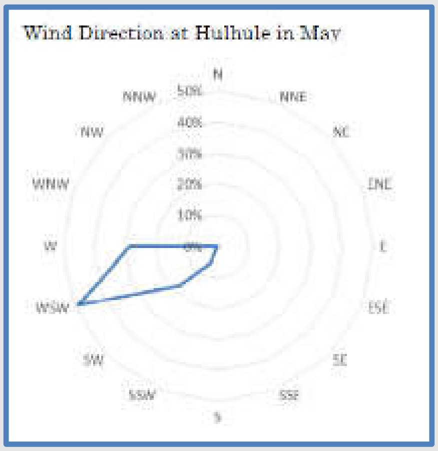
Source: LHI (2018)

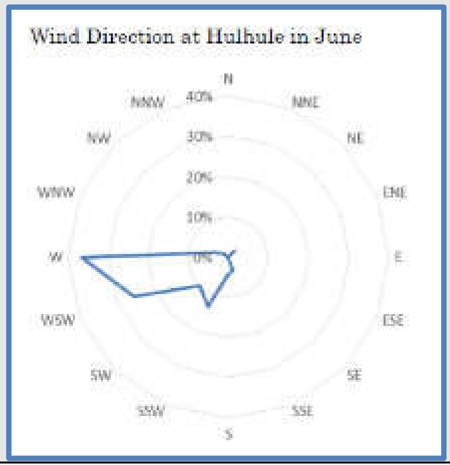
Figure 66: Monthly Wind Pattern and Spatial Distribution of Wind Speed and Directions

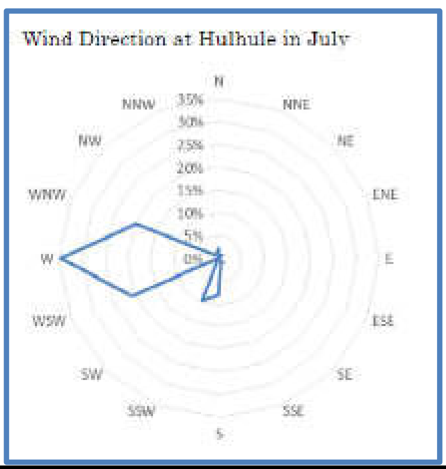


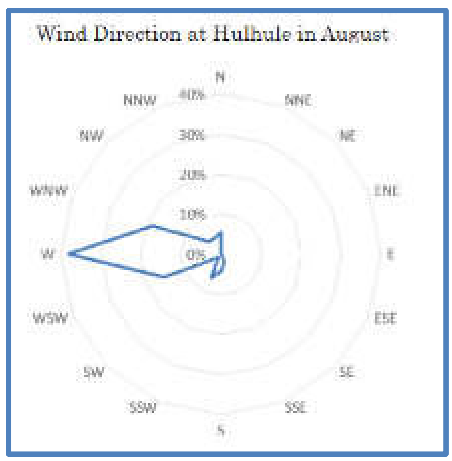

Wind Direction at Hulhule in March
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
25%
20%
15%
10%
0%

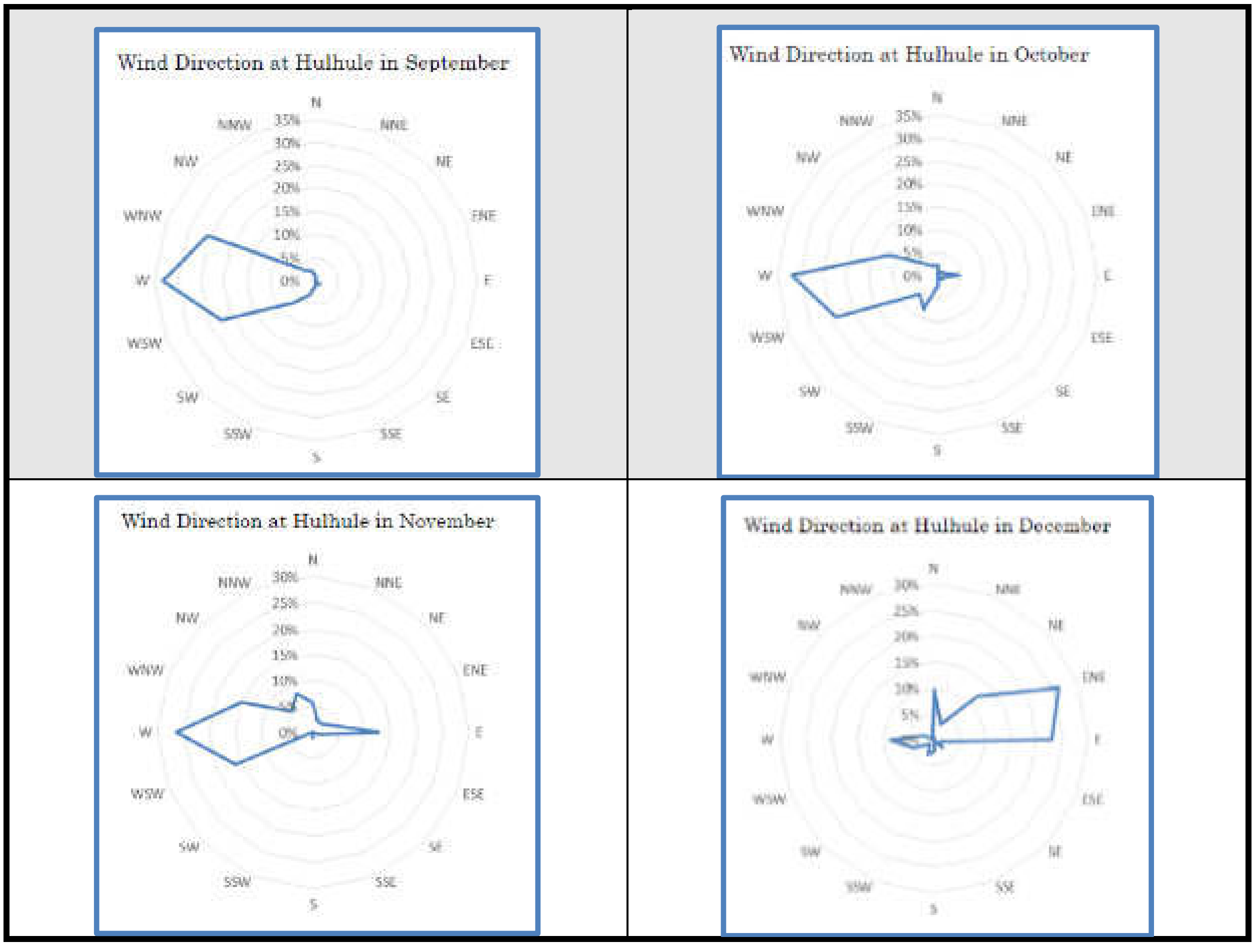

Wind Direction at Hulhule in April
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
50%
40%
30%
20%
10%
0%


Wind Direction at Hulhule in May
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
50%
40%
30%
20%
10%
0%


Wind Direction at Hulhule in June
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
40%
30%
20%
10%
0%


Wind Direction at Hulhule in July
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
35%
30%
25%
20%
15%
10%
5%
0%


Wind Direction at Hulhule in August
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
40%
30%
20%
10%
0%



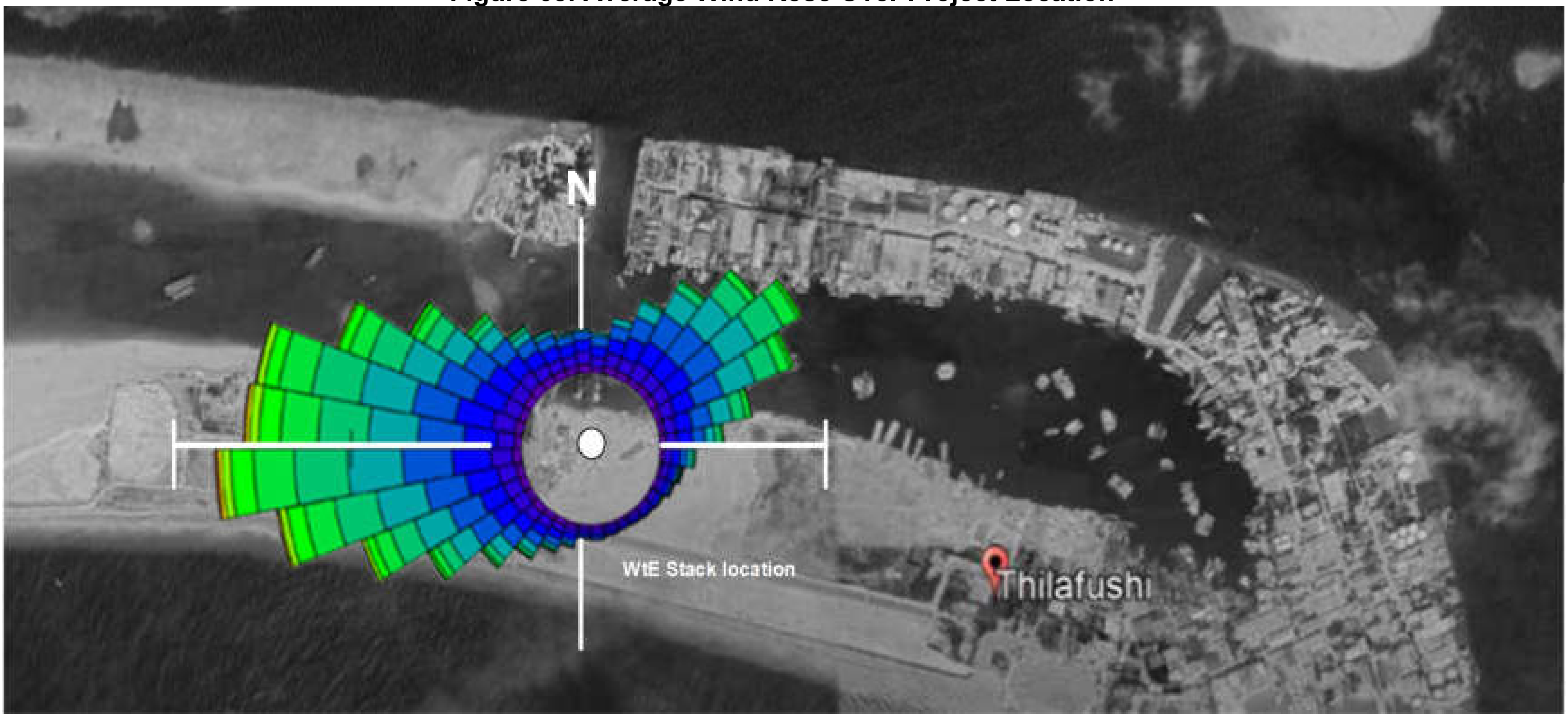
262. Figure 65 illustrates clearly the wind distribution pattern in terms of direction and frequency. The length of the “slices” represents the percentage of occurrence while the color code illustrates wind speed. Furthermore, Figure 65 shows the occurrence of wind by values in different directions and various speeds. According to the analysis, two dominant wind directions can be observed; i.e. West and North-East. The wind from the South-East quadrant is negligible. Significantly, calm conditions are rare, occurring 2.01% of the time. Figure 68 shows the wind pattern at the proposed project site by superimposing the wind rose pattern over the project site map.

Figure 67: Directional Distribution of Wind Statistics (% Occurrence for Wind Speed vs. Wind Direction)

Speed (m/s) \ Dir (Deg.N)	0 – 10	10 – 20	20 – 30	30 – 40	40 – 50	50 – 60	60 – 70	70 – 80	80 – 90	90 – 100	100 – 110	110 – 120	120 – 130	130 – 140	140 – 150	150 – 160	160 – 170	170 – 180
0 – 1	0.03	0.08	0.06	0.05	0.06	0.07	0.06	0.04	0.09	0.03	0.03	0.05	0.04	0.06	0.05	0.04	0.05	0.08
1 – 2	0.17	0.24	0.20	0.21	0.24	0.28	0.21	0.19	0.20	0.14	0.14	0.14	0.10	0.12	0.10	0.10	0.11	0.12
2 – 3	0.29	0.38	0.43	0.48	0.44	0.45	0.43	0.35	0.34	0.23	0.19	0.16	0.15	0.14	0.13	0.11	0.11	0.13
3 – 4	0.31	0.40	0.57	0.67	0.67	0.72	0.60	0.49	0.42	0.24	0.19	0.16	0.13	0.10	0.09	0.09	0.09	0.08
4 – 5	0.26	0.38	0.58	0.86	1.03	1.05	0.90	0.61	0.37	0.20	0.10	0.08	0.07	0.03	0.04	0.04	0.05	0.09
5 – 6	0.10	0.19	0.42	0.68	0.89	1.13	1.00	0.50	0.30	0.16	0.06	0.05	0.03	0.03	0.03	0.01	0.04	0.05
6 – 7	0.02	0.04	0.09	0.28	0.69	0.90	0.72	0.39	0.19	0.08	0.05	0.03	0.02	0.01	0.00	0.01	0.02	0.01
7 – 8	0.00	0.01	0.03	0.08	0.23	0.47	0.35	0.18	0.08	0.03	0.03	0.02	0.01	0.01				0.01
8 – 9		0.00	0.03	0.02	0.06	0.12	0.11	0.04	0.01	0.01	0.02	0.00						
9 – 10				0.02	0.04	0.05	0.03	0.00	0.00	0.00	0.00							
10 – 11						0.00	0.01											
11 – 12																		
12 – 13																		
13 – 14																		
14 – 15																		
15 – 16																		
Total	1.18	1.70	2.42	3.33	4.44	5.22	4.42	2.86	2.00	1.12	0.81	0.69	0.54	0.51	0.44	0.41	0.47	0.58

Speed (m/s) \ Dir (Deg.N)	180 – 190	190 – 200	200 – 210	210 – 220	220 – 230	230 – 240	240 – 250	250 – 260	260 – 270	270 – 280	280 – 290	290 – 300	300 – 310	310 – 320	320 – 330	330 – 340	340 – 350	350 – 360	Total
0 – 1	0.03	0.06	0.07	0.08	0.06	0.06	0.07	0.08	0.11	0.03	0.08	0.07	0.08	0.06	0.07	0.06	0.06	0.03	2.07
1 – 2	0.11	0.16	0.19	0.18	0.24	0.21	0.23	0.24	0.30	0.23	0.30	0.23	0.27	0.29	0.27	0.24	0.23	0.18	7.07
2 – 3	0.12	0.17	0.19	0.28	0.32	0.49	0.51	0.53	0.64	0.53	0.64	0.54	0.48	0.45	0.39	0.34	0.31	0.29	12.16
3 – 4	0.08	0.16	0.22	0.27	0.44	0.65	0.73	0.98	1.10	0.95	1.13	0.92	0.77	0.58	0.41	0.38	0.35	0.28	16.39
4 – 5	0.08	0.13	0.20	0.31	0.48	0.75	0.97	1.28	1.40	1.36	1.31	1.11	0.82	0.55	0.38	0.29	0.21	0.19	18.62
5 – 6	0.04	0.07	0.11	0.21	0.41	0.70	1.07	1.40	1.63	1.45	1.51	1.15	0.75	0.48	0.23	0.14	0.09	0.08	17.39
6 – 7	0.03	0.04	0.06	0.11	0.20	0.40	0.76	1.24	1.58	1.49	1.43	0.98	0.57	0.25	0.12	0.07	0.03	0.02	12.89
7 – 8	0.02	0.02	0.02	0.06	0.09	0.21	0.50	0.90	1.18	1.07	0.98	0.62	0.33	0.15	0.05	0.03	0.00	0.01	7.78
8 – 9	0.01	0.00	0.01	0.02	0.04	0.09	0.25	0.52	0.65	0.62	0.43	0.30	0.14	0.04	0.03	0.02			3.60
9 – 10			0.00	0.01	0.01	0.02	0.12	0.21	0.24	0.28	0.21	0.08	0.04	0.01	0.00				1.39
10 – 11				0.01	0.00	0.01	0.03	0.06	0.13	0.12	0.06	0.02	0.02	0.00					0.47
11 – 12							0.01	0.02	0.08	0.04	0.02	0.01	0.00	0.01					0.18
12 – 13							0.01	0.01	0.04	0.01	0.01	0.01	0.00						0.09
13 – 14						0.00			0.01	0.01									0.02
14 – 15									0.00										0.00
15 – 16										0.00									0.00
Total	0.51	0.81	1.08	1.53	2.28	3.60	5.26	7.42	9.13	8.22	8.09	6.03	4.27	2.89	1.95	1.56	1.28	1.06	100

Figure 68: Average Wind Rose Over Project Location



263. Besides the annual monsoonal wind variations, there are occasional tropical storms in the central region of the Maldives which increases wind speeds up to 110 km/h, precipitation to 30 to 40 cm over a 24 hour period and storm surges up to 3 m in the open ocean (UNDP, 2006).

264. Recent meteorological data was obtained from Lakes Environmental https://www.weblakes.com/services/met_data.html) which employs the Weather Research and Forecasting (WRF) model to compute accurate wind fields and provide modeled meteorological data.[22] Below is the frequency distribution and wind rose of Maldives for 2018 based on MM5 AERMET processed prognostic meteorological data.

Table 21: Wind Direction Frequency Diagram for Maldives, 2018

	Directions / Wind Classes (m/s)	0.50 - 2.10	2.10 - 3.60	3.60 - 5.70	5.70 - 8.80	8.80 - 11.10	>= 11.10	Total
1	348.75 - 11.25	0.00502	0.00400	0.00731	0.00342	0.00000	0.00000	0.01975
2	11.25 - 33.75	0.00662	0.00628	0.01370	0.01199	0.00000	0.00000	0.03858
3	33.75 - 56.25	0.00765	0.01267	0.02500	0.01450	0.00137	0.00000	0.06119
4	56.25 - 78.75	0.00947	0.01267	0.02078	0.00970	0.00000	0.00000	0.05263
5	78.75 - 101.25	0.00811	0.01370	0.01290	0.00571	0.00000	0.00000	0.04041
6	101.25 - 123.75	0.00788	0.00993	0.00422	0.00285	0.00000	0.00011	0.02500
7	123.75 - 146.25	0.00639	0.00868	0.00685	0.00126	0.00000	0.00000	0.02317
8	146.25 - 168.75	0.00377	0.00742	0.01016	0.00354	0.00000	0.00000	0.02489
9	168.75 - 191.25	0.00491	0.00856	0.01587	0.00537	0.00000	0.00000	0.03470
10	191.25 - 213.75	0.00514	0.01438	0.02078	0.01769	0.00000	0.00000	0.05799
11	213.75 - 236.25	0.00913	0.01781	0.03185	0.05342	0.00148	0.00000	0.11370
12	236.25 - 258.75	0.00856	0.01747	0.04075	0.08950	0.01005	0.00616	0.17249
13	258.75 - 281.25	0.01005	0.01564	0.04669	0.06815	0.01107	0.00457	0.15616
14	281.25 - 303.75	0.00902	0.01450	0.02443	0.03779	0.00342	0.00034	0.08950
15	303.75 - 326.25	0.00970	0.01221	0.01975	0.00936	0.00011	0.00000	0.05114
16	326.25 - 348.75	0.00628	0.00788	0.00753	0.00502	0.00000	0.00000	0.02671
	Sub-Total	0.11769	0.18379	0.30856	0.33927	0.02751	0.01119	0.98801
	Calms							0.01199
	Missing/Incomplete							0.00000
	Total							1.00

* Reference bearing CW 90^0

[22] The data is obtained by running the NCAR MM5 (5th-generation Mesoscale Model) prognostic meteorological model for a specified location and site domain. Once the MM5 preprocessing has been completed, the MM5 output file is converted into a format recognized by the AERMET model (meteorological preprocessor for the AERMOD model). The final output is generated by creating a pseudo met station at the specified site location.

Figure 69: MM5 Frequency Distribution of Wind Speed and Direction 2018 Maldives Meteorology

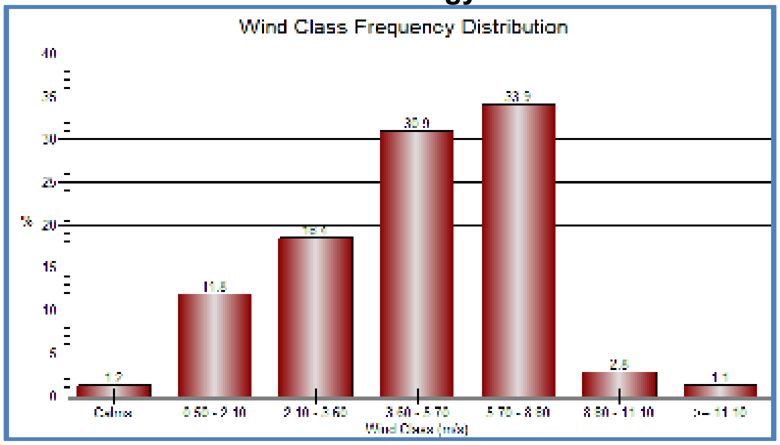
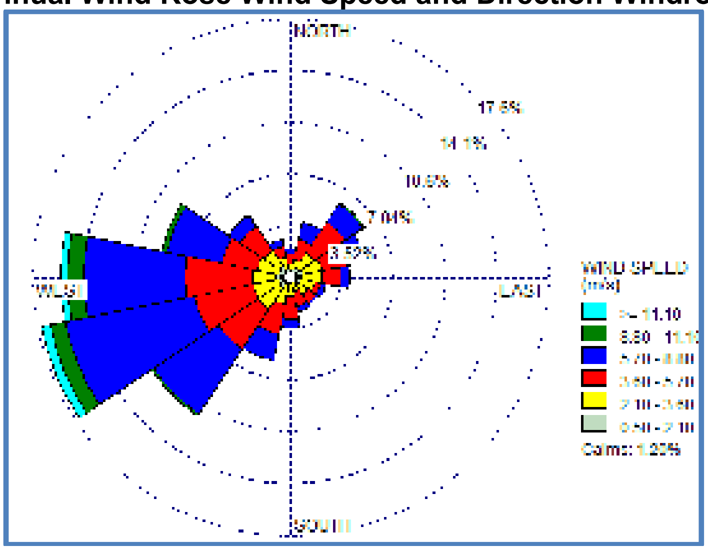


Figure 70: MM5 Annual Wind Rose Wind Speed and Direction Windrose, 2018 Maldives



265. Windrose diagram generated using WRPlot view Version 5.8 software which utilizes SCRAM (.DAT) files. Wind direction was oriented in “Blowing from” configuration. Figure above, present the annual wind rose diagram at Maldives Synoptic Station.

266. **Natural hazards. Natural hazards.** The fragile ecological profile, low elevation, combined with its economic dependence on limited sectors makes Maldives highly vulnerable to natural hazards. The disaster risk profile of Maldives identifies earthquakes and tsunamis, cyclones/thunderstorms, floods (due to rain), drought (prolonged dry periods), storm surges, strong winds, and tornadoes (waterspouts) as critical disasters to the Maldives. Climate change further exacerbates the vulnerability of Maldives to these disasters.

267. The primary sources of hazard risks in the Maldives are strong winds during monsoons or freak storms, earthquakes, island interior flooding caused by heavy rain, coastal flooding caused by high surf, storm surges, prolonged strong monsoonal winds, high astronomical tides or tsunamis, and sea level rise.

268. **Earthquakes and tsunami**. While earthquake events have been documented, there is little recorded evidence of tsunami events in historic records of the Maldives. History tells us that between 1729 and 1815 the Maldives had experienced earthquakes. Although magnitude and exact locations of these historical earthquakes around the Maldives is unavailable, descriptions of the events indicate extensive damage has been caused. Three major earthquakes of magnitude 7.0 or greater had struck the Maldives region in 1944, 1983 and 2003. Earthquakes are usually felt as tremors without notable damages. However, in 2003 an earthquake measuring 7.6 occurring in Carlsberg Ridge had reported some damage in Addu city.

269. Although 67 tsunamis originated from the Sumatra Subduction zone in the east and 13 from the Makran Coast Zone in the north and Carlsberg Transform Fault Zone in the south since 1816, historical records do not indicate that the Maldives was affected by these tsunamis. The only record of damage caused by a tsunami in the Maldives is the 26th December 2004 Indian Ocean tsunami. This was one of the most apocalyptical natural disasters experienced in Maldivian history. Wave heights of about 2.5m were recorded in Hanimaadhoo and a wave height of 2.1m was observed in Malé.

270. The disaster risk profile of Maldives (UNDP, 2006) places Thilafushi as being located in a severe tsunami risk zone with a probable maximum wave height between 3.2 and 4.5 m. The high levels of fluctuations of sea level during the Indian Ocean Tsunami showed that rising and falling of the water levels are enough to inundate any unprotected coastline of Maldives including Thilafushi Island. However, there are no records of major damages on the island. The lack of impact on Malé has been associated with the submarine topography, tide level at the time and the location of the earthquake epicenter (Ali, 2005).

271. **Cyclone, storm surges and flood**. Thilafushi Island is in a moderate cyclonic hazard zone which has the potential for a maximum probable cyclonic wind speed of 69.6 knots. It has the potential for a 1.53 m storm tide in a 500-year return period (UNDP, 2006).

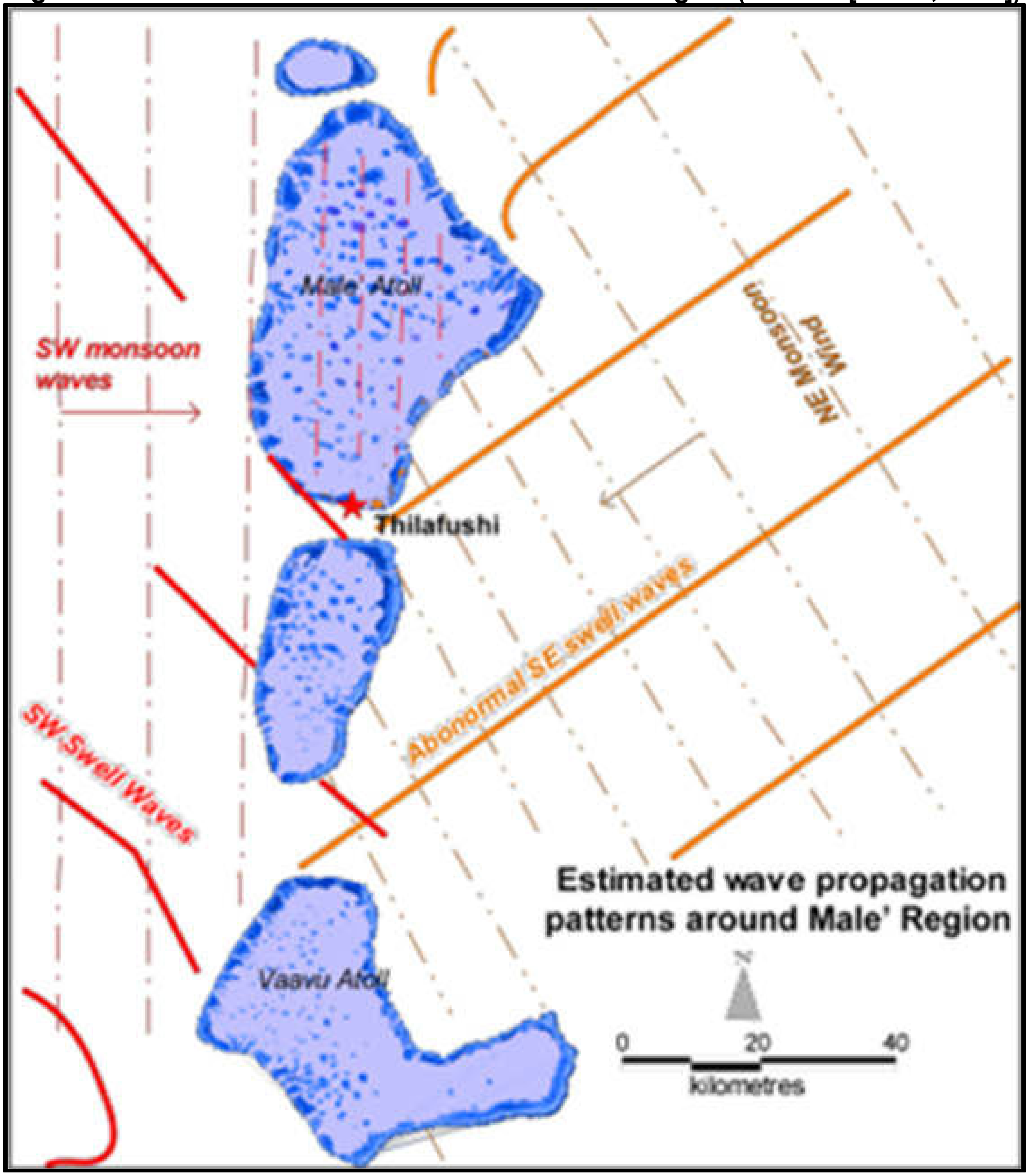
272. Wave studies around the Maldives have identified the presence of swell waves approaching predominantly from a southwest to a southerly direction (Kench et.al (2006), DHI (1999), Binnie Black & Veatch (2000) and Naseer (2003).

273. Coastal flooding and related wind damage can be considered as the most frequent natural hazards that occur in Maldives (Maniku (1990), Luthfy (1994)). Most of these risk factors (apart from earthquakes, wind damage and rainfall flooding), stem from the extremely low elevation of all Maldivian islands: the average elevation is 1.5 m above sea level. In spite of the occasional natural hazards, the Maldives are in general relatively free from high risk natural disasters.

274. Spatial variations in hazards are evident across Maldives (Maniku, 1990). Northern atolls are more exposed to intense storm systems, increasing the risk of wind damage in these atolls. In comparison, southern atolls experience less storms systems, but are more exposed to flooding events, probably as a result of exposure to intense South Indian Ocean storm surges and wind-waves during south west monsoons. Southern atolls are also more likely to experience earthquakes.

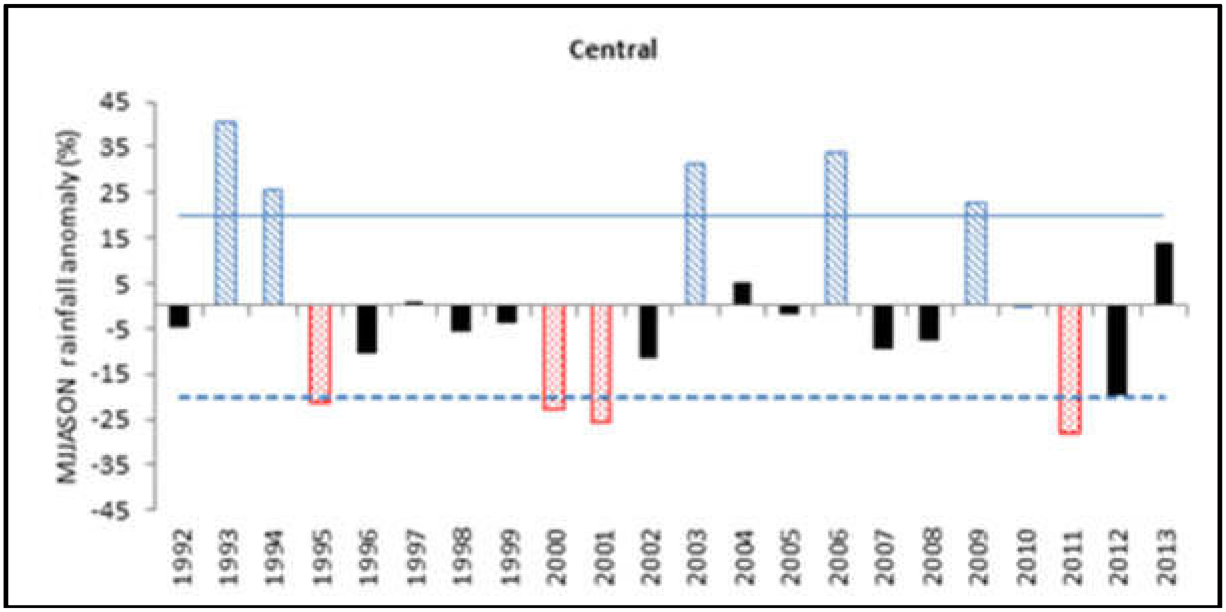
275. Thilafushi is protected from predominant swell waves. However, the island is still exposed to abnormal swell waves originating from intense storms in the southern hemisphere (Figure 71). Waves generated from such abnormal events could travel against the predominant swell propagation patterns causing flooding on the eastern and southern islands of Maldives (UNDP, 2009).

Figure 71: Estimated wave conditions around Malé region (source: [UNDP, 2009])



276. **Disasters and Extreme Events - Flooding Due to Rain.** Although floods due to rain are the most frequent natural events in the Maldives, no criteria exist for the case of the Maldives for declaring flood disasters. Furthermore, no proper mechanism exists for collecting or recording data on flood events and hence it is difficult to determine frequency of floods and their trends for the Maldives. Figure 72 shows flood years together with drought years for the central region of the Maldives (MEE, 2016). The Cross bars indicate the flood years, dotted bars indicate the drought years. The solid line is the sum of mean and standard deviation and dotted line is the difference between mean and standard deviation. It should be noted that this method identifies the likelihood of flooding and actual flood events experienced can be very different.

Figure 72: Flood and drought years for central regions Maldives based on Maldives monsoon rainfall.



2. Air Quality

277. Major causes and sources of ambient air quality deterioration in the Maldives include power generation (e.g. diesel generators), fuel combustion from motorized vehicles (e.g. motorbikes, cars), burning and incineration of municipal waste, and construction activities (e.g. dust generated from concrete, cement). In addition to these local sources, trans-boundary flow of air pollutants also contributes to the overall degradation of ambient air quality of the Maldives (United Nations Environment Program, 2002).

278. Air pollutants generated from these local sources vary in their chemical properties and composition. The pollutants can be broadly categorized into the following groups: Gaseous pollutants (e.g. SO2, NOx), Persistent Organic Pollutants (e.g. PCDDs, PCBs), Heavy Metals (e.g. Lead, Cadmium), and Particulate matter (e.g. PM2.5, PM10) (Kampa & Castanas, 2008).

279. At the proposed project site in Thilafushi, ambient air quality monitoring was conducted to document the current baseline condition at the island. Several sampling activities in 2018 and 2019 were undertaken by the PMU through its consultant, Water Solutions. Three locations were selected at Thilafushi and one location at Villingili. Villingili is the nearest inhabited island and the sampling site at this island will serve as the control site for future monitoring activities under the project. The air quality monitoring activities were done for a period of one week each in 2018 and 2019.

280. **Selection of Sampling Locations**. In total, ambient air quality monitoring was conducted at 4 locations. First station (AQ1) was selected in the downwind direction of the proposed project site (i.e. the potential direction of stack emission plume from the plant), and second station (AQ2) was placed at the crosswind direction of the plume. Third station (AQ3) was selected in the crosswind direction of the smoke plume from the existing dump site at Thilafushi. Fourth station (AQ4) was selected at Vilingili as a control site. See Figure 73 below for these locations as shown on the map.

Figure 73: Sampling Locations of Ambient Air Quality Monitoring

281. Predominant wind direction is an important criterion in selection of the air quality sampling stations as gaseous and particulate emissions from the project activities have a greater chance of dispersal along the predominant wind direction and affect the downwind human habitations. The monitoring network for ambient air quality was developed based on the following key criteria:

(i) Regional meteorology (primarily wind speed and direction);
(ii) Important receptor locations (e.g. nearby inhabitation);
(iii) Proposed project activities; and
(iv) Logistics for operating the air monitoring equipment.

282. The predominant wind directions in Maldives are dependent on the NE and SW monsoons. The wind directions for all seasons recorded at the National Meteorological Centre, Maldives reveal that apart from the winter months (when winds primarily blow from NW-NE), winds predominantly blow from the west.

283. The exact location of the ambient air stations was selected by PMU through its consultant, Water Solutions / Kocks, to ensure the locations experience free air flow and are established at height between 1.5 – 5 meters. Because of the location of the island, strong gusts and variations of wind directions were noted which have the potential to influence the dispersion and in turn affect the air sampling. Therefore, the sampling activities took into consideration and systematically recorded wind directions and strong gusts. The rationale for selecting the four sampling stations are summarized in Table 22 below.

Table 22: Summary and Description of Selected Ambient Air Monitoring Stations

Station Name	Station Coordinates	Rationale of Location Selection
Thilafushi Downwind (AQ1)	4°10'56.6 N 73°26'53.3 E	This downwind station with respect to the proposed facility has been selected to establish the baseline that could be compared with the monitoring to be undertaken during the construction and operational phases of the project to detect actual project imprints to the air quality of the nearest receptor.
Thilafushi crosswind (AQ2)	4°10'57.3 N 73°25'59.4 E	The crosswind station with respect to the proposed facility has been selected to establish the general baseline of the island, for comparison with the downwind station at the time of project activities
Thilafushi crosswind (AQ3)	4°11'07.6 N 73°26'37.4 E	The crosswind station with respect to the existing dumpsite at the Thilafushi has been selected to establish the general baseline of the island
Vilingili Island (AQ4)	4°10'26.4 N 73°28'59.9 E	The crosswind station with respect to Thilafushi has been selected as a control site and to detect project imprints to air quality of the nearest receptor due to trans-island transportation of pollutants

284. **Ambient Air Quality Sampling Instrument**. The instruments used for taking air quality reading are the Aeroqual series 500 monitors and sensors. Aeroqual is a portable handheld monitor suited for surveying common indoor and outdoor pollutants compatible with over 30 different sensors. The Series 500 can be deployed for short term fixed monitoring by adding an optional outdoor enclosure. The Aeroqual Series 500 is also highlighted as the leading instrument for measuring ozone, nitrogen dioxide and carbon monoxide by the United States Environmental Protection Agency (US EPA).

285. **Results of Baseline Ambient Air Quality Monitoring**. On each sampling day, 1 set of 24-hour average samples were collected continuously. PM_{10}, $PM_{2.5}$, Sulfur dioxide (SO_2) and Oxides of nitrogen (NOx) were measured continuously during the sampling period. **Table 23** below shows the readings for all parameters.

Table 23: Results of Baseline Ambient Air Quality Monitoring at Selected Locations

Reading Description	Parameters / Results[a]			
	PM10	**PM2.5**	**SO2**	**NO2**
	µg/m3	µg/m3	µg/m3	µg/m3
	Thilafushi Downwind (AQ-1) (19 - 25 March 2019)			
Minimum	7.0	8.0	5.0	0
Maximum	427.0	384.0	72.0	87.0
Mean	**26.5**	**26.9**	**25.3**	**59.5**
99th Percentile	147.0	122.0	76.0	78.0
	Thilafushi Crosswind (AQ-2) (20 - 25 August 2019)			
Minimum	8.0	5.0	0.0	49.0
Maximum	134	112	18.5	65.0
Mean	**19.3**	**12.1**	**9.8**	**56.0**
99th Percentile	37.6	24.6	16.5	60.0
	Thilafushi Downwind (AQ-3) (25 - 31 August 2019)			
Minimum	4.0	1.0	2.0	53.0
Maximum	690.0	362.0	112.2	81.0
Mean	**88.4**	**42.8**	**32.4**	**64.9**
99th Percentile	281.0	85.4	40.3	72.1
	Vilingili Island (AQ-4) (3 - 9 March 2019)			
Minimum	13.0	22.7	2.0	2.0
Maximum	41.0	41.0	19.0	87.0

Reading Description	Parameters / Results[a]			
	PM10	PM2.5	SO2	NO2
	μg/m3	μg/m3	μg/m3	μg/m3
Mean	**22.7**	**22.1**	**7.6**	**60.6**
99th Percentile	32.0	32.0	2.0	70.8
WHO Standard (μg/m3)	**50.0[a]**	**25.0[a]**	**20.0[a]**	**200.0[b]** **40.0[c]**

[a] Based on 24-hour averaging period; [b] Based on 1-hour averaging period; [c] Based on 1-year averaging period

286. Ambient air quality results obtained from the monitoring undertaken indicate that mixed results when compared with the WHO guidelines for ambient air quality.

(i) The 24 hourly PM10 values recorded for the stations generally varied in the range of 4.0 - 690.0 μg/m³. The mean values of PM10 recorded at AQ1, AQ2 and AQ4 were found to be in compliance with the WHO standard specified for such pollutant equivalent to 50 μg/m³. However, the mean value of PM10 recorded at AQ3 is 88.4 μg/m³, which exceeds WHO standard specified for such pollutant equivalent to 50 μg/m³.

(ii) The 24 hourly PM2.5 values recorded for the stations generally varied in the range of 1.0 - 384.0 μg/m³. The mean values for PM2.5 at AQ2 and AQ4 were found to be in compliance with the WHO standard specified for such pollutant equivalent to 25 μg/m³. However, mean values for PM2.5 at AQ1 and AQ3 are 26.9 μg/m³ and 42.8 μg/m³, respectively, which exceed WHO standard specified for such pollutant equivalent to 25 μg/m³.

(iii) The 24 hourly SO2 values recorded for the stations generally varied in the range of 0.0 - 112.2 μg/m³. The mean values for SO2 at AQ2 and AQ4 were found to be in compliance with the WHO standard specified for such pollutant equivalent to 20 μg/m³. However, mean values for SO2 at AQ1 and AQ3 are 25.3 μg/m³ and 32.4 μg/m³, respectively, which exceed WHO standard specified for such pollutant equivalent to 20 μg/m³.

(iv) The results of the 24-hourly standard values for NO2 have not been compared. WHO standards does not provide 24-hourly standard for NO2 to check for any possible non-compliances. However, if compared with the hourly averaging, the values are below the WHO standard of 200 μg/m³.

287. Based on field visits and visual observations, the non-compliances for various parameters at different sampling locations in Thilafushi may be attributed to the continuous and instantaneous burning of wastes at the existing dumpsite. The government plans to stop fires on Thilafushi and start baling waste by July 2020 as interim SWM solution to stop open dumping until the WTE facility is commissioned. It is expected that once these measures are implemented the air quality at the sampling locations will improve.

Figure 74: Ambient SO2, PM10 and PM2.5 measured at Thilafushi

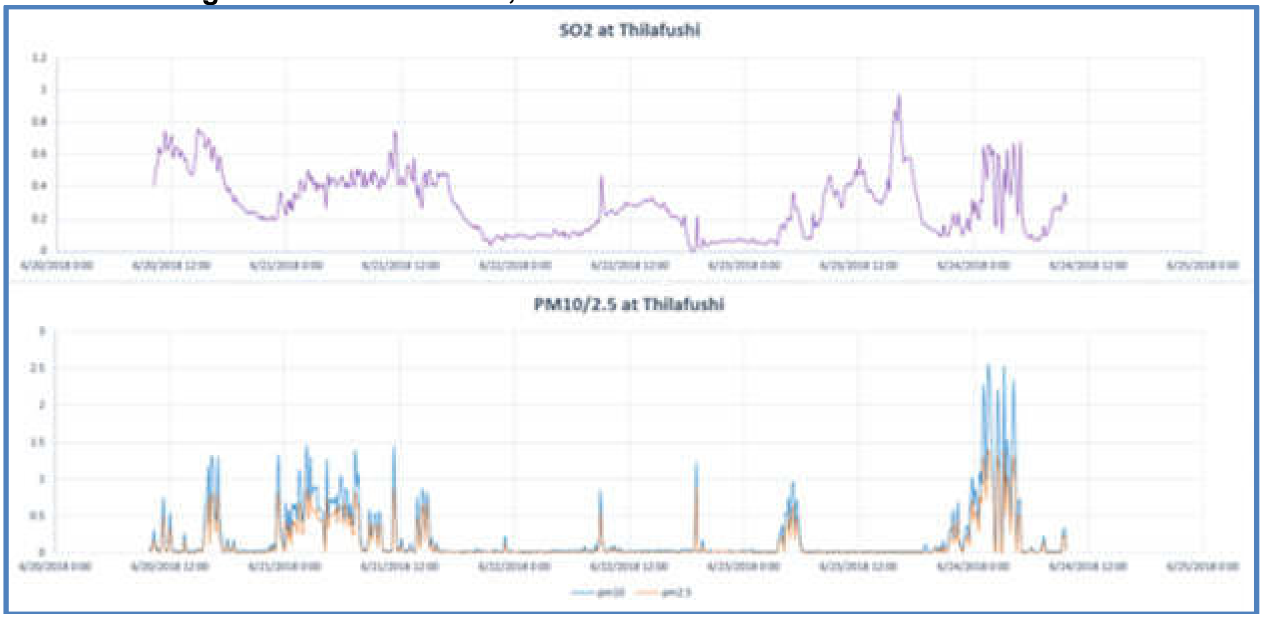
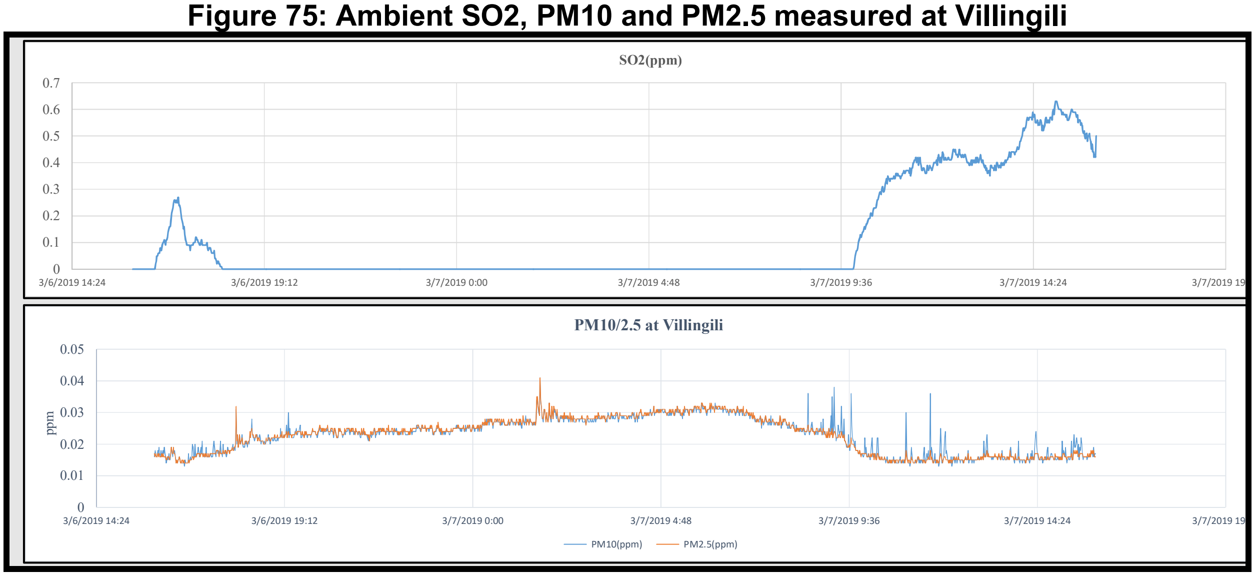


Figure 75: Ambient SO2, PM10 and PM2.5 measured at Villingili



288. Monthly ambient air quality data gathering in Thilafushi shall be undertaken strategically during the design phase of the project. The DBO Contractor shall:

(i) undertake ambient air quality measurements for each season of the year at the identified sampling locations in this EIA report (and any other locations in the Thilafushi island as may be deemed by the DBO Contractor as important sampling locations);

(ii) follow required sampling methodology and averaging time as indicated in the WHO Ambient Air Quality Guidelines; and

(iii) include results of analyses in the updating of the EIA during the detailed design phase.

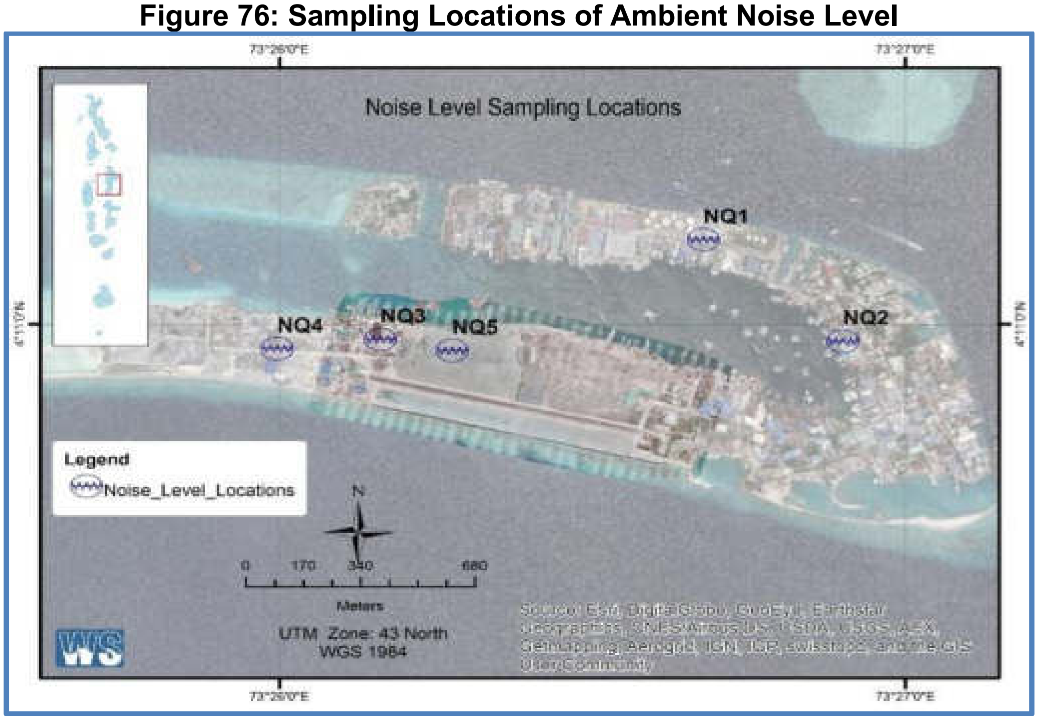
3. Noise Level

289. Ambient noise levels were measured to establish baseline at five locations in Thilafushi. The measurement was done using handheld sound level meter. Measurements were conducted during the day time from 10:00 am to 12:00 pm and during the night from 10:00 pm to 12:00 pm. The day time was considered as 7:00 a.m. to 10:00 p.m., while the night time was considered as 10:00 p.m. to 7:00am. Another set of measurements were conducted at the two nearest receptors on hourly basis for 24 hours. Table 24 summarizes the explanation on the selection of baseline monitoring stations. Figure 76 is the map that shows the sampling locations.

Table 24: Rationale in the Selection of Locations for Ambient Noise Level Measurements

Station Name	Station Coordinates	Monitoring Rationale
NQ1 *(Thilafushi)*	4°10'26.4 N 73°28'59.9 E	The station was selected as it represents a major industrial location of the island and is also located close to the harbor. The location lies north of the proposed facility on the opposite side of the lagoon.
NQ2 *(Thilafushi)*	4°10'56.6 N 73°26'53.3 E	The station was selected as it represents a major industrial location of the island. The location lies east of the proposed facility on the opposite side of the lagoon. The location has various industrial activities in its proximity
NQ3 *(Thilafushi)*	4°10'58.3 N 73°26'09.6 E	This station was selected as it is located near the boundary of the proposed WTE facility.
NQ4 *(Thilafushi)*	4°10'57.3 N 73°25'59.4 E	This station was selected as it is located west of proposed WTE facility. The area has less development and less activity during the day time.
NQ5 *(Thilafushi)*	4°10'57.3 N 73°26'14.4 E	This station was selected as it is located at the proposed WTE facility.

Figure 76: Sampling Locations of Ambient Noise Level



290. **Results**. There is high background noise in Thilafushi, which can be attributed to the roar from the sea, windy conditions and closely packed industrial areas and movement of boats. Thilafushi is quieter during the night as there are no activity on the island. The ambient noise levels comply with WHO Guideline Values for commercial and industrial locations. Table 25 shows the summary of noise level measurements during the day time from 10:00 am to 12:00 pm and during the night from 10:00 pm to 12:00 pm, while Table 26 shows the summary of noise level measurements at nearest potential receptors conducted hourly for 24 hours. The complete report on noise level measurements is in Appendix 9.

Table 25: Summary of Noise Level Measurements During Day Time and Night Time

S. No	Locations	Noise Level dB (A) Day Time	Noise Level dB (A) Night Time
NQ1	Thilafushi (25 August 2019)	65.1	58.7
NQ2	Thilafushi (25 August 2019)	64.2	51.8
NQ3	Thilafushi (25 August 2019)	56.3	50.0
NQ4	Thilafushi (25 August 2019)	56.0	48.9
NQ5	Thilafushi (25 August 2019)	54.6	49.0
WHO Guideline Values for Ambient Noise Level		70	70

Table 26: Summary of Noise Level Measurements at Nearest Receptors (24 hours)

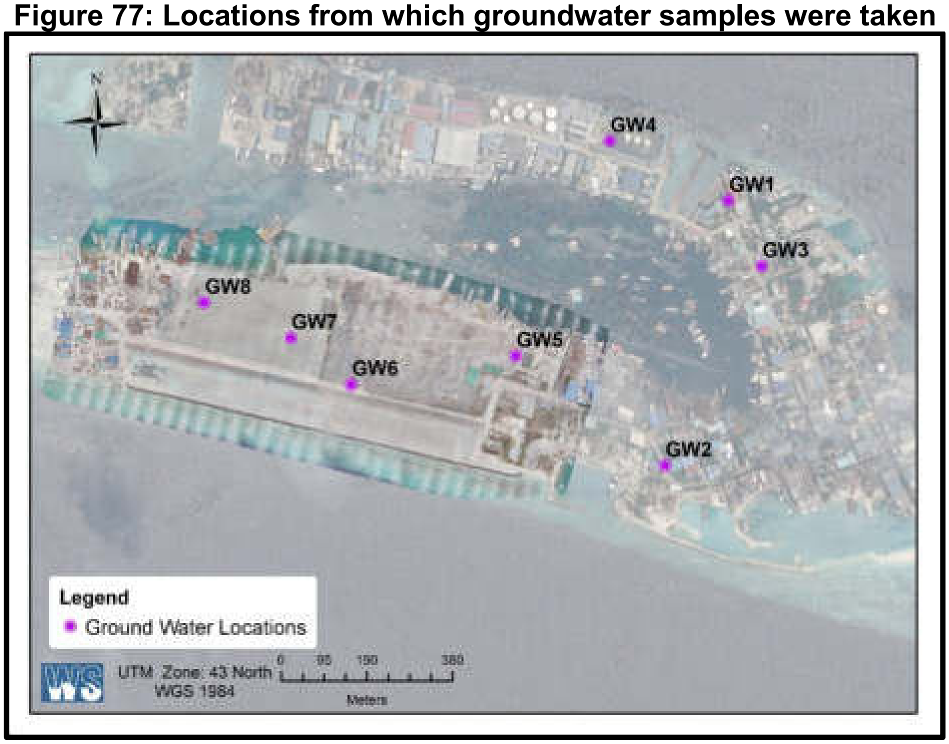
		Noise Level dB (A)	
Date	Time	NQ3	NQ4
6/10/2019	7:00	50.1	52.4
6/10/2019	8:00	54.4	54.3
6/10/2019	9:00	55.7	56.2
6/10/2019	10:00	56.5	56.8
6/10/2019	11:00	57.1	55.4
6/10/2019	12:00	56.8	57.4
6/10/2019	13:00	57.4	56.4
6/10/2019	14:00	57.3	55.9
6/10/2019	15:00	56.7	55.4
6/10/2019	16:00	56.8	56.1
6/10/2019	17:00	51.3	54.3
6/10/2019	18:00	49.4	49.4
6/10/2019	19:00	50.1	48.9
6/10/2019	20:00	49.6	48.6

		Noise Level dB (A)	
Date	Time	NQ3	NQ4
6/10/2019	21:00	49.3	48.3
6/10/2019	22:00	50.1	48.5
6/10/2019	23:00	50.3	48.3
7/10/2019	0:00	50.1	48.1
7/10/2019	1:00	50.1	48.1
7/10/2019	2:00	50.3	48.3
7/10/2019	3:00	50.8	47.8
7/10/2019	4:00	50.2	48
7/10/2019	5:00	49.5	49.1
7/10/2019	6:00	49.8	49.3

4. Groundwater Quality

291. On 2 April 2019, groundwater samples were collected from eight wells in Thilafushi. See Figure 77 below for the locations of these wells. These wells include 4 old wells (GW1 – GW4) and 4 freshly dug wells (GW5 – GW8).

Figure 77: Locations from which groundwater samples were taken



292. For each location, the samples were collected from mid-water level in clean two 500 ml PET bottles and one 250 ml glass bottle, after rinsing with water from the sampling points. For microbial tests, samples were collected in 300 ml sterile bags.

293. Samples for microbiology testing were stored in an icebox and transferred to MWSC Quality Assurance Laboratory for testing. Other samples were sent to Sri Lanka (at Bureau Veritas laboratory) for testing. All groundwater samples were tested for Conductivity, pH, Salinity, Temperature, Turbidity, Chloride, Total Dissolved Solids (TDS), Total Coliform, heavy metals (As, Mn, Fe, Pb, Hg, Cd), Ammonia, Nitrates, Oil, Grease and Polynuclear Aromatic Hydrocarbons (PAH). The results of these laboratory tests are shown below in Table 27. Copies of laboratory analyses are in Appendix 10.

294. Based on analysis, water samples collected did not comply with parameters on coliform, total dissolved solids, iron, and manganese based on the National Drinking Water Quality Standards (NDWQS). Therefore, if not treated, the groundwater is not an acceptable source of drinking water.

295. Additional groundwater quality monitoring and sampling activities shall be undertaken by the DBO Contractor during the detailed design phase of the project to establish better and more robust baseline data. The DBO Contractor shall include results of laboratory analyses from these groundwater sampling activities in the updating of the EIA report during the detailed design phase.

Table 27: Groundwater Quality Test Results

Parameters	Results								LoQ	Unit	Test Method
	GW1	GW2	GW3	GW4	GW5	GW6	GW7	GW8			
Physical Appearance	Clear	Pale brown with particl es	Pale yellow with particl es	Pale yellow with particles	Olive green with particl es	Olive green with particl es	Yellow with particl es	Cloud y and opaq ue	-	-	-
Chloride	183	1715	7200	470	3125	6325	6125	1005	-	mg/l	In-house Method (Adapted from M926 Chloride analyzer)
Nitrate*	1.7	6.1	5	7.5	25.5	34.5	12.2	3.4	-	mg/l	Method 8171(Adapted from HACH DR5000)
Phosphate*	0.07	0.23	0.21	<0.05(Lo Q)	0.46	0.57	2.27	0.72	0.05	mg/l	Method 8048(Adapted from HACH DR5000)
Total Coliforms	>242 0	291	>2420	1986	>2420	10	>2420	4	-	mg/l	Colilert®-18/Quanti-Tray®2000
Turbidity*	1.3	4	0.6	0.4	151	177	1845	348	-	NTU	APHA 23rd ed: 2017: 2130 B
pH at 25°C*	7.3	7.2	7.4	8	7.1	6.7	7.9	7.8	-	mg/l	APHA 23rd ed: 2017 :4500H+
Iron (as Fe) *	0.4	3.9	0.6	ND	5.9	5.7	0.7	0.4	-	mg/l	APHA 23rd ed: 2017: 3125 B
Manganese (as Mn)	0.02	0.09	0.006	ND	0.2	0.3	0.01	0.07	-	mg/l	APHA 23rd ed: 2017: 3125 B
Arsenic (as As)	ND	ND	ND	ND	ND	ND	ND	ND	0.001	mg/l	APHA 23rd ed: 2017: 3125 B
Total Dissolved Solids*	794	4020	12946	1003	6155	11554	11327	2188	-	mg/l	APHA 23rd ed: 20 I 7: 2540 C
Electrical Conductivity at 25°C*	1.39	7.39	20.6	1.87	12.3	25	18.7	3.8	-	mS/c m	APHA 23rd ed: 20 I 7: 2510 B
Cadmium (as Cd)*	ND	ND	ND	ND	ND	ND	ND	ND	0.000 1	mg/l	APHA 23rd ed: 20 I 7: 3125 B
Lead (as Pb)"	ND	ND	ND	ND	ND	ND	ND	ND	0.001	mg/l	APHA 23rd ed: 20 I 7: 3125 B
Mercury (as Hg)	ND	ND	ND	ND	ND	ND	ND	ND	0.000 05	mg/l	APHA 23rd ed: 20 I 7: 3125 B
Polynuclear Aromatic Hydrocarbons*											
Naphthalene	ND	ND	ND	ND	ND	ND	ND	ND	1	µg/l	CPSD -AN-00576

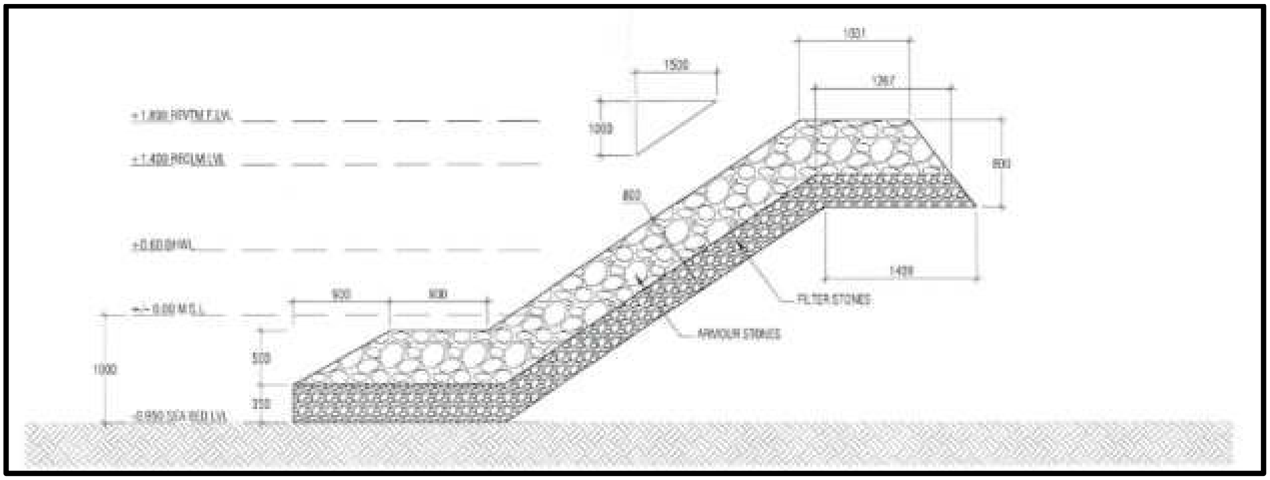
Parameters	Results								LoQ	Unit	Test Method
	GW1	GW2	GW3	GW4	GW5	GW6	GW7	GW8			
Acenaphthylene	ND	ND	ND	ND	ND	ND	ND	ND	1	µg/l	CPSD -AN-00576
Acenaphthene	ND	ND	ND	ND	ND	ND	ND	ND	1	µg/l	CPSD -AN-00576
Fluorene	ND	ND	ND	ND	ND	ND	ND	ND	1	µg/l	CPSD -AN-00576
Phenanthrene	ND	ND	ND	ND	ND	ND	ND	ND	1	µg/l	CPSD -AN-00576
Anthracene	ND	ND	ND	ND	ND	ND	ND	ND	1	µg/l	CPSD-AN-00576
Fluoranthene	ND	ND	ND	ND	ND	ND	ND	ND	1	µg/l	CPSD -AN-00576
Pyrene	ND	ND	ND	ND	ND	ND	ND	ND	1	µg/l	CPSD -AN-00576
Benzo[a] anthracene	ND	ND	ND	ND	ND	ND	ND	ND	1	µg/l	CPSD -AN-00576
Chrysene	ND	ND	ND	ND	ND	ND	ND	ND	1	µg/l	CPSD -AN-00576
Benzo[a]pyrene	ND	ND	ND	ND	ND	ND	ND	ND	1	µg/l	CPSD -AN-00576
Benzo[e]pyrene	ND	ND	ND	ND	ND	ND	ND	ND	1	µg/l	CPSD -AN-00576
Indeno[1,2,3-cd]pyrene	ND	ND	ND	ND	ND	ND	ND	ND	1	µg/l	CPSD -AN-00576
Dibenzo [a,h]anthracene	ND	ND	ND	ND	ND	ND	ND	ND	1	µg/l	CPSD -AN-00576
Benzo[g,h.i]perylene	ND	ND	ND	ND	ND	ND	ND	ND	1	µg/l	CPSD -AN-00576
Benzo[b [fluoranthene	ND	ND	ND	ND	ND	ND	ND	ND	1	µg/l	CPSD -AN-00576
Benzo[j]fluoranthene	ND	ND	ND	ND	ND	ND	ND	ND	1	µg/l	CPSD -AN-00576
Benzo[k]tluoranthene	ND	ND	ND	ND	ND	ND	ND	ND	1	µg/l	CPSD -AN-00576

D. Coastal Environment

296. The coastal environment of the proposed site for the development RWMF is protected by coastal protection structures. 877 m long rock boulder revetment has been constructed on southern side to protect the reclaimed land while on northern side of the reclaimed land is protected with a 911 m long concrete quay wall. A section of the rock boulder revetment is shown in Figure 78 and Figure 79 shows the cross section of the quay wall.

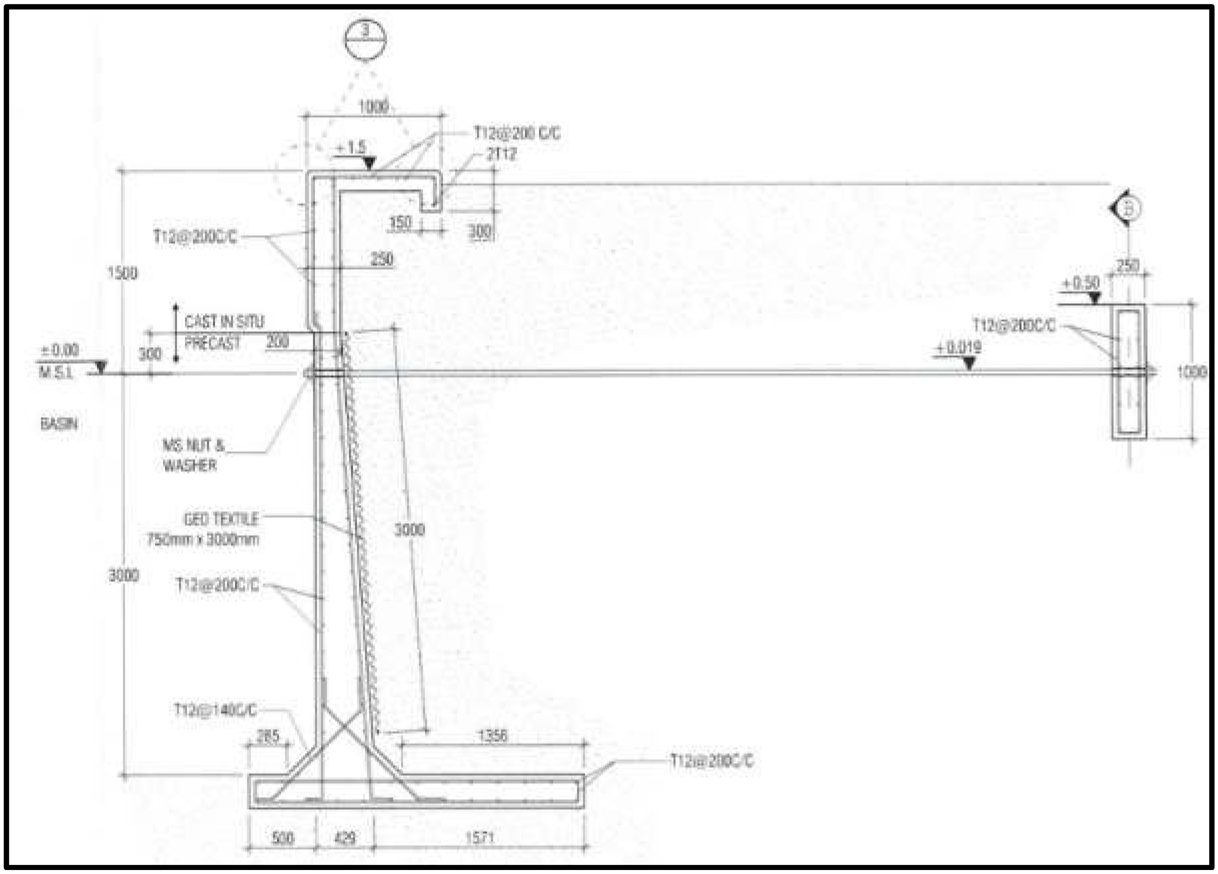
297. The revetment runs from the seafloor about -1m MSL to the crest level at MSL +1.8m. The slope of the revetment is 1 in 2 with rock boulders.

Figure 78: Design details of the rock revetment protecting the southern side of the reclaimed land



298. The quay walls are constructed with prefabricated reinforced concrete elements which are placed on the boundary of the reclaimed area. The elements are coupled by a capping beam as shown in Figure 79.

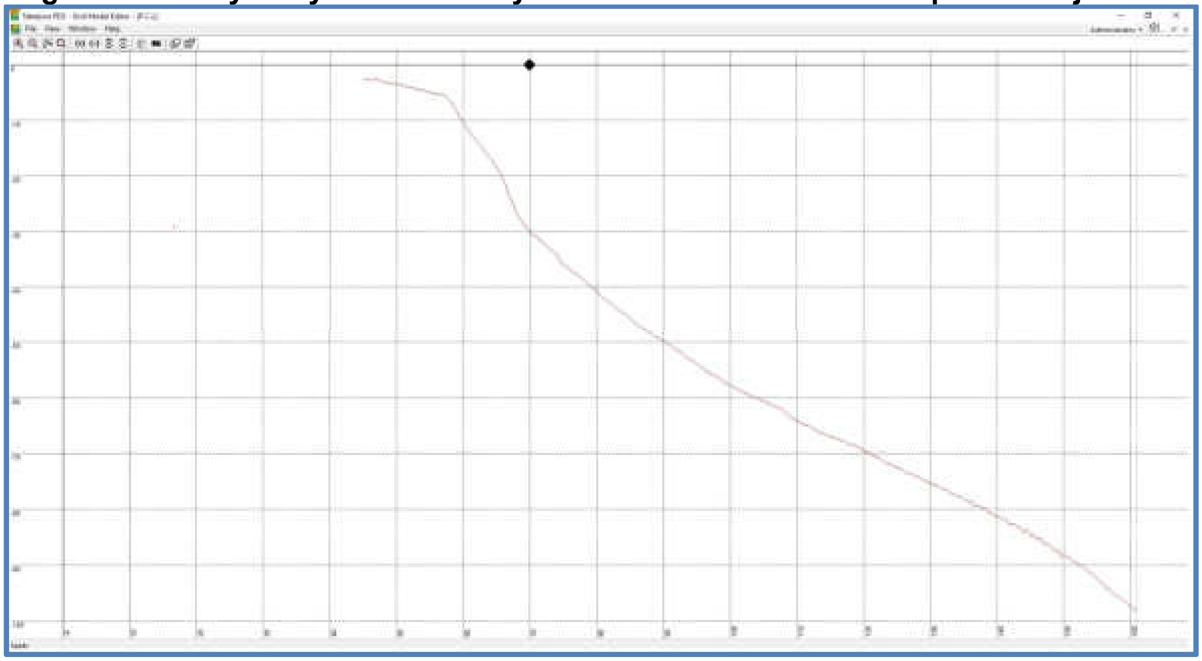
Figure 79: Design details of the quay wall protecting the northern side of the reclaimed land



1. Bathymetry

299. A detailed bathymetric survey of the southern side of Thilafushi reef system has been undertaken by PMU through its consultant, Water Solutions. The reef system of the Thilafushi Island comprises of an ocean ward reef flat, a lagoon ward reef and a central deep lagoon. The reef flat areas on the ocean ward side of the reef system (south of the proposed location) have a fairly flat depth ranging from -1.0 to -1.5m MSL. The reef system hosting Thilafushi does not host any other islands. The reef system is approximately 4.65 km long, 0.94 km wide (width of ring reef, including the lagoon area). The profile of this ocean-ward side of the reef system is shown in Figure 80 below.

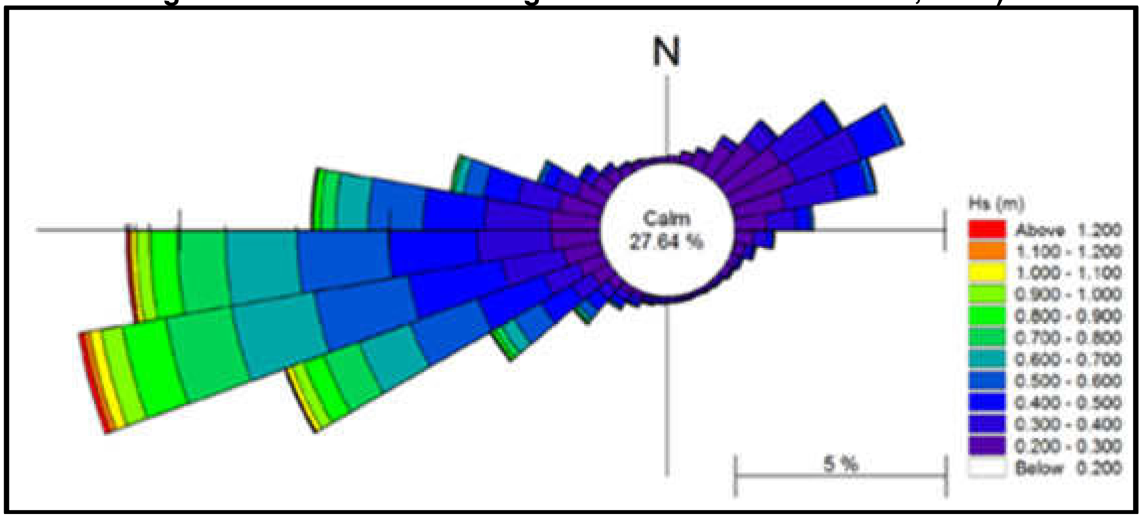
Figure 80: Bathymetry of the Reef System at Southern Side of Proposed Project Site



2. Hydrology

300. **Wave**. Two major types of waves have been reported on the coasts of the Maldives: waves generated by local monsoon wind and swells generated by distance storms. The local monsoon predominantly generates wind waves which are typically strongest during April-July in the south-west monsoon period. During this season, swells generated north of the equator with heights of 2-3 m sustained for periods of 18-20 seconds have been reported in the region. Local wave periods are generally in the range 2-4 seconds and are easily distinguished from the swell waves. Thilafushi Island is exposed to wind generated waves during NE monsoon and during transition periods. It is also expected to experience swell waves throughout the year. The southern side is likely to experience residual swell waves approaching from the South west and direct swell waves approaching from the SE (Naseer, 2003). LHI (2018) reported maximum significant wave height observed was over 1.2 m based on the field measurements that were taken in the Thilafushi reef system. Figure 81 graphically illustrate the wave height distribution pattern in terms of direction, occurrence and height.

Figure 81: Annual Wave Height Distribution Source: LHI, 2018)



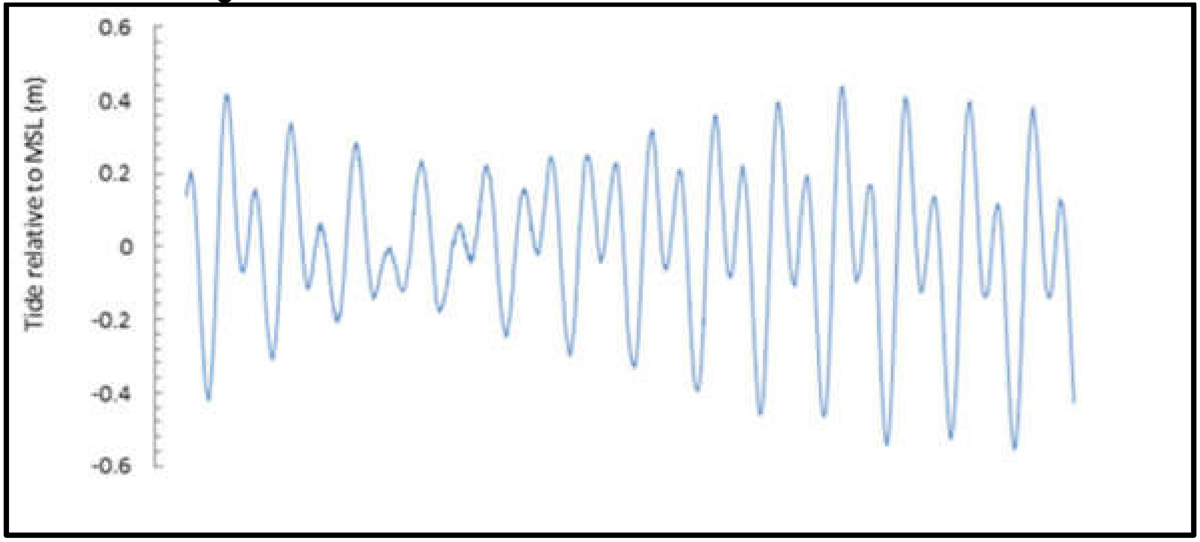
301. Distant cyclones and low-pressure systems originating from the intense South Indian Ocean storms are reported to generate long distance swells that occasionally cause flooding in the Maldives. The swell waves that reached Malé and Hulhule in 1987 are thought to have originated from a low-pressure system off the west coast of Australia and had significant wave heights in the order of 3 meters.

302. In addition, the Maldives have been subject to earthquake generated tsunami reaching heights of 4.0m on land (UNEP, 2005). Historical wave data from the Indian Ocean countries show that tsunamis have occurred in more than 1 occasion, most notable been the 1883 tsunami resulting from the volcanic explosion of Krakatoa (Choi and others, 2003) as well as the Indian Ocean tsunami of 2004.

303. The proposed site is located away from the ocean-ward side and protected on the atoll lagoon with the presence of land. The proposed land for the development of the RWMF is unlikely to be affected by wave activity provided the proposed coastal protection measures for the reclaimed land would be undertaken as planned.

304. **Tide.** The tide observed in Maldives can be classified as a mixed diurnal tide. The tidal variations are small and the average tidal range in Maldives is approximately 1 m (MEE, 2016). The variations of the tidal levels for the respective stations are given in the Figure 82. Tide affects wave conditions, wave generated and other reef-top currents. Tide levels are believed to be significant in controlling the amount of wave energy reaching the island, as no wave energy crosses the edge of the reef at low tide under normal conditions. In the Maldives where the tidal range is small (1 m), tides may have significantly important influence on the formation, development and sediment movement process around the island tides also may play an important role in lagoon flushing, water circulation within the reef and water residence time within an enclosed reef highly depends on tidal fluctuations.

Figure 82: Tide observed in Malé is mixed diurnal in nature



305. Tide data is important information in any coastal development project as it determines the elevation of the structures relative to a datum. A permanent tidal record station has been established at Velana International Airport by Maldives Meteorological Service. The maximum tidal range recorded at this tide station is 1.2m. The highest astronomical tide level is +0.62m (MSL) and lowest astronomical tide level is -0.72m MSL. The following table gives a summary of the tide levels for the tide datum has been widely used in Maldives.

Table 28: Summary of the Tide Levels Hulhule Island, Male Atoll

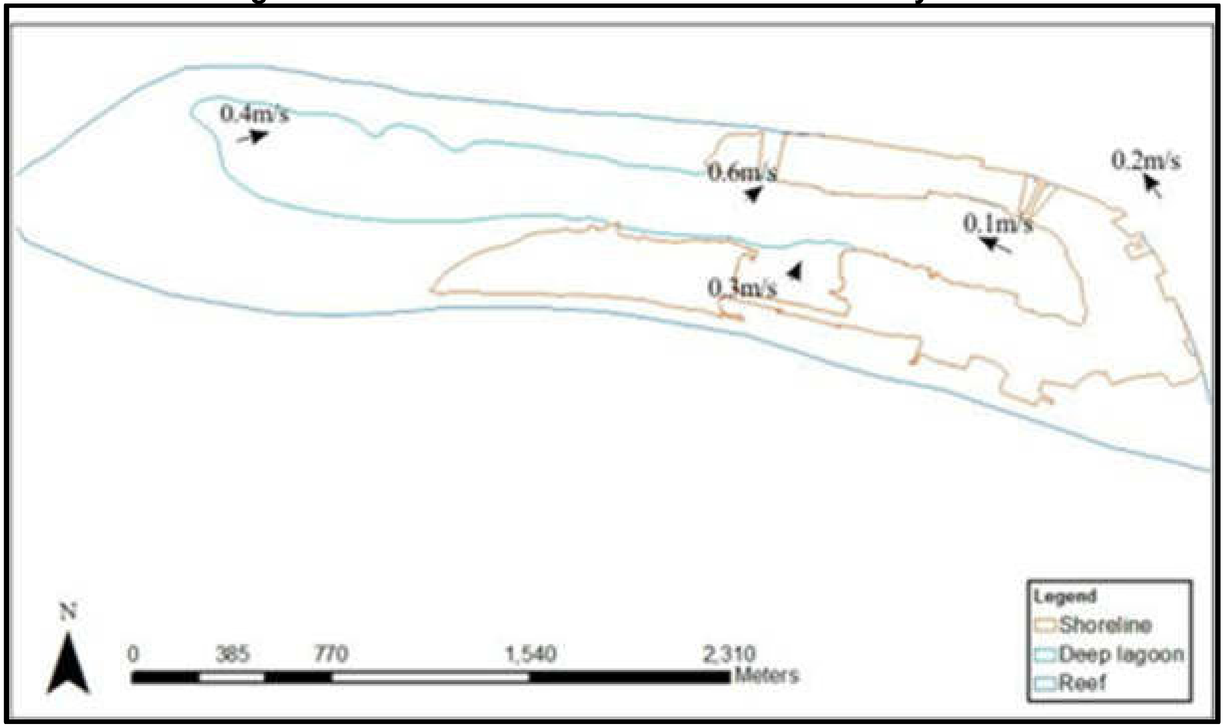
Water level from MSL (m)	Malé (2007-2011)
Highest High water (HHW)	0.62
Mean Highest High water (MHHW)	0.34
Mean High water (MHW)	0.33
Mean Low water (MLW)	-0.36
Mean Lowest Low water (MLLW)	-0.37
Lowest Low water (LLW)	-0.72

Source: MEE (2016).

306. **Surface Currents**. Currents that affect the reef system of Thilafushi can be caused by tidal currents, wind-induced currents and wave-induced currents. Generally current flow through the country is defined by the two-monsoon season winds. Westward flowing currents are dominant from January to March with the change in current flow pattern taking place in April and December. In April the westward currents become weak while the eastward currents start to take over. In December the eastward currents are weak with the westward currents becoming more prominent. Hence, currents within the site are very likely to be heavily influenced by the monsoons.

307. Current measurements were undertaken on the island in June 2017 during the field assessment phase. Generally, long term studies are required to establish the prevailing site-specific current patterns. However, due to time limitations of the present study a snapshot assessment was undertaken using drogue technique. The findings of the measurements are presented in Figure 83.

Figure 83: Measurement of Currents at the Reef System



308. The open ocean currents were generally slow during flood and ebb tides but increased closer to the Thilafushi channel during the flood tide. Current speeds with the lagoon showed a consistent average speed between 0.1 - 0.2 m/s. This was mainly due to the blocked nature of the inner lagoon. The speed increased an average of 0.3 m/s close to the Thilafushi Channel.

309. **Sea Surface Salinity and Sea Surface Temperature**. Sea Surface Temperatures (SST) of Malé region, based on satellite derived measurements, generally vary between 28 and 29 (Singh et al, 2001). It was also reported in Addu Atoll (Stoddart, 1966). Singh et al. (2001) reported that here has been gradual increase in SST in the order of +1.6°C per decade along the central regions of the Maldives. Salinity measurements in the open ocean and within the atoll lagoon of Maldives usually range between 33 - 35‰ (Stoddart, 1966). However, there is a slight salinity gradient observed on the reef flat, especially from the island coastline to the reef edge. This gradient is highest following heavy rainfall (Stoddart, 1966).

310. The results of the field assessment for SST and Salinity by CDE (2011) reported that the temperature values recorded were uniform across the sampling sites and depths in Thilafushi reef system. Slight variations in the salinity were observed between the outer reef and inner lagoon. The salinity was reported at 30.5 ‰ while the temperature was 23.1 °C.

311. For the purpose of EIA, in situ testing was carried out for temperature and salinity changes at depth with the use of a Valeport mini sound velocity profiler (SVP). Although the SVP is designed to measure sound velocity with depth, the device also records temperature and computes salinity. As a result, it is possible to obtain conductivity, temperature and depth (CTD) profiles from the SVP. The purpose of the use of SVP's was to determine the temperature and salinity fluctuations within the first 30 meters of the water column. The figures below outline the CTP profiles taken from the SVP.

Figure 84: CTD profiles obtained from water sample locations (SW1–SW4) (3rd July 2018).

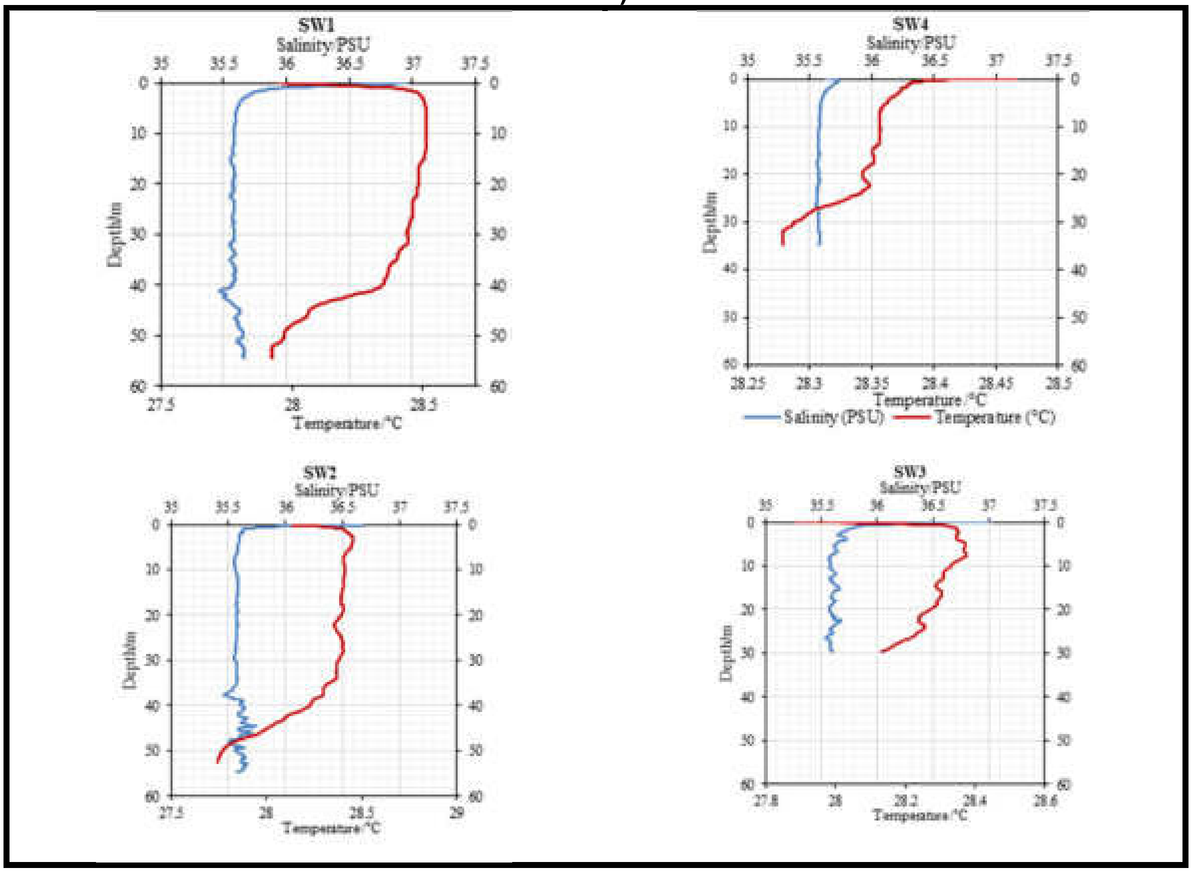
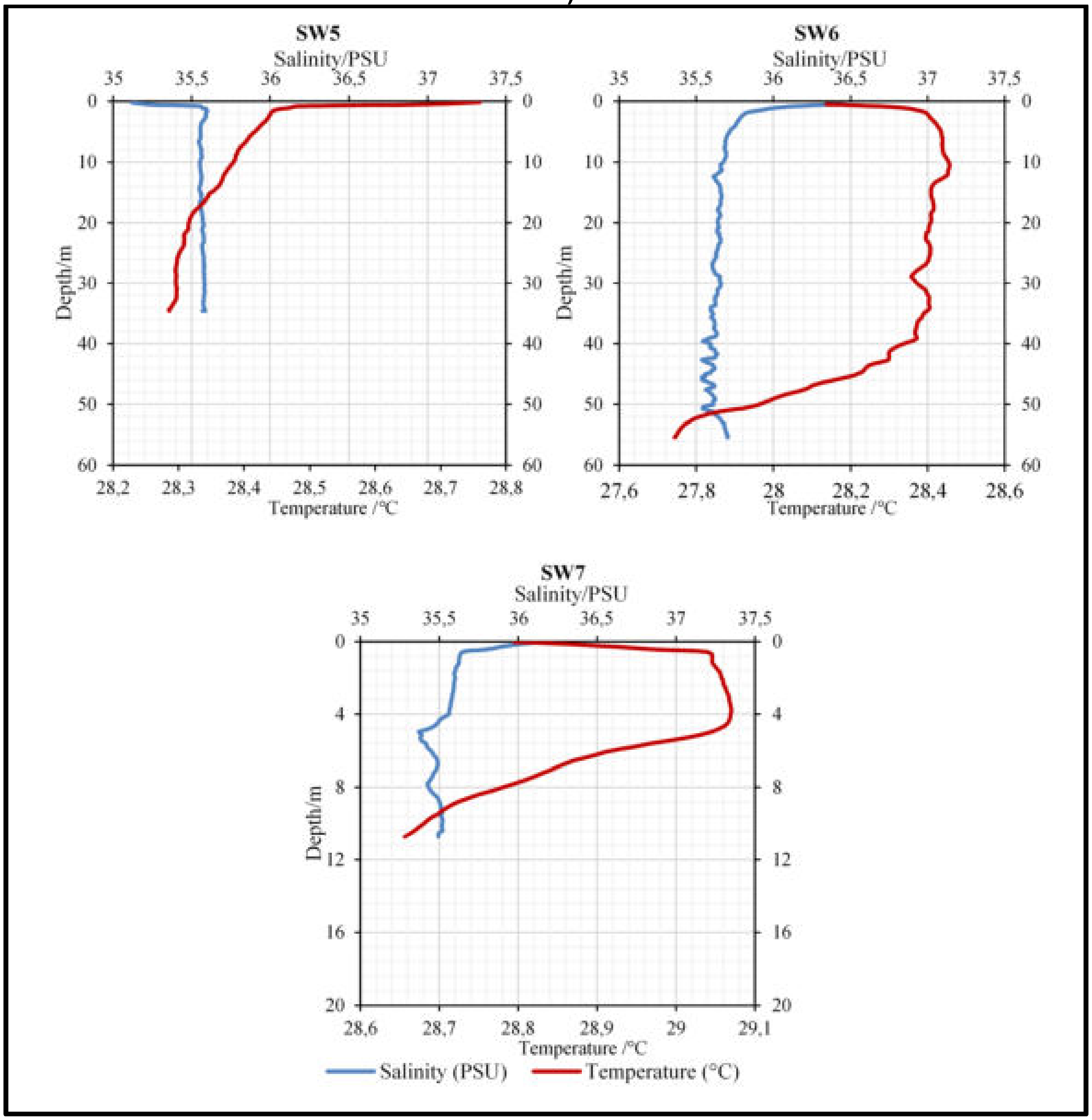


Figure 85: CTD profiles obtained from water sample locations (SW5 – SW7) (3rd July 2018).



312. **Marine water quality**. The primary objective of the marine water quality sampling was to determine the baseline conditions of the marine water around the project area. Qualitative and quantitative assessments were made on seawater from sites SW1 – SW7. Laboratory analysis were done for heavy metals (As, Cr, Cu, Ni, Pb, Zn, Hg, Cd), Ammonia, nitrates, PH, Turbidity, Oil and Grease and BOD. BOD was analyzed in MWSC, Malé. The remainder of the parameters were tested at Bureau Veritas laboratory, Sri Lanka. The table below outlines the results of the laboratory tests. These results show compliance with the Maldives Marine Monitoring Standards. Copies of the laboratory analyses are consolidated in Appendix 11.

313. Quarterly marine water quality data gathering at these sampling locations or sites shall be undertaken strategically during the design phase of the project. The DBO Contractor shall:

(i) undertake marine water quality measurements for each season of the year at the identified sampling locations or sites used in this EIA report (and any other locations as may be deemed by the DBO Contractor as important sampling locations or sites);
(ii) follow required sampling methodology per requirements of the Maldives EPA; and
(iii) include results of analyses in the updating of the EIA during the detailed design phase.

Figure 86: Marine Water Quality Sampling Locations

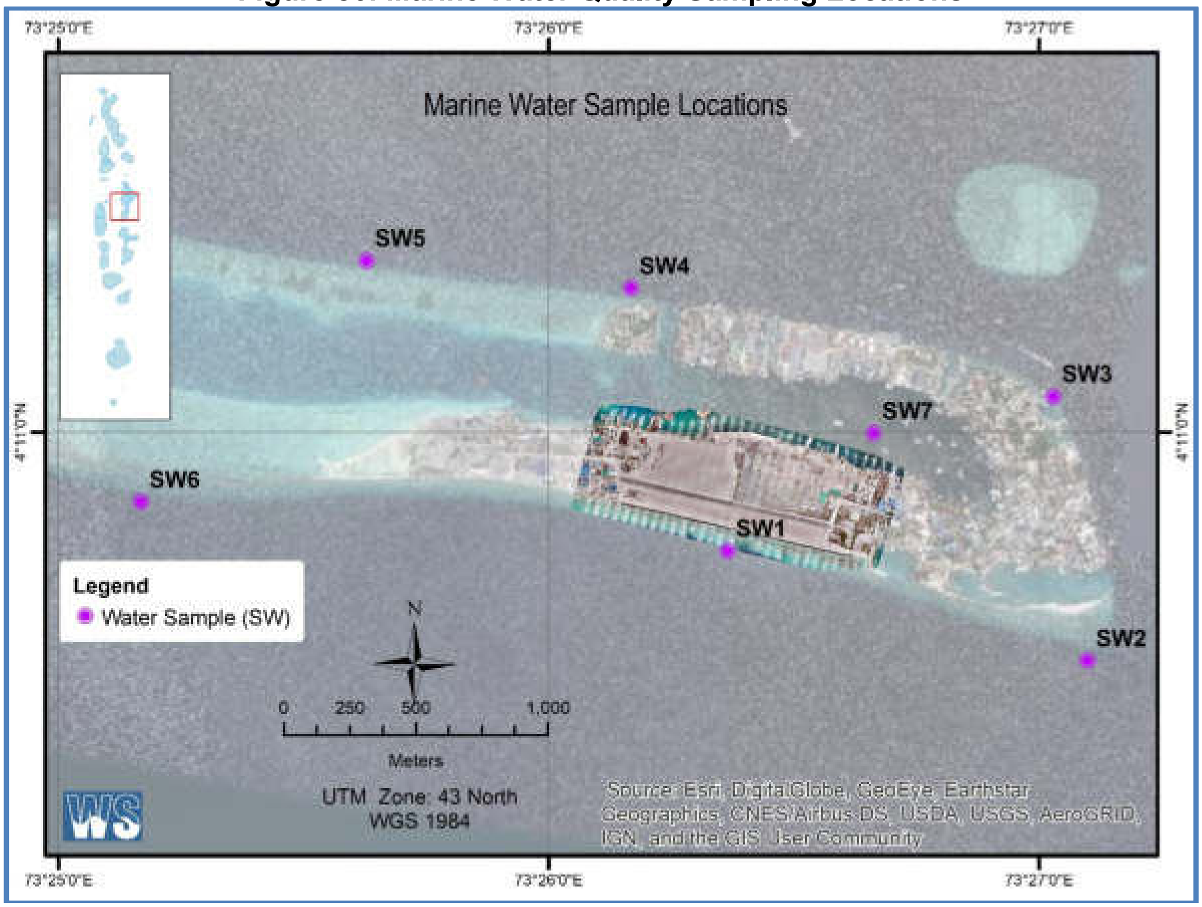


Table 29: Water quality results from sites SW1 to SW7

Parameters	Sites Date of Sampling: 03 July 2018							LOQ[23]	Unit	Test Method	Corresponding Maldivian Marine Monitoring Standard	
	SW1	SW2	SW3	SW4	SW5	SW6	SW7				Parameter	Reference
Temperature at receiving (℃)	24.2	24.2	24.2	24.2	24.2	24.2	24.2	-	℃	APHA 20th Edition – 2250B	18 – 32 °C	GBRMPA, 2009[24]
Biological Oxygen Demand (BOD)	1	1	1	1	< 1 LoQ 1 mg/l	< 1 LoQ 1 mg/l	< 1 LoQ 1 mg/l	< 1 mg/l	mg/l	HACH Method 8043	<2mg/l	
Turbidity	0.3	0.2	0.1	0.2	0.3	0.2	0.2	-	NTU	APHA 2130 B	3 – 5 NTU (max)	
pH at 24℃	8.4	8.4	8.4	8.4	8.4	8.4	8.2	-	-	FD-MTHD-007:2013 Reference to APHA 4500H+	8 – 8.3	
Nitrate (NO_3^-)	0.3	0.4	0.4	0.4	0.5	0.3	0.5	-	mg/l	APHA 4500 – NO_3-E	< 5mg /l	
Oil & Grease	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	2.0	mg/l	FD-MTHD-032:2013 Reference to APHA 5520B	n/a	
Free Ammonia (NH_3)	0.05	<0.02	<0.02	<0.02	0.05	0.05	<0.02	-	mg/l	SLS 614 Appendix A:2013	2 – 3 mg/l (max)	
Salinity	36	37	37	37	36	37	36	-	ppt	Alpha 2520	32 – 42 ppt	GBRMPA, 2009
Heavy Metals												
Arsenic (As)	ND	ND	ND	ND	ND	ND	ND	0.001	mg/l	CPSD-AN-00581-MTHD with ICP-MS	n/a	
Cadmium (Cd)	ND	ND	ND	ND	ND	ND	ND	0.0001	mg/l		n/a	
Lead (Pb)	ND	ND	ND	ND	ND	ND	ND	0.001	mg/l		n/a	
Mercury (Hg)	ND	ND	ND	ND	ND	ND	ND	0.00005	mg/l		n/a	
Nickel (Ni)	ND	ND	ND	ND	ND	ND	ND	0.001	mg/l		n/a	
Copper (Cu)	ND	ND	ND	ND	ND	ND	ND	0.001	mg/l		n/a	
Zinc (Zn)	ND	0.003	0.004	ND	ND	0.003	0.008	0.001	mg/l		n/a	
Chromium (Cr)	ND	ND	ND	ND	ND	ND	ND	0.001	mg/l		n/a	

[23] Limit of Quantitation: the lowest concentration of the contaminant that can be reliably measured
[24] Great Barrier Reef Marin Park Authority (2009) Outlook Report 2009

314. **Sediments**. The sediment regime around the present waste disposal area is likely to reflect the leaching of pollutants from the dumped wastes at the Thilafushi Island. As unplanned dumping of wastes on this island has the potential to contaminate sediments of the inner lagoon and outer reef flat area, six sampling stations were selected to get a representative status of the extent of contamination of the sediments due to the current waste disposal methods. Results of sediment analysis show heavy metal contents (cadmium, lead, zinc, copper, chromium, nickel, mercury, arsenic) are below the trigger values. See Table 30 for the results.

Figure 87: Sediment Sample Locations

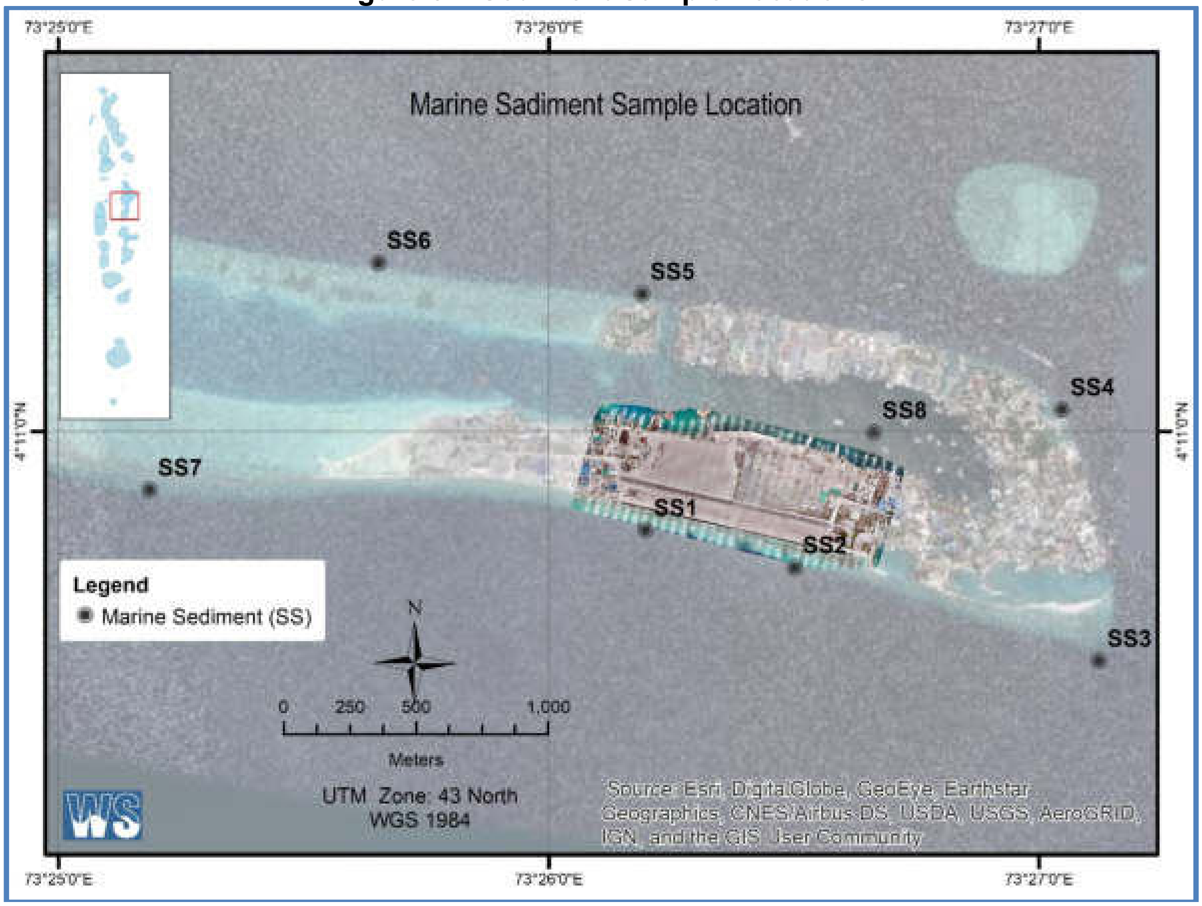


Figure 88: Sediment Grab and Sediment Sample from Inner Lagoon (SS8).

Table 30: Sediment chemical properties from sites SS1 to SS8

Test	Unit	Test method	Results Date of Sampling: 23 – 24 April 2018								Limit of Determination	Trigger Value[25]
			SS1	SS2	SS3	SS4	SS5	SS6	SS7	SS8		
Cadmium (Cd)	mg/kg	Microwave Digestion/ Detection by ICP-Md	ND	ND	ND	ND	ND	ND	0.06	0.07	0.05	1.5
Lead (Pb)	mg/kg		0.06	ND	ND	4.0	0.6	0.3	ND	8.2	0.05	50
Zinc (Zn)	mg/kg		ND	ND	ND	ND	ND	ND	0.3	10.6	0.05	200
Copper (Cu)	mg/kg		ND	0.3	0.1	2.7	0.08	0.6	0.3	15.9	0.05	65
Chromium (Cr)	mg/kg		0.2	0.4	0.4	1.7	0.3	0.4	ND	2	-	80
Nickel (Ni)	mg/kg		ND	ND	ND	ND	ND	ND	ND	ND	0.05	
Mercury (Hg)	mg/kg		ND	ND	ND	ND	ND	ND	ND	ND	0.05	
Arsenic (As)	mg/kg		0.2	0.2	0.2	1.1	0.2	0.2	0.2	1.0	-	20
Polycyclic aromatic hydrocarbons (PAH)	-	-	-		-	-	-	-	-	-	-	

Note: ICP – MS – Inductively Coupled Plasma Mass Spectrometry/ND: Not Detected.

[25] Trigger values, values below which it is unlikely that there will be any biological disturbance for organisms inhabiting the sediment. Values used are those published by the Australian and New Zealand Environment Conservation Council (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* National Water Quality Management Strategy Paper No. 4

E. Biological Environment

315. The marine environment of Thilafushi consists of shallow lagoon, deep lagoon, reef-flat, and reef slope areas. Thilafushi Island is situated on the southern rim of North Male 'Atoll near Gulhifalhu. Almost half of Thilafushi lagoon is now reclaimed. The deep lagoon area is used as a mooring basin.

1. The Lagoon and Reef System

316. Thilafushi consists of deep, shallow lagoon, reef flat and reef slope areas. More than half of the shallow lagoon or reef flat area is now reclaimed. The south wing of Thilafushi is wider compared to north wing. The widest reef flat area is on the south wing on the west side of the reef. The enclosed deep lagoon area towards east is well protected with very restricted water movement. This area is used by vessels as a mooring basin. The stagnant water coupled with waste dumping in this area has degraded the lagoon environment on the east side. The deep lagoon of this area has very low visibility, the bottom substrate of the deep lagoon consists mainly of sand. Towards the east of deep lagoon, the bottom substrate is mainly mud and garbage debris.

317. A coral reef survey of Thilafushi reef was carried out to establish a baseline of the existing coral reef environment. The baseline assessment assessed the diversity and abundance of coral reef, fish, and significant invertebrates that are commonly associated with the reef environment of Maldives. The method involved determining percentage of various benthic substrate (categories) using standard benthic categories for coral reef benthic substrate sampling as described by Hodgson et.al (2006) in Reef Check Instruction Manual: A Guide to Reef Check Coral Reef Monitoring.

318. **Benthic Survey of April 2018**. All surveys were carried out by underwater SCUBA diving. The marine surveys were carried out by surveyors who had been trained to undertake Reef Check surveys as outlined in the Reef Check Instruction Manual: A Guide to Reef Check Coral Reef Monitoring (2006). Based on the Guide to Reef Check Coral Reef Monitoring (2006) photo quadrat surveys were done in order to measure the benthic composition at 7 sites (M1 – M7) located on the outer reef around Thilafushi island. At each of the survey sites benthic composition and fish abundance was surveyed at depths of 5 meters and 10 meters. The inner lagoon was not surveyed as the area is not of ecological importance.

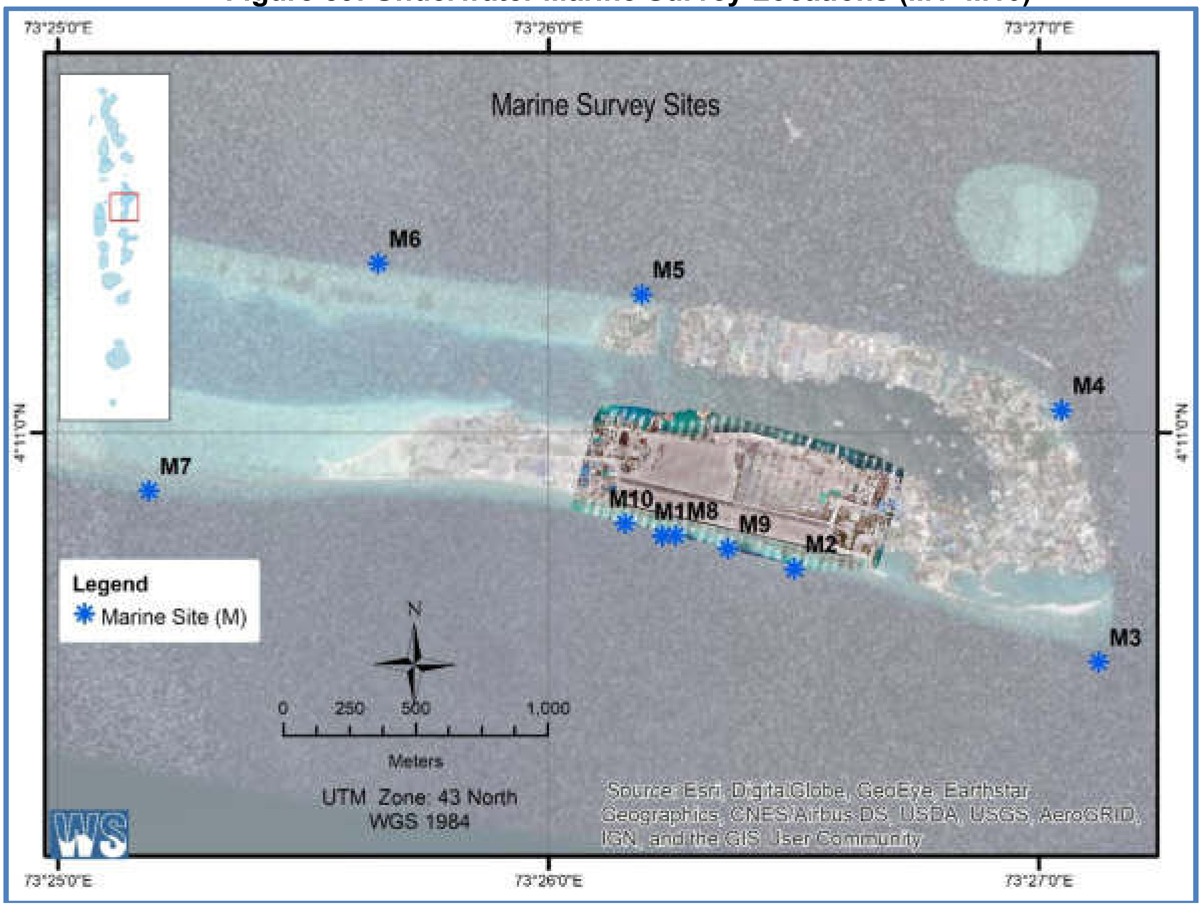
319. The photo quadrat surveys were undertaken. A transect line of 20 meters at each site is set out, the surveyor then places a half a meter quadrat made from PVC along the transect line and takes a photo directly from vertically above. The second photo is then taken along in the same manner after approximately 1 m away from the first photo. In this manner, photos are taken along the transect line and in total, 10 photos on each transect line are taken. In each of the sites 4 transects were place in two depths (5 & 10m). The surveys were undertaken on 23-24 April 2018.

320. **Reef Profile and Underwater Marine Life Survey of September 2019**. Three additional sites (M8 – M10) were surveyed on 1 September 2019 using photo quadrat methods. This particular underwater survey was conducted to provide more in-depth information at three alternative sections of the southern coastal boundary of the proposed project site where the cooling water discharge line from the WTE plant will be laid. Section V provides the detailed discussions on the result of this additional survey. Unlike the conventional reef transect surveys, the three sections were assessed for benthic composition by undertaking photo quadrats from

the top reef of up to 30 meters, along the reef profile. Before start of the survey, the starting points of the three sections were marked using a plastic bottle tied with a rope and weight at its end. The weight rested at the top reef, approximately 5 meters from the reef slope. This allowed the divers to descent from the exact required location up to 30 meters. Photos were taken using the half meter quadrat made from PVC along the transect line (vertical) and takes a photo directly from above. The second photo is then taken along in the same manner after approximately 1 below the first photo. In this manner, photos are taken along the transect line.

321. Figure 89 below shows the locations of the marine surveys undertaken in April 2018 and September 2019.

Figure 89: Underwater Marine Survey Locations (M1–M10)



322. **Data Processing Methodology**. Analysis of the photos was done using a computer program called, CPCe (Coral Point Count with Excel extensions). This is an internationally recognized software used all over the word to assess the benthic composition of the reefs. In this program, photographs are analyzed using pre-defined benthic categories. Depending on the type of survey, these categories can be user defined at any given level. Users can have very complex levels ranging from individual coral families or have broader assessment categories. As the objective of this survey was to assess the impact of dredging and reclamation, it made sense to use a broader category. Hence, benthic categories adopted by the Reef Check protocol were utilized. A text file containing these categories was created and imported to CPCe. The Reef Check protocol allows categorizing life forms followed under the Reef Check protocol, which emphasizes on benthic composition categorizing such as hard corals, sand, rock and others. The

emphasis is not on recording corals to their species levels, but rather the general coral and other life forms such as hard and soft corals. This method is more accurate as the percentage of healthy coral cover and other life forms can be more accurately recorded even by a non-experienced surveyor.

323. The following are definition of benthic categories used in this survey.

(i) **HC:** All living coral including bleached coral; includes fire, blue and organ pipe corals

(ii) **SC**: Include zoanthids but not anemones (OT)

(iii) **DC**: Coral that has died within the past year; appears fresh and white or with corallite structures still recognizable

(iv) **ALG**: All macro-algae except coralline, calcareous and turf (record the substrate beneath for these); Halimeda is recorded as OT; turf is shorter than 3cm.

(v) **SP**: All erect and encrusting sponges (but no tunicates).

(vi) **RC**: Any hard substrate; includes dead coral more than 1 year old and may be covered by turf or encrusting coralline algae, barnacles, etc.

(vii) **RB**: Reef rocks between 0.5 and 15cm in diameter

(viii) **SD**: Sediment composed of particles of less than 0.5cm in diameter; in water, falls quickly to the bottom when dropped.

(ix) **SI**: Sediment that remains in suspension if disturbed; recorded if color of the underlying surface is obscured by silt.

(x) **OT**: Any other sessile organism including sea anemones, tunicates, gorgonians or non-living substrate.

(xi) **SG**: All types of sea grass observed categorized in the field SG.

324. Each of the 10 photos from transect are imported, cropped and prepared for analysis. The CPCe program then generates a matrix of random points overlaid on the image for each point to be visually identified. Users can then input the defined categories for each photo and once all the photos are analyzed, the results are displayed on a table.

325. **Status of Site 1 (M1)**. Site 1 was selected from the Southern rim of the island reef. The site was chosen as the site was adjacent to the proposed waste rehabilitation center. The substrate at the site is dominated by rock at depths of 5 (58 ± 14.2%) and 10 (64.5 ± 2.78) meters respectively. Hard coral cover was observed to be moderate at the site at depths of 5 (19.5 ± 5.91) and 10 (21 ± 2.68) meters. Massive porites were the dominating the group of hard coral observed at the site at both the depths. Fishes observed to be abundant at a depth of 5 meters were surgeon fishes, damselfishes and butterflyfishes. Fishes observed to be abundant at a depth of 10 meters were anthias, damselfishes and triggerfishes. The following graph outlines the status of site 1(M1) at depths of 5 and 10 meters.

Figure 90: Percentage Benthic Composition at site 1(M1) at Depths of 5 and 10 meters ± Standard Error (SE) (23 April 2018).

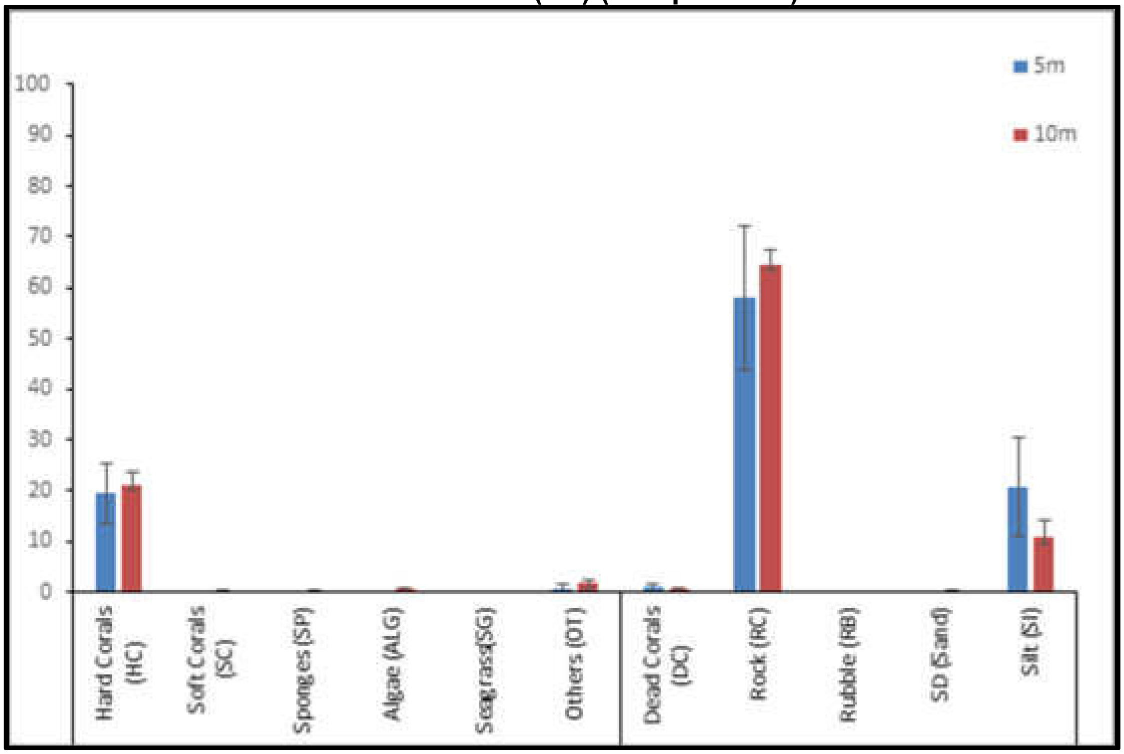
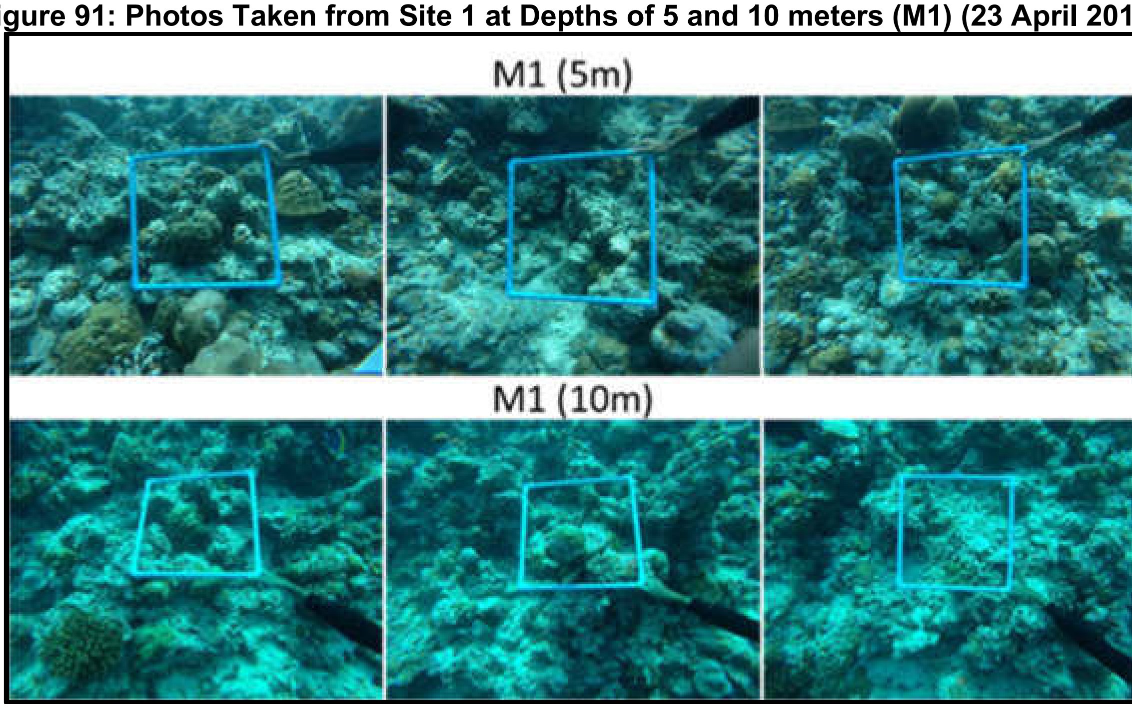


Figure 91: Photos Taken from Site 1 at Depths of 5 and 10 meters (M1) (23 April 2018).



326. **Status of Site 2 (M2)**. Site 2 was selected from the Southern rim of the island reef east of site 1. The site was chosen as the site was adjacent to the proposed waste rehabilitation center. The substrate at the site is dominated by rock at depths of 5 (71.25 ± 3.86%) and 10 (63 ± 6.14) meters respectively. Hard coral cover was observed to be moderate at the site at depths of 5

(22.25 ± 2.95) and 10 (23.25 ± 5.17) meters. Massive porites were the dominating group of hard coral observed at the site at both the depths. Fishes observed to be abundant at depth of 5 meters were anthias, surgeon fishes, damselfishes, parrotfishes, triggerfishes and butterflyfishes. Fishes observed to be abundant at depth of 10 meters were anthias, damselfishes, butterflyfishes and triggerfishes. The following graph outlines the status of site 2(M2) at depths of 5 and 10 meters.

Figure 92: Percentage Benthic Composition at Site 2 (M2) ± SE (24 April 2018).

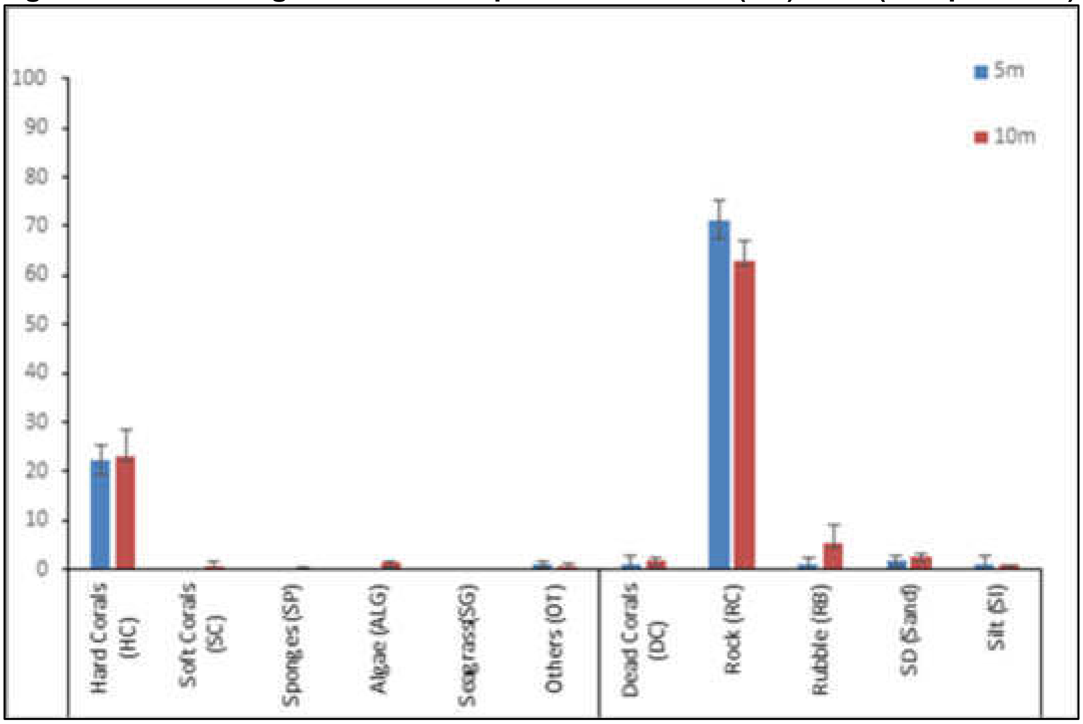
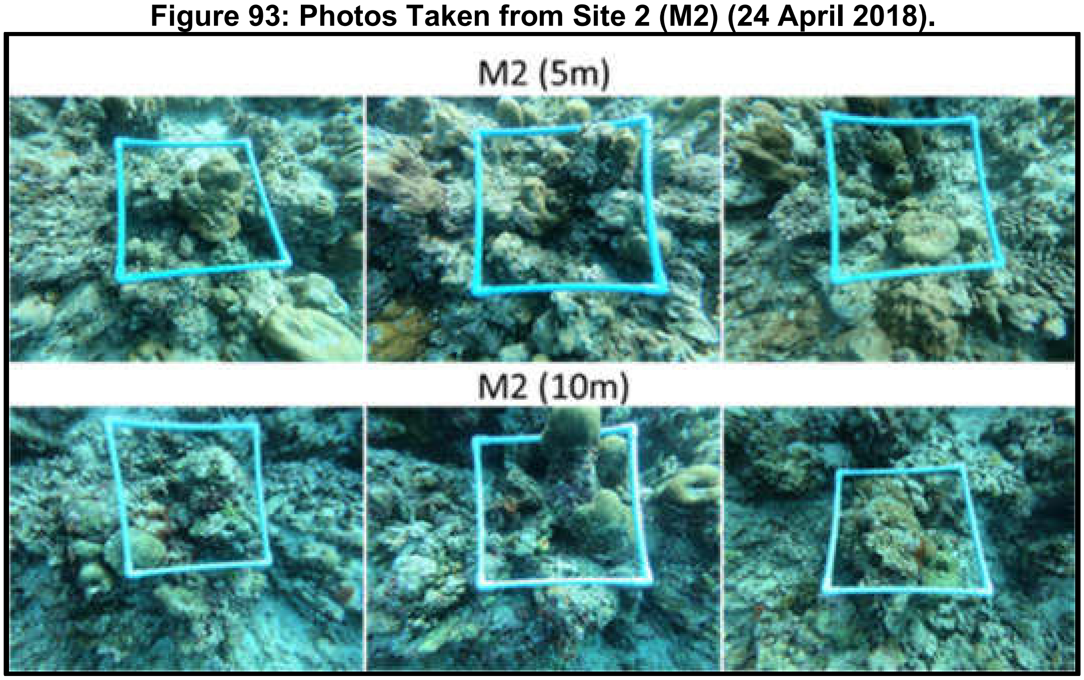


Figure 93: Photos Taken from Site 2 (M2) (24 April 2018).



327. **Status of Site 3 (M3**). Site 3 was selected from the Southern eastern corner of the island reef. The site was chosen as a control site as well as to get a broader understanding of the ecological baseline around the reef. The substrate at the site is dominated by rock at depths of 5 (76.25 ± 2.10%) and 10 (65.75 ± 2.46) meters respectively. Hard coral cover was observed to be moderate at the site at depths of 5 (17 ± 2.48) and 10 (16.5 ± 0.65) meters. Massive porites were the dominating group of hard coral observed at the site at both the depths. Fishes observed to be abundant at a depth of 5 meters were surgeon fishes and jacks and trevallies. Fishes observed to be abundant at a depth of 10 meters were anthias, damselfishes and triggerfishes. The following graph outlines the status of site 3(M3) at depths of 5 and 10 meters.

Figure 94: Percentage Benthic Composition at Site 3 (M3) ± SE (23rd April 2018).

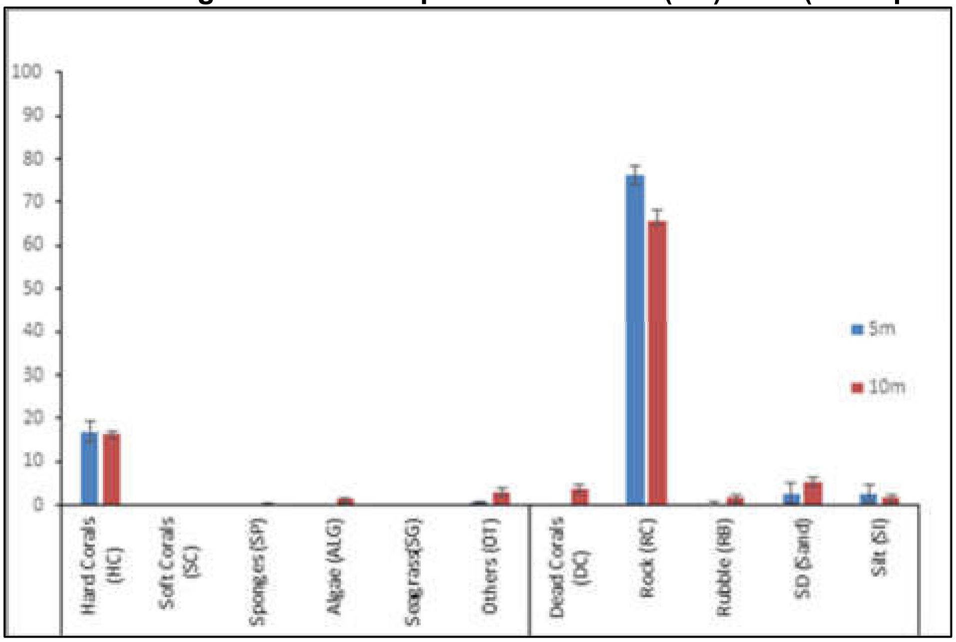
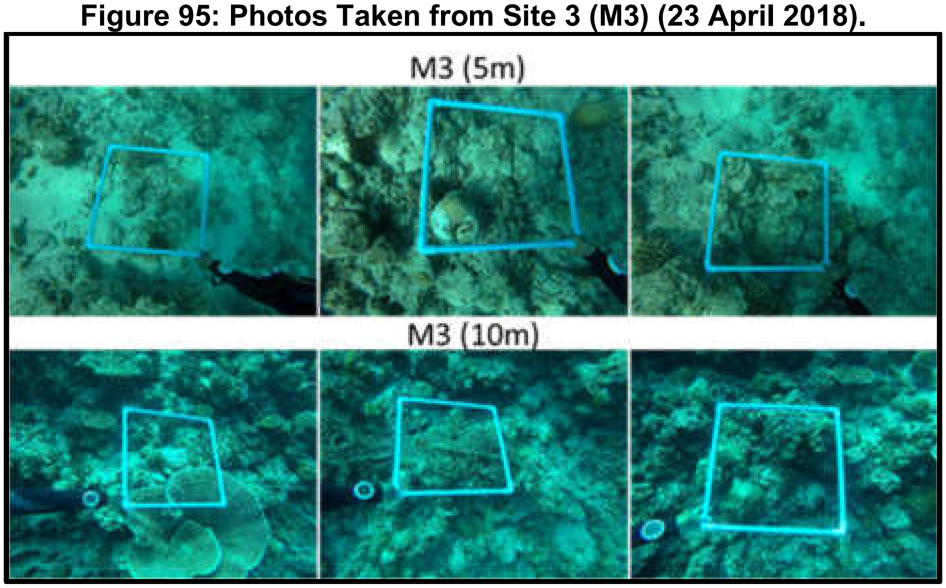


Figure 95: Photos Taken from Site 3 (M3) (23 April 2018).



328. **Status of Site 4 (M4)**. Site 4 was selected from the North-eastern rim of the island reef. The site was chosen as a control site as well as to get a broader understanding of the ecological

baseline around the reef. The substrate at the site is dominated by rubble at depths of 5 (67 ± 4.49%) and 10 (60 ± 6.42) meters respectively. Hard coral cover was not observed at the site at depths of 5 and 10 meters. Fishes observed to be abundant at a depth of 5 meters were surgeon fishes, butterfly fishes and fusiliers. Fishes observed to be abundant at a depth of 10 meters were only fusiliers. The following graph outlines the status of site 4(M4) at depths of 5 and 10 meters.

Figure 96: Percentage Benthic Composition at Site 4 (M4) ± SE (24 April 2018).

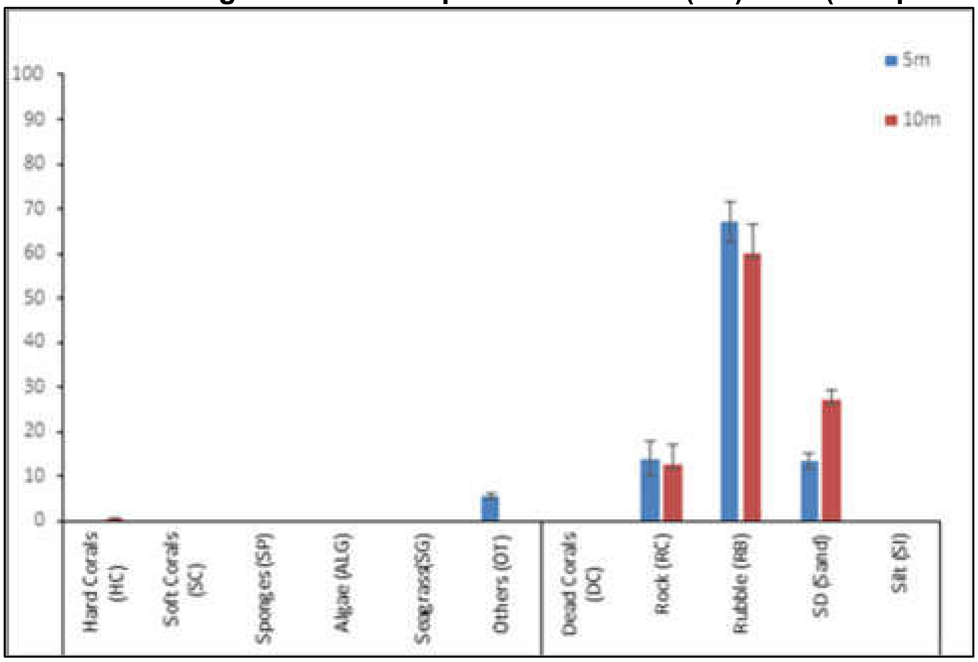
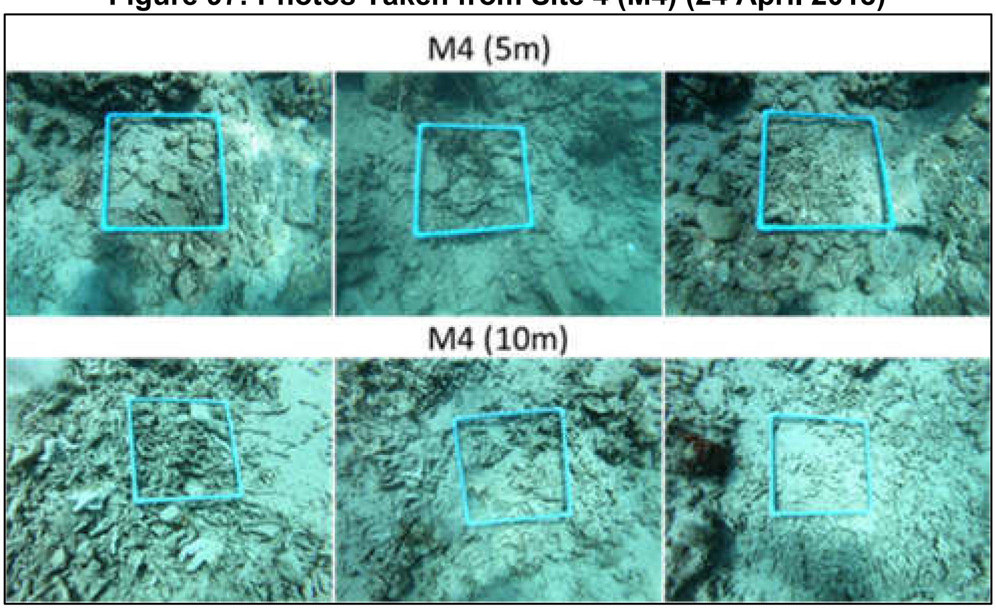


Figure 97: Photos Taken from Site 4 (M4) (24 April 2018)



329. **Status of Site 5 (M5)**. Site 5 was selected from the Northern rim of the island reef close proximity to the entrance channel. The site was chosen as a control site as well as to get a broader understanding of the ecological baseline around the reef. The substrate at the site is dominated by rock at depths of 5 (46.75 ± 6.28%) and 10 (51.5 ± 5.81) meters respectively. Hard coral cover

was observed to be low at the site at depths of 5 (5 ± 1.58) and 10 (4.25 ± 0.75) meters. Massive porites were the dominating group of hard coral observed at the site at both the depths. Fishes observed to be abundant at a depth of 5 meters were surgeon fishes and parrotfishes. Fishes observed to be abundant at a depth of 10 meters were surgeon fishes, damselfishes and triggerfishes. The following graph outlines the status of site 5(M5) at depths of 5 and 10 meters.

Figure 98: Percentage Benthic Composition at Site 5 (M5) ± SE (24 April 2018)

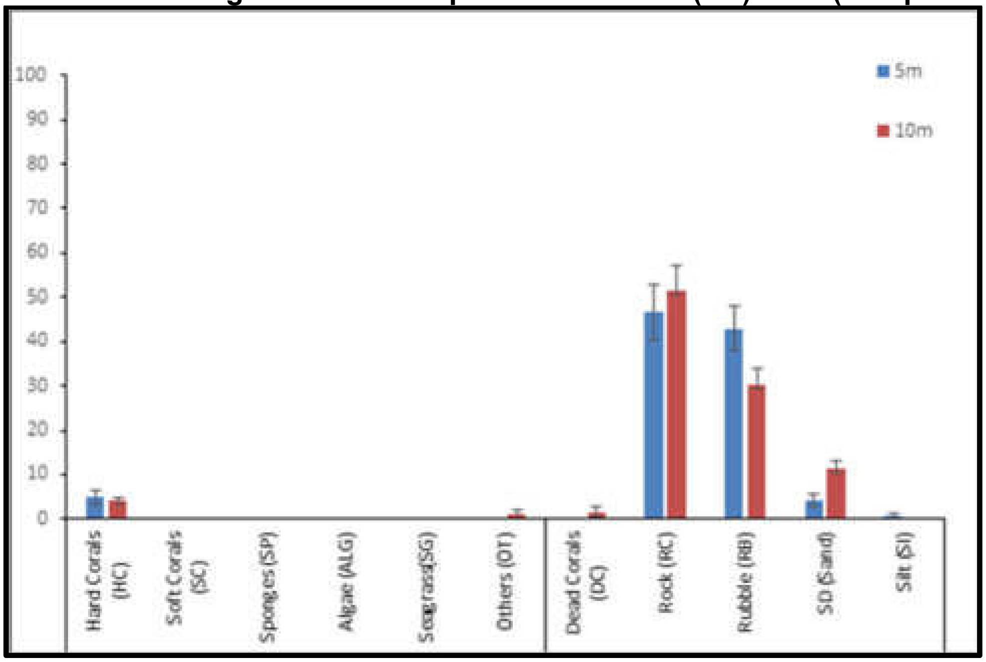
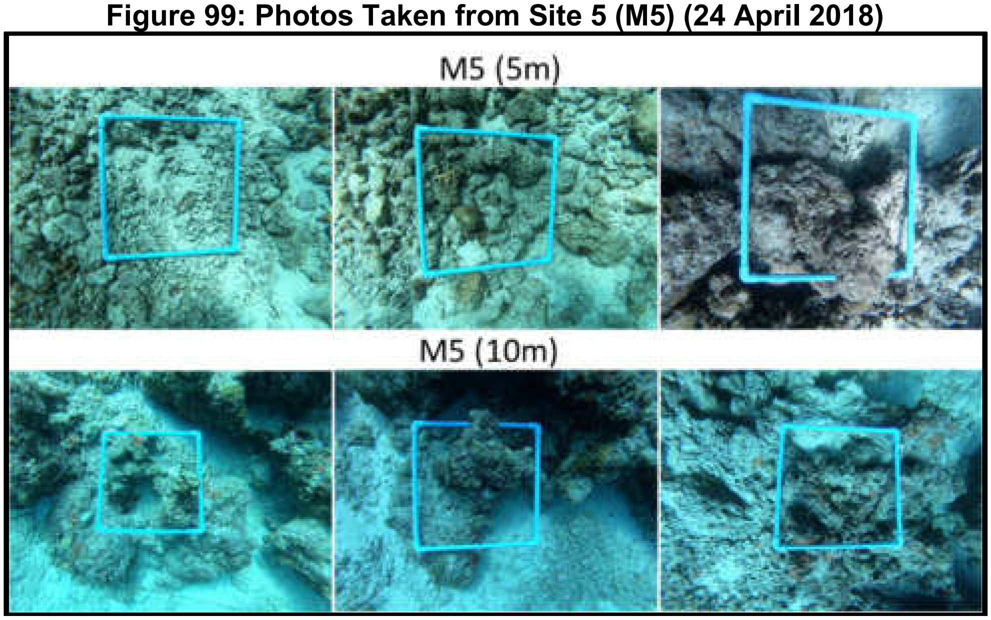


Figure 99: Photos Taken from Site 5 (M5) (24 April 2018)



330. **Status of Site 6 (M6).** Site 6 was selected from the Northern rim of the island reef west of site 5. The site was chosen as a control site as well as to get a broader understanding of the ecological baseline around the reef. The substrate at the site is dominated by rock at depths of 5 (80.5 ± 4.19%) and 10 (36.5 ± 5.85) meters respectively. Hard coral cover was observed to be

low at the site at depths of 5 (8.75 ± 2.53) and 10 (14 ± 2.58) meters. Particular group of hard corals were not observed to dominate the substratum. A diverse group of corals from groups such as Acropora, Pocillopora and Porites were observed at the site. Fishes observed to be abundant at a depth of 5 meters were surgeon fishes, wrasses, triggerfishes, damselfishes and butterfly fishes. Fishes observed to be abundant at a depth of 10 meters were surgeon fishes, damselfishes, triggerfishes and butterfly fishes. The following graph outlines the status of site 6(M6) at depths of 5 and 10 meters.

Figure 100: Percentage Benthic Composition at Site 6 (M6) ± SE (24 April 2018)

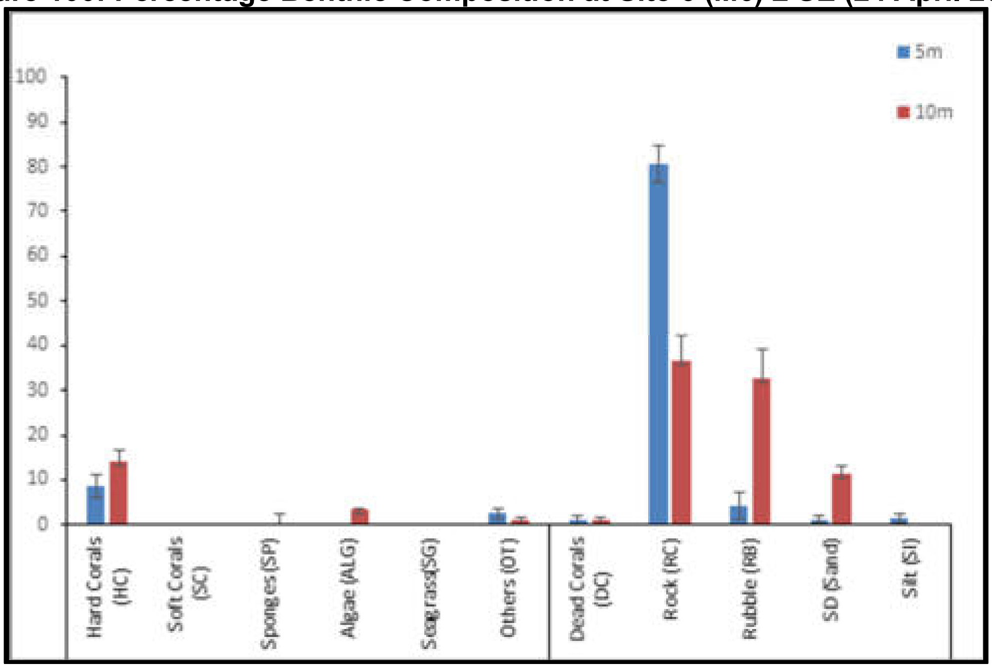
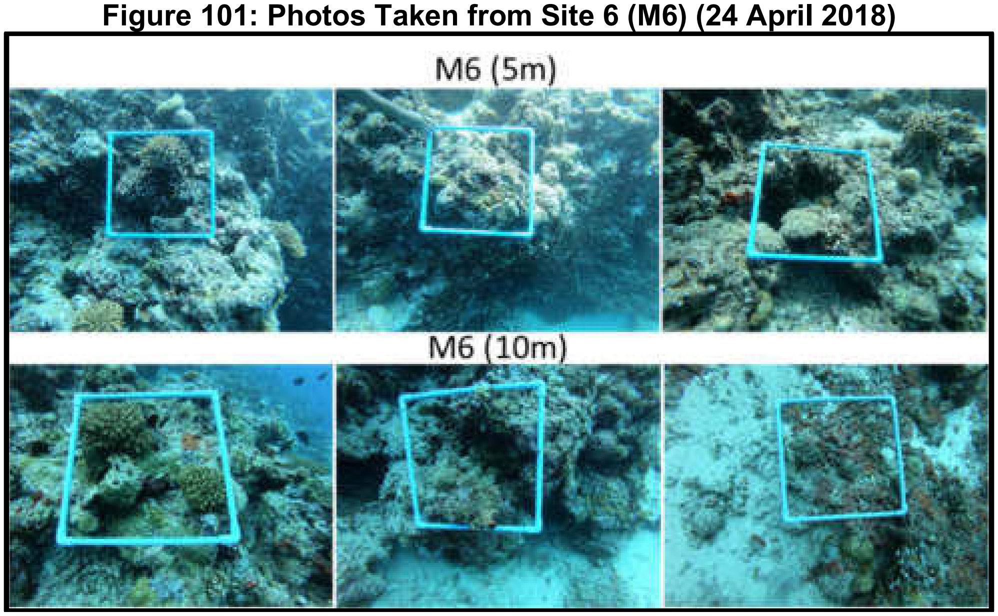


Figure 101: Photos Taken from Site 6 (M6) (24 April 2018)



331. **Status of Site 7 (M7).** Site 7 was selected from the Southern rim of the island reef west of site 1. The site was chosen as a control site as well as to get a broader understanding of the ecological baseline around the reef. The substrate at the site is dominated by rock at depths of 5 (76 ± 5.87%) and 10 (77.75 ± 3.33) meters respectively. Hard coral cover was observed to be low at 5 meters (5 ± 1%) and moderate in 10 meters (17.5 ± 3.2). Massive porites were the dominating group of hard coral observed at the site at both the depths. Fishes observed to be abundant at a depth of 5 meters were surgeon fishes, damselfishes and butterfly fishes. Fishes observed to be common at a depth of 10 meters were surgeon fishes. The following graph outlines the status of site 7(M7) at depths of 5 and 10 meters.

Figure 102: Percentage Benthic Composition at Site 7 (M7) ± SE (23 April 2018)

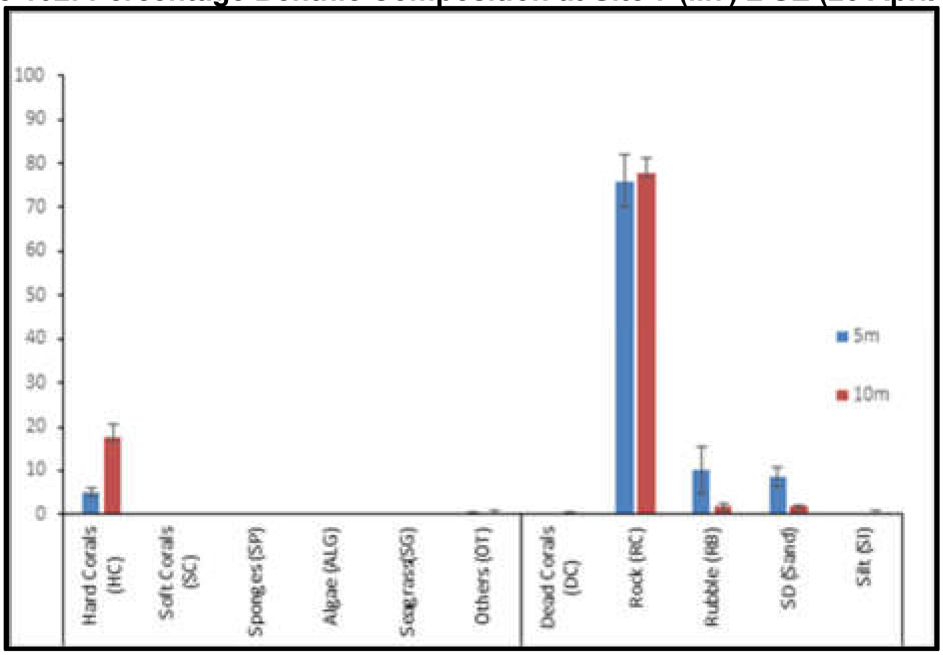
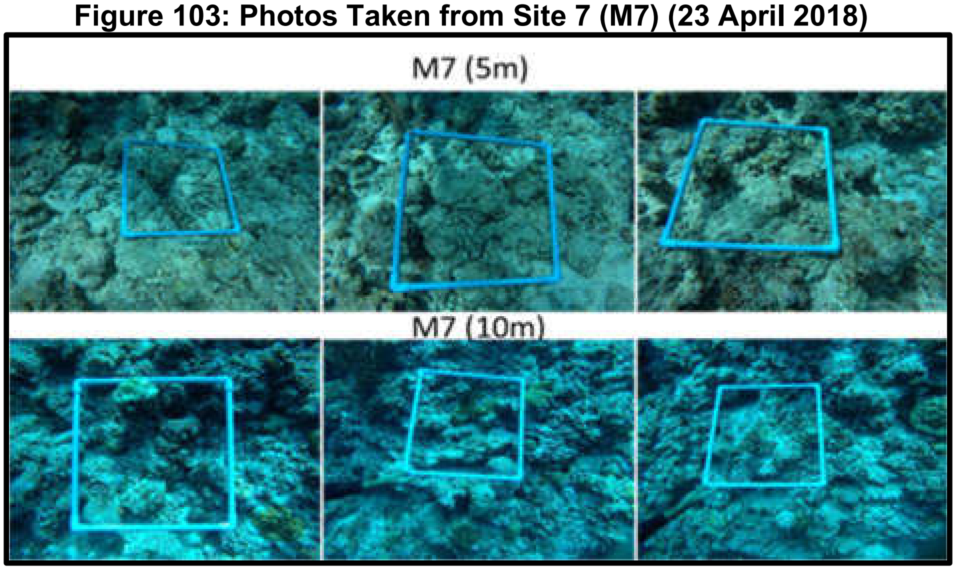


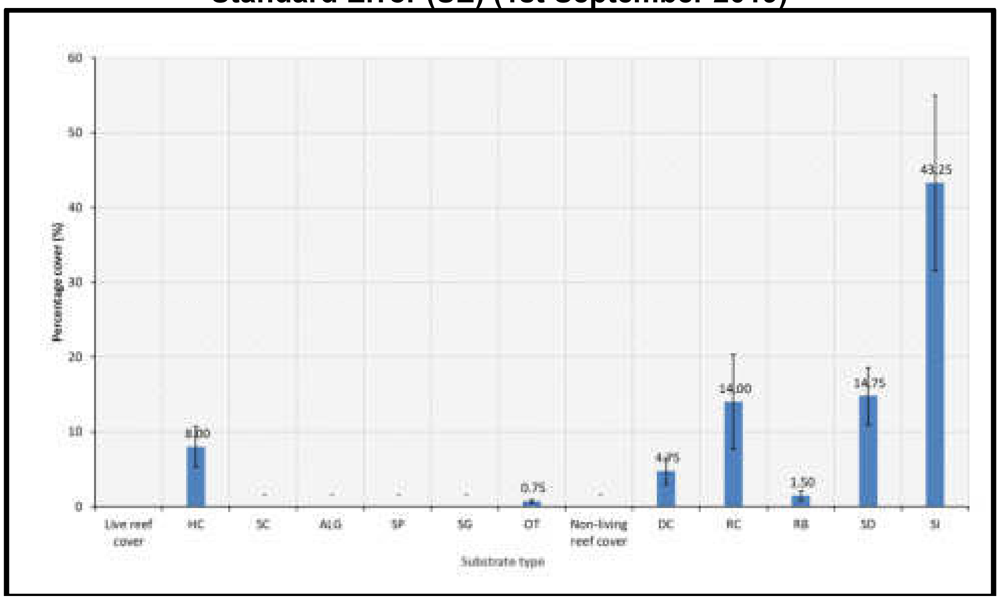
Figure 103: Photos Taken from Site 7 (M7) (23 April 2018)



332. **April 2018 Underwater Survey Results**. The highest coral cover was observed at the depth of 10 meters in site M2 adjacent to the current waste dumping area. Therefore, there is the possibility the leachate from landfill is not having any negative impacts on the reef at site M2.

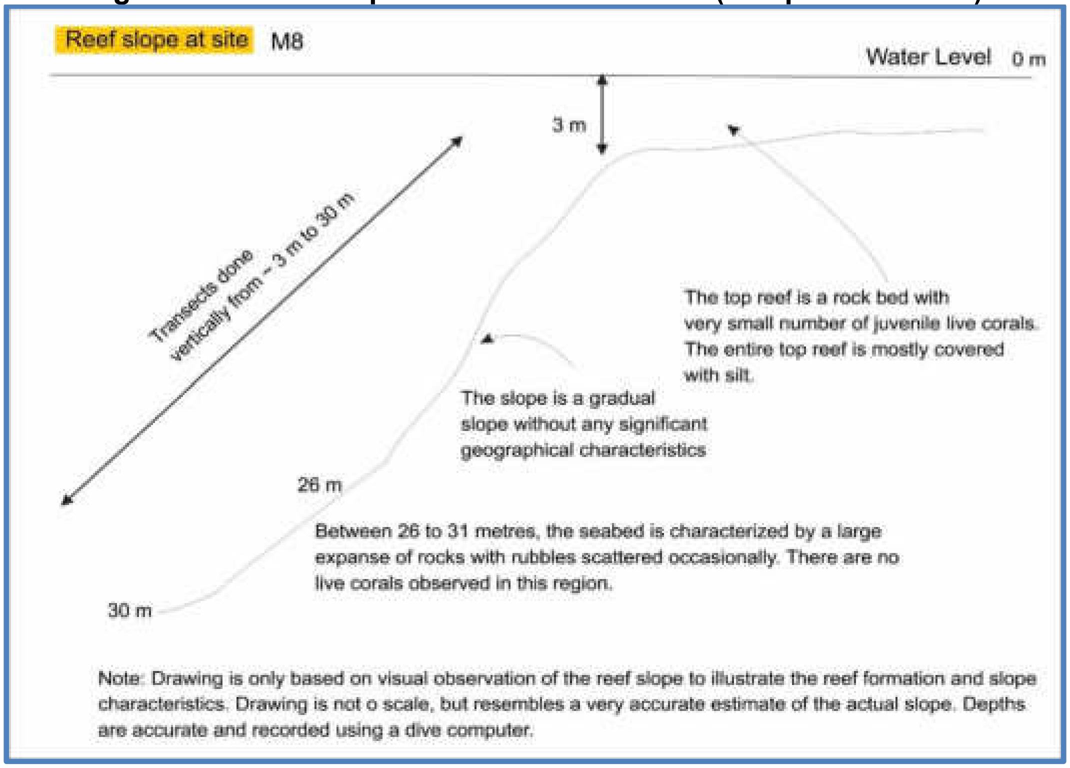
333. **Status of Site M8.** Site M8 was selected from the Southern rim of the island reef. The site was chosen as the best alternative location to lay the hot water discharge line and outfall (see Section IV on Alternative Analysis). The substrate at the site is dominated by silt along the entire transect line (43 ± 11.69%). Hard coral cover was observed to be low (8 ± 2.71). Massive porites were the dominating the group of hard coral observed at the site. Fishes observed to be very rare. It is to be noted that just a week prior to the survey, due to the severe weather, this entire stretch of reef has been hit by strong waves causing the sediments on the western side of the Thilafushi to be spread along most part of the southern side. This has resulted in large areas of the reef being covered with silt, which were observed at various sampling sites (M9 and M10). Figure 104 below outlines the status of site M8.

Figure 104: Percentage benthic composition at site M8 at depths from ~ 3 to 30 meters ± Standard Error (SE) (1st September 2019)



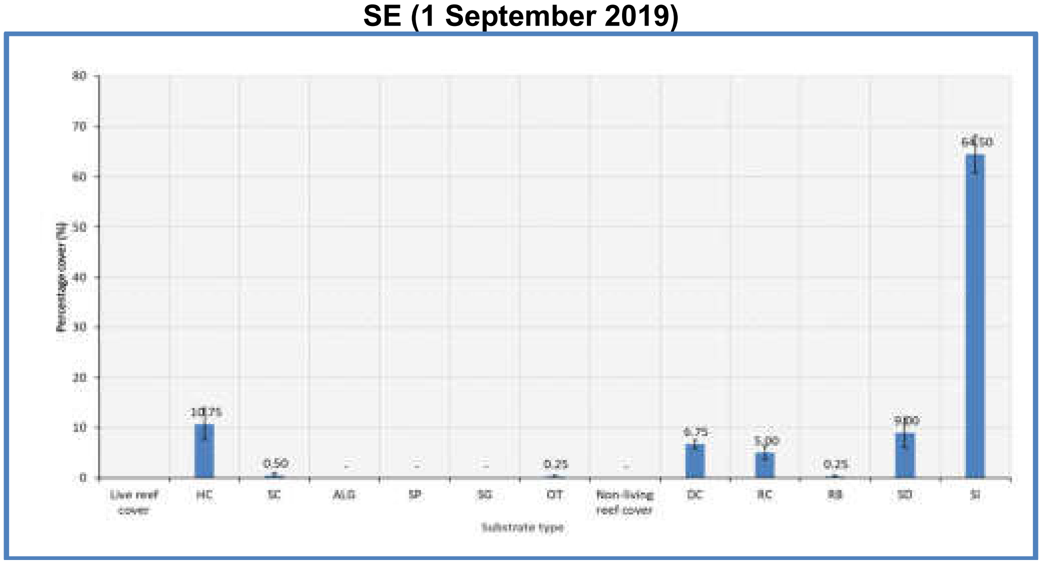
334. The following figure illustrates the reef slope characteristics at site M8.

Figure 105: Reef Slope Characteristics at M8 (1 September 2019)



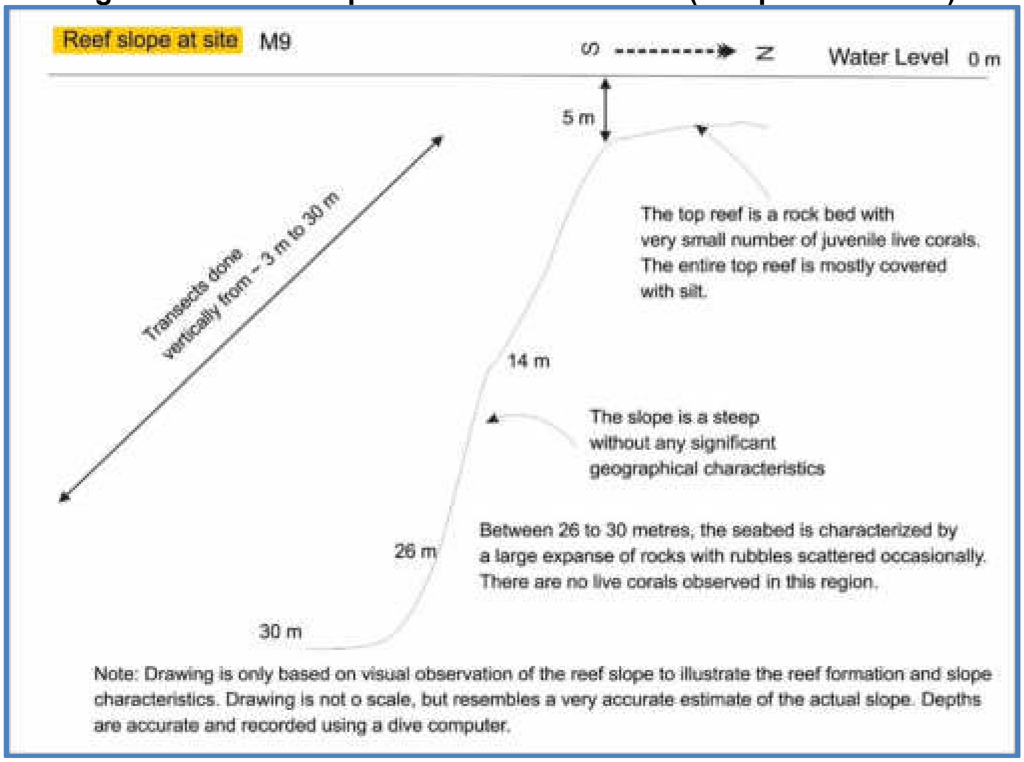
335. **Status of Site M9**. Site M9 was also selected from the Southern rim of the island reef east of site 1. The site was also chosen as an alternative location to lay the hot water discharge line and outfall (see Section IV on Alternative Analysis). The substrate at the site is dominated by silt (64.5 ± 3.77%). Hard coral cover was observed to be low along the surveyed depths from approximately 3 to 30 meters (10.75 ± 3.22). Massive porites were the dominating group of hard coral observed at the site. Fishes observed were very low and includes anthias and surgeon fishes (refer to the fish census table for details). The following graph outlines the status of site M9.

Figure 106: Percentage benthic composition at site M9 at depths from ~ 3 to 30 meters ± SE (1 September 2019)



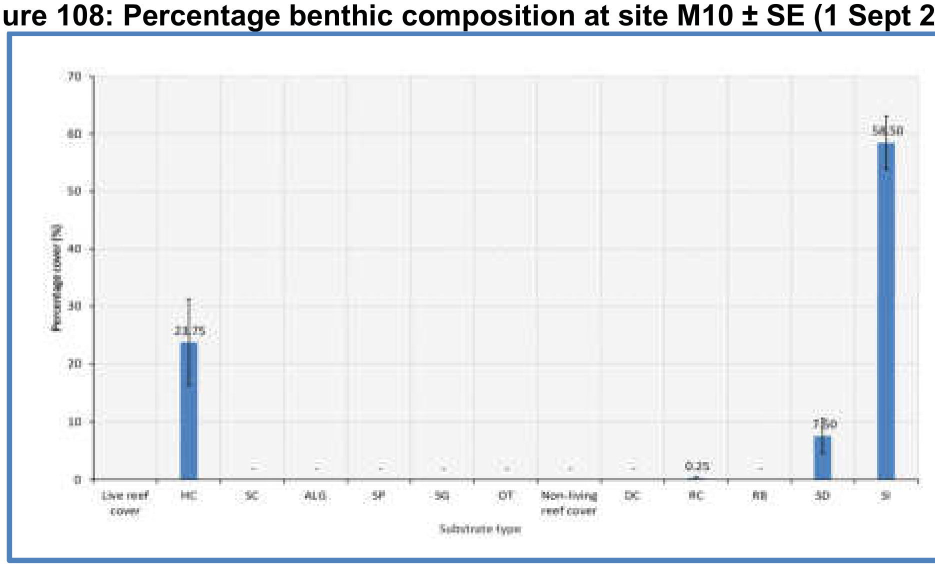
336. The following image illustrates the reef slope characteristics at site M9.

Figure 107: Reef slope characteristics at M9 (1 September 2019)



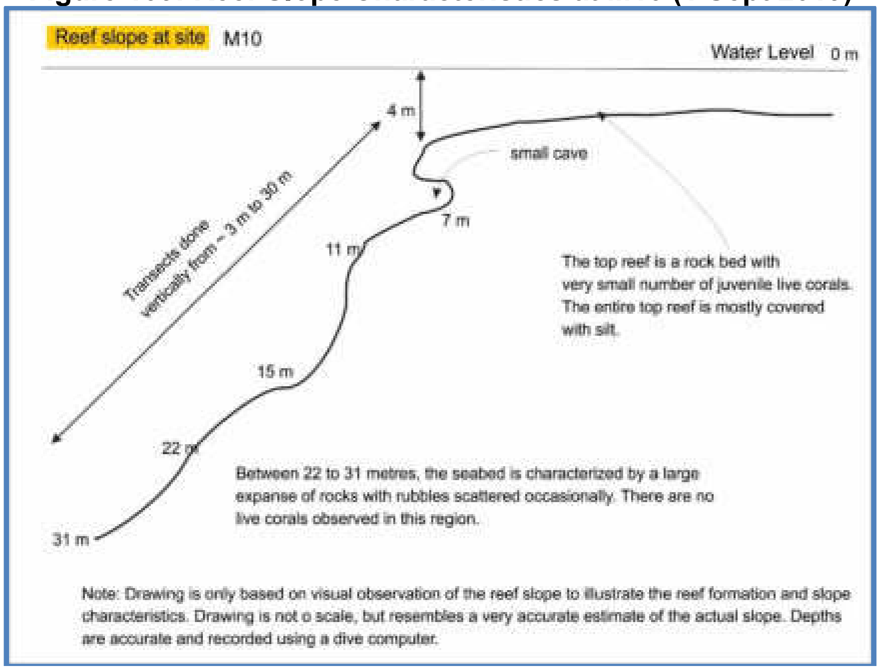
337. **Status of site M10**. Site M10 was also selected from the Southern side of the island reef. The site was also chosen as an alternative location to lay the hot water discharge line and outfall (see Section IV on Alternative Analysis). The substrate at the site is dominated by silt (58.50 ± 4.57 %). Hard coral cover was observed to be moderate (23.75 ± 7.43). Massive Porites were the dominating group of hard coral observed at the site. Fishes observed to be very low. The following graph outlines the status of site M10.

Figure 108: Percentage benthic composition at site M10 ± SE (1 Sept 2019)



338. The following figure illustrates the reef slope characteristics at site M10.

Figure 109: Reef Slope Characteristics at M10 (1 Sept 2019)



2. Manta Tow Survey

339. The following table outlines the results of the Manta Tow survey around the reef edge.

Table 31: Manta Tow Survey Results of Approximate Substrate Cover

	Love Coral cover%	Dead coral cover%	Soft corals cover%	Rock cover %	Rubble cover %	Silt cover %	Benthic diversity	Fish diversity
5 meters								
	5	8	-	15	2	70	low	low
10 meters								
	10	6	-	27	7	50	Low	low

340. The Manta Tow survey showed that coral reef system along the surveyed stretch at M8, M9, and M10 sections is not in very good conditions in term of percentage live coral cover, diversity of corals, benthic and pelagic life. The overall live coral cover of the reef system appeared to be approximately 5% at 5 meters depth and approximately 10% at 10 meters depth. The reef substrate at both these depths were dominated by silt. Abundance and diversity of fish was also lower along the stretch. The live coral cover was highest at 10 meters. The corals in most abundance were massive type coral head belonging to the genus Porites.

341. **Protected marine species**. During the Manta tow survey, no protected marine species such as sharks were observed and recorded.

342. **Reef Aesthetics.** This attribute was assessed by visual observations based on the observer's judgment and experience of the relative merits of a reef in the Maldives. This value

judgment incorporated coral cover, diversity of life forms, fish life, reef structure and general appeal. The following categories were used to determine aesthetics of the reef system:

(i) **Very poor** (mostly dead corals, pelagic life not abundant and diversity very low, structure uniform).
(ii) **Poor** (Lot of dead corals, pelagic life not abundant and diversity low, some differences in structure).
(iii) **Average** (Live corals about 10%, pelagic life abundant, diversity low, some structural variations exists).
(iv) **Good** (Live corals about 20% pelagic life abundant, diverse, structural variations exists).
(v) **Very good** (Live corals about 30%, pelagic life abundant, diverse, overhangs, and other structures).
(vi) **Excellent** (Live corals over 40%, pelagic life very abundant, very diverse, lots of different structures, overhangs, caves, gullies, and different habitat types exists.

343. Reef aesthetics of Thilafushi's coral reef system (along the 500 meters) is regarded as very poor, given that substantial level of the reef is covered in silt and poor diversity of life forms. Fish life and abundance are very poor at the time of surveying and generally this stretch of reef can be considered to be "very poor".

i. ***Fishery***

344. The amount and type of fish present at a given site can be a good indicator of the marine environment. For example, increased grazers are generally a sign of increased nutrients in the area, thus decreased coral cover and increased algal cover. 15-minute fish counts were done in sites M1-M7 in depths of 5 and 10m. The counts include mega fauna in addition to fishes. The fishes were identified to family level, however some protected species such as the napoleon wrasse, were identified to species level. However, the abundance of this species is rare at site M3, which is more than 1 km away from the project location. The following table outlines the fish count survey at all the sites.

Table 32: Fish abundances observed at sites 1 to 7 at a depth of 5 and 10 meters

Family/Subfamily	**Site M1**		**Site M2**		**Site M3**		**Site M4**		**Site M5**		**Site M6**		**Site M7**	
Depth	**5m**	**10 m**	**5m**	**10 m**	**5m**	**10m**	**5m**	**10m**	**5m**	**10m**	**5m**	**10m**	**5m**	**10 m**
Anthias (Anthiadinae)	R	A	A	A	R	A	C	-	R	C	C	C	R	-
Surgeonfishes (Acanthuridae)	A	C	A	C	A	C	A	C	A	A	A	A	A	C
Wrasses (Labridae)	C	C	-	C	-	-	C	C	C	C	A	-	C	-
Parrotfishes (Scaridae)	C	C	A	C	R	R	C	R	A	-	C	C	C	-
Triggerfishes (Balistidae)	C	A	A	A	-	A	R	-	C	A	A	A	C	-
Boxfishes (Ostraciidae)	-	-	R	-	-	-	-	-	-	-	-	-		-
Damselfishes (Pomacentridae)	A	A	A	A	-	A	C	-	R	A	A	A	A	-
Groupers (Serranidae)	R	-	R	R	R	-	R	-	R	R	R	R	R	-
Moorish idol (Zanclidae)	R	R	R	R	R	R	R	R	C	R	R	R	R	R
Butterflyfishes (Chaetodontidae)	A	C	A	A	C	C	A	C	R	C	A	A	A	-
Goatfishes (Mullidae)	-	-	R	R	-	-	C	C	R	-	R	-	R	-
Hawkfishes(Cirrhitidae)	-	-	R	R	R	-	-	-	R	-	R	-	-	-
Threadfin and Whiptail breams (Scolopsis)	-	-	-	R	-	-	-	-	-	-	-	-	-	-
Octopus (Octopodidae)	-	-	R	-	-	-	-	-	-	-	-	-	-	-
Fusiliers (Caesionidae)	-	-	-	-	-	-	A	A	-	-	-	-	-	-
Rabbitfishes (Siganidae)	-	-	-	-	-	-	R	-	-	-	R	-	-	-
Gobies (Gobiidae)	-	-	-	-	R	-	-	R	R	-	-	-	-	-
Pipefishes and seahorses (Syngnathinae)	-	-	-	-	-	-	R	-	R	R	-	-	-	-
Puffers (Tetraodontidae)	-	-	-	-	R	-	R	-	C	-	R	-	-	-
Emperors or scavengers (Lethrinidae)	-	-	-	-	-	-	-	-	C	-	R	-	-	-
Jacks and Trevalleys (Carangidae)	-	-	-	-	A	-	-	-	R	-	-	-	-	-

Family/Subfamily	Site M1		Site M2		Site M3		Site M4		Site M5		Site M6		Site M7	
Depth	5m	10 m	5m	10 m	5m	10 m	5m	10 m	5m	10 m	5m	10 m	5m	10 m
Angelfishes (Pomacanthidae)	-	-	-	-	-	-	-	-	R	-	R	R	-	-
Lizardfishes (Synodontidae)	-	-	-	-	-	-	-	-	R	-	-	-	-	-
Squirrelfishes, soldierfishes (Holocentridae)	-	-	-	-	-	-	-	-	-	-	R	-	-	-
Grunts and Sweetlips (Haemulidae)	-	-	-	-	-	-	-	-	-	R	R	-	-	-
Eels and Morays (Anguilliformes)	-	-	-	-	-	R	-	-	-	-	-	-	-	-
Napoleon Wrasse (Cheilinus undulatus)	-	-	-	-	-	R	-	-	-	-	-	-	-	-
Sharks & Rays (Elasmobranchii)	-	-	-	-	-	R	-	-	-	-	-	-	-	-
Sea Turtles (Chelonioidea)	-	-	-	-	-	R	-	-	-	-	-	-	-	-

A= Abundant (Meaning that during the 15-minute time swim survey, species counts were recorded more than 50, hence it is difficult to count their numbers). C=Common (Meaning that during the 15-minute time swim survey, they were spotted occasionally and throughout the survey, but their numbers were less than 50). R=Rare (Meaning that during the survey, only few of these species were observed, often 1 or 2.

ii. *Aquatic Biology*

345. Plankton are the base of the marine food chain. The phytoplankton and zooplankton abundances in the area could possibly be affected by the presence of heavy metals. If the plankton community is thriving in these areas the heavy metals maybe bio accumulating in the food chain. Therefore, plankton counts were done around Thilafushi Island in order to establish a baseline. A plankton net of 50µm mesh was built to carry out the survey. The plankton tows were carried out at sites where the marine water samples were collected.

346. **Data Collection Methodology**. A plankton net of opening 0.48 x 0.48 m was tied to a 20m rope and released from a vessel. The net was allowed to drift for 20 meters and then towed towards the boat. Any organisms or particles larger than 50µm gets caught up in the net and collected in the cod end.

347. **Zooplankton**. Analyses of the samples were done using a microscope using a Sedgewick rafter counting chamber. The chamber has a volume of approximately 1ml. The samples collected from the net were approximately 150 – 250ml in volume. For the zooplankton count, the samples were transferred to a beaker diluted to approximately 500 – 900 ml and the volume recorded. The purpose of dilution is to reduce the number of plankton in the optical view of the microscope for ease of counting. Two sub-samples were counted from each sample. To calculate Total count in the sample, the counts in the subsamples were averaged. Thereafter the average value in the sub samples were multiplied with the total Volume in the diluted sample to obtain the Total count in the Sample. From the Total count in the sample and from the opening area of the net and the distance towed, the abundance of zooplankton per meter cube was calculated using the formula, Abundance = Total Count in the Sample / (Distance towed x Opening area). During the survey the zoo plankton were classified into Rotifera, Protozoa, Chordata, Mollusca, Annelida, Cnidaria, Crustacea and Chaetognatha. Additionally, Copepods were classified into three groups, Calanoida, Cyclopoida and Harpacticoida.

348. **Phytoplankton**. Analyses of the samples were done using a microscope using a Sedgewick rafter counting chamber. The chamber has a volume of approximately 1ml. The samples collected from the net were approximately 150 – 250ml in volume. For the phytoplankton count, the samples were transferred filtered through a 200µm sieve to remove large zooplankton for ease of counting. Thereafter the sample was transferred to a beaker and diluted to approximately 500 – 900 ml and the volume recorded. The purpose of dilution is to reduce the number of plankton in the optical view of the microscope for ease of counting. Two sub-samples were counted from each sample. To calculate Total count in the sample the counts in the subsamples were averaged. Thereafter the average value in the sub samples was multiplied with the total Volume in the diluted sample to obtain the Total count in the Sample. From the Total count in the sample and from the opening area of the net and the distance towed, abundance of zooplankton per meter cube was calculated using the formula, Abundance = Total Count in the Sample / (Distance towed x Opening area).

349. **Limitations of the methodology.** The above method gives approximate estimates of abundances for each group/genera of plankton. Using a Sedgewick rafter to count zooplankton limits the subsample volume to 1ml thus, rare groups in plankton would likely not be observed in the counts. The method is reliable to estimate the total abundance of common groups of Zooplankton which are greater than 50µm in size and phytoplankton greater than 50 µm and less than 200µm.

350. **Zooplankton Abundance - Common Phyla**. Crustaceans were observed to be of the highest abundance amongst the zooplankton from all 7 sites. Additionally, the highest abundance of zoo plankton was observed from site 7 (PKT 7). The lowest abundance of zooplankton was observed from site 5. The table and figures below outline the variation in zooplankton abundance between the sites.

Table 33: Abundance of common phyla of zooplankton from sites PKT 1 to PKT 7

	Abundance at sites (Individuals/m^3)						
Phyla	**PKT 1**	**PKT 2**	**PKT 3**	**PKT 4**	**PKT 5**	**PKT 6**	**PKT 7**
Rotifera	174	760	1,270	293	195	814	1,519
Protozoa	260	2,170	1,563	1,172	781	1,628	868
Chordata	347	705	1465	977	391	746	217
Mollusca	87	163	391	NA	98	339	217
Annelida	174	54	98	NA	98	68	NA
Cnidaria	217	380	98	488	NA	NA	NA
Crustacea	3,212	7,378	16,113	9,277	1,465	6,782	21,267
Chaetognatha	43	109	488	98	NA	NA	217
Total Zooplankton	7,769	19,151	37,598	21,582	4,492	17,158	45,573

Figure 110: Abundance of common phylum of zooplankton from sites PKT 1 to PKT 7.

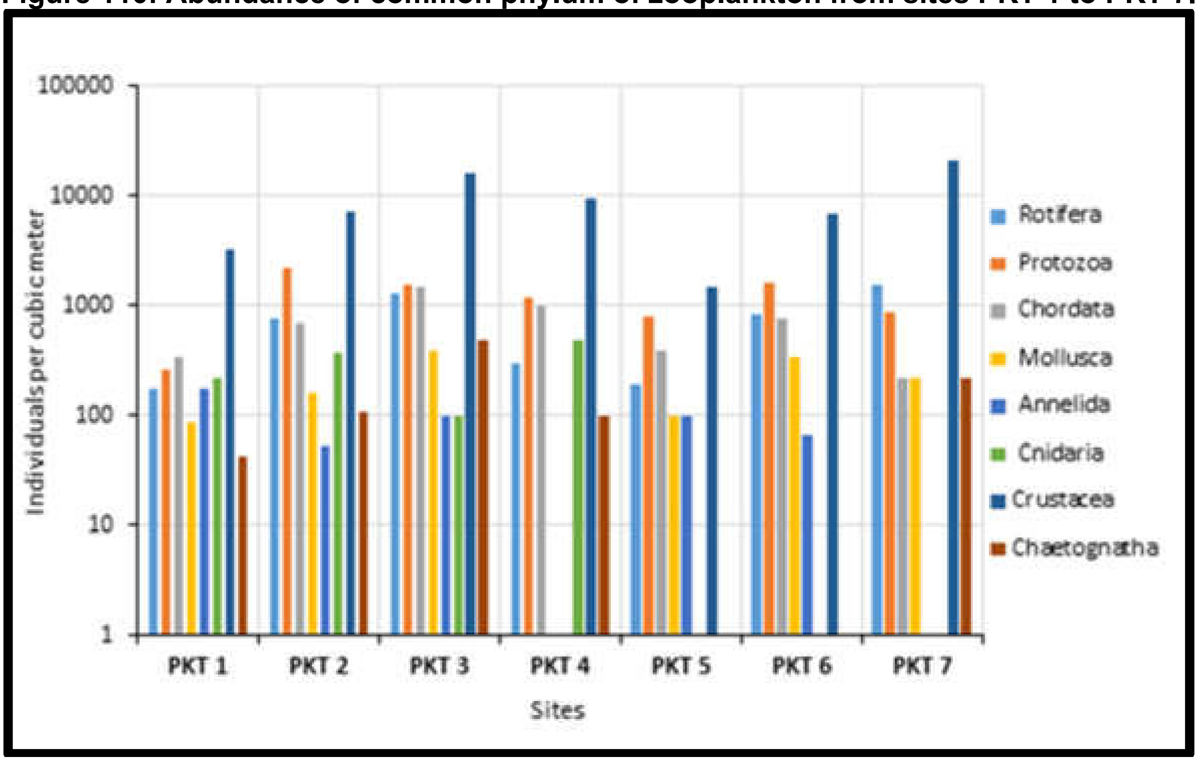
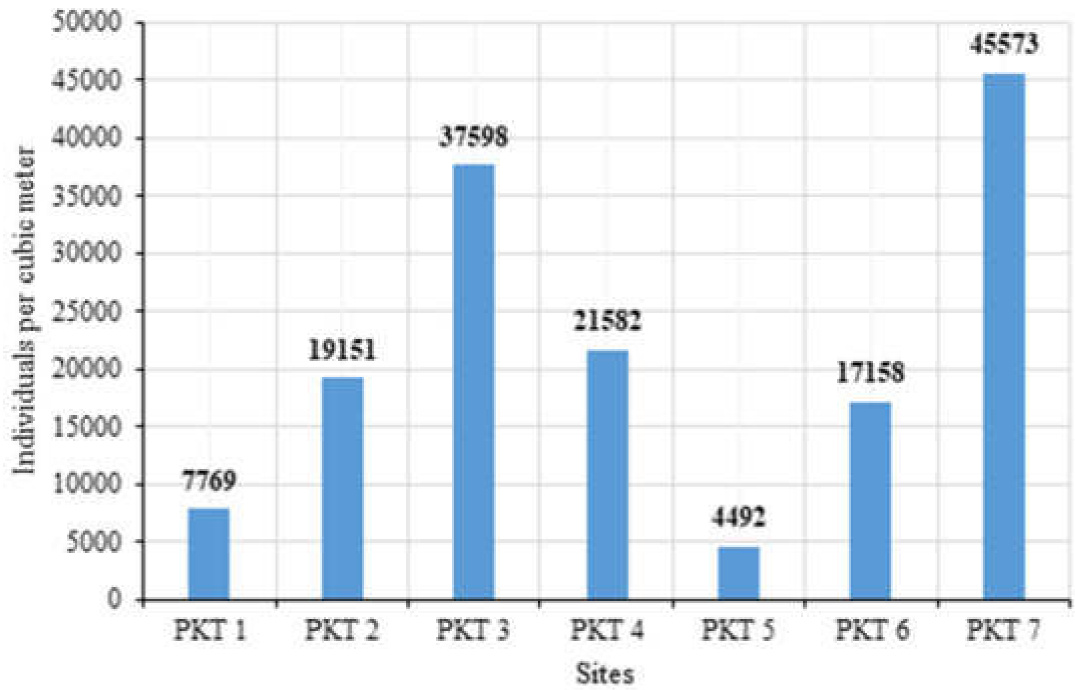


Figure 111: Total abundance of zooplankton from sites PKT 1 to PKT 7.

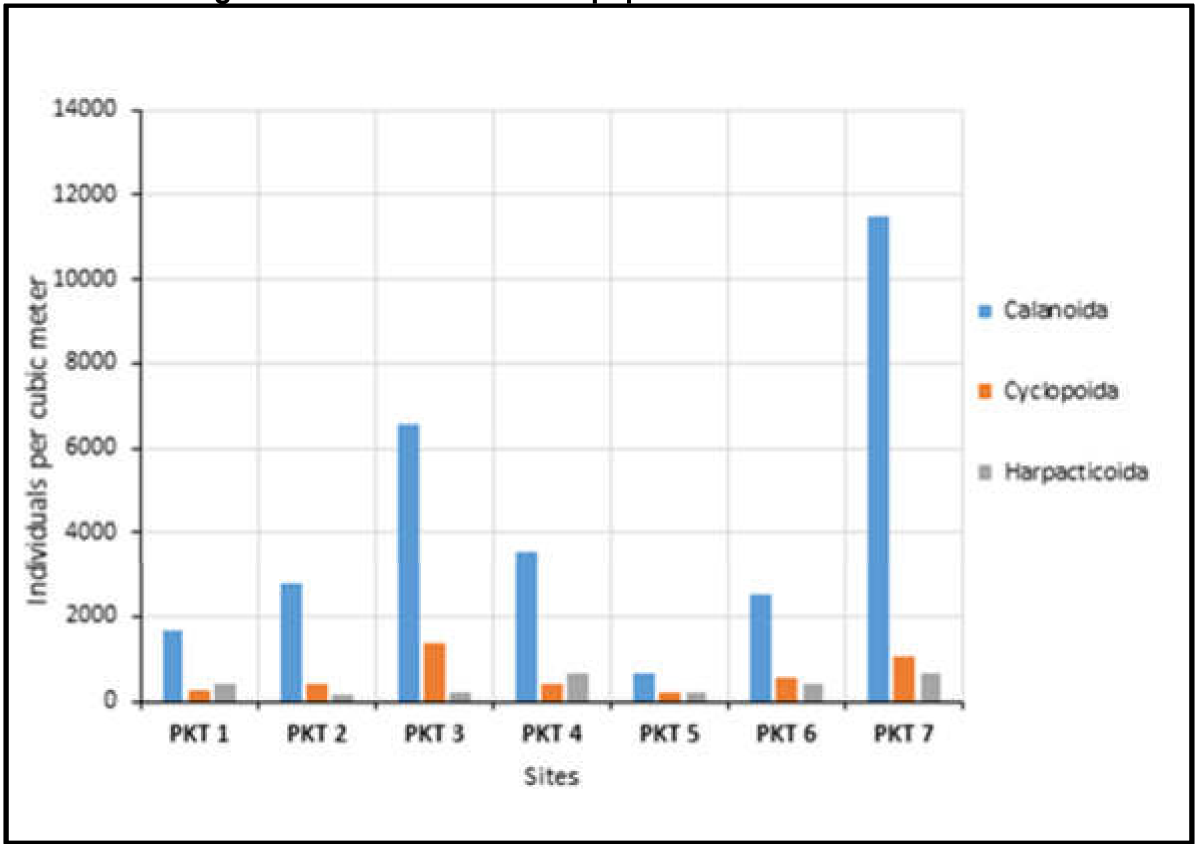


351. **Zooplankton Abundance - Copepods**. The dominating group of copepods observed in the sites were calanoids. The highest abundance of copepods was observed at site 7 and the lowest abundance of copepods at site 5. The table and figure below outline the variation in copepod abundance between the sites.

Table 34: Abundance of copepods from sites PKT 1 to PKT 7

Order	Abundance at Sites (Individuals/m^3)						
	PKT 1	PKT 2	PKT 3	PKT 4	PKT 5	PKT 6	PKT 7
Calanoida	1693	2767	6543	3516	684	2509	11502
Cyclopoida	260	434	1367	391	195	543	1085
Harpacticoida	391	163	195	684	195	407	651

Figure 112: Abundance of copepods from sites PKT 1 to PKT 7.



340. Phytoplankton Abundance. Diatoms were observed to be of the highest abundance, amongst the phytoplankton from all 7 sites. Additionally, the highest abundance of phytoplankton was observed from site 7 (PKT 7). Additionally, the lowest abundance of phytoplankton was observed from site 5. The Figures below show the variation in phytoplankton abundance between the sites.

Figure 113: Abundance of diatoms and dinoflagellates from sites PKT 1 to PKT 7

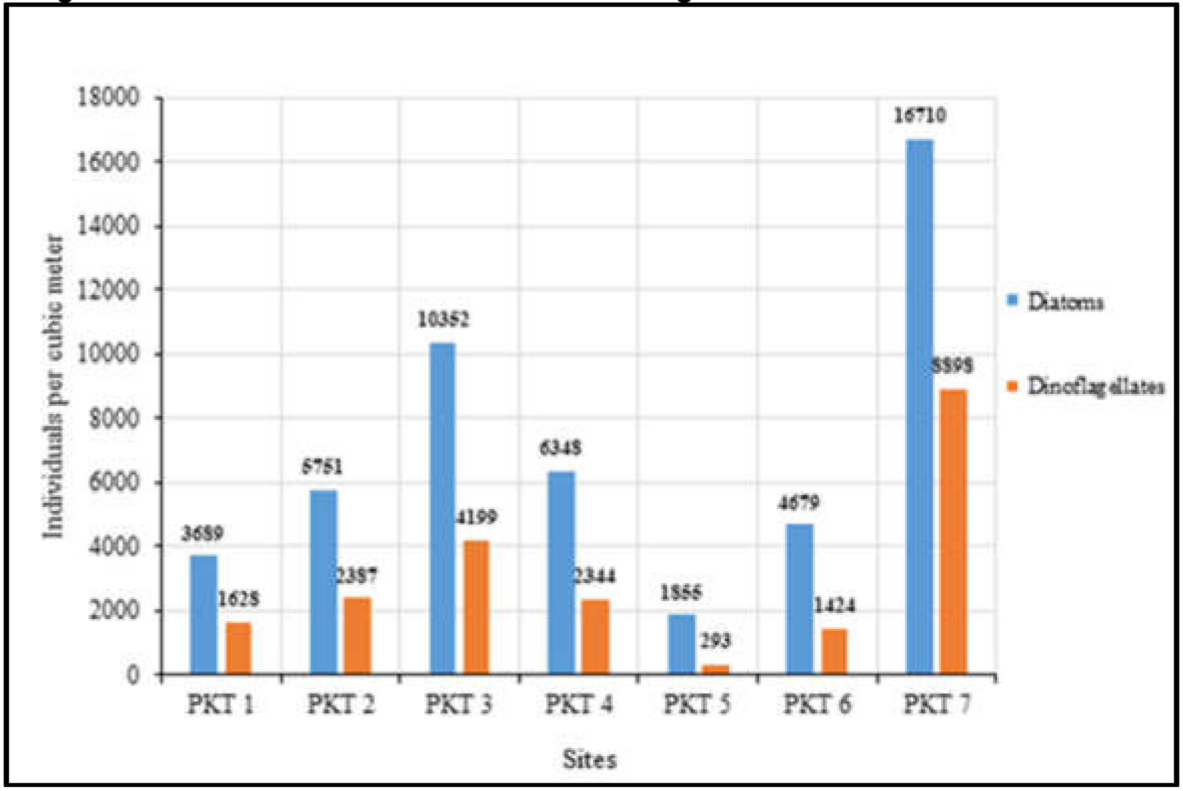


Figure 114: Total abundance of phytoplankton from sites PKT 1 to PKT 7