

# Environmental Impact Assessment

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## Maldives: Greater Malé Waste-to-Energy Project – Waste to Energy Plant (Part A)

### Appendices

Prepared by the Ministry of Environment, Climate Change and Technology for the Ministry of Finance and the Asian Development Bank. This is an updated version of the draft originally posted in July 2020 available on <https://www.adb.org/projects/documents/mld-51077-003-eia-2>.

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## Rapid Environmental Assessment (REA) Checklist

### Instructions:

- (i) The project team completes this checklist to support the environmental classification of a project. It is to be attached to the environmental categorization form and submitted to the Environment and Safeguards Division (SDES) for endorsement by the Director, SDES and for approval by the Chief Compliance Officer.
- (ii) This checklist focuses on environmental issues and concerns. To ensure that social dimensions are adequately considered, refer also to ADB's (a) checklists on involuntary resettlement and Indigenous Peoples; (b) poverty reduction handbook; (c) staff guide to consultation and participation; and (d) gender checklists.
- (iii) Answer the questions assuming the "without mitigation" case. The purpose is to identify potential impacts. Use the "remarks" section to discuss any anticipated mitigation measures.

**Country/Project Title:** MLD / Greater Malé Waste-to-Energy Project

**Sector Division:** SAUW

Screening Questions	Yes	No	Remarks
A. Project Siting Is the project area...			The WTE project will be located in Thilafushi, an island on the southern rim of North Malé atoll, and on the eastern line of atolls within the archipelago. Thilafushi is an island classified as industrial zone and about 9.5km from Malé, the capital city of Maldives. In terms of geographic coordinates, Thilafushi is located at 04° 11' 00" N and 73° 26' 44" E.
▪ Densely populated?		✓	The island is classified as industrial island with no residential area. Population density is low. Baseline socio-economic profile shows there are no communities in Thilafushi. It is estimated that there 140 companies and less than 1,500 workers in the whole island.
▪ Heavy with development activities?		✓	Most locators in the island do not engage in heavy development activities. Survey shows that most establishments are warehouses and workshops only.
▪ Adjacent to or within any environmentally sensitive areas?			
○ Cultural heritage site		✓	Not applicable. No cultural heritage site in the island.
○ Protected Area	✓		The project site is located near 3 protected areas (Lions Head – 1 km away; Hans Hass – 2 km away; and Kuda Haa – 5 km away). Assessment of likely impacts of the project to these protected areas has been included in the EIA.
○ Wetland		✓	Not applicable. No wetland in and around the island.
○ Mangrove		✓	Not applicable. No mangrove in and around the island.

Screening Questions	Yes	No	Remarks
o Estuarine		✓	Not applicable. No estuarine in and around the island.
o Buffer zone of protected area		✓	Not applicable. No buffer zone in and around the island.
o Special area for protecting biodiversity		✓	Not applicable. Apart from the protected areas mentioned above, there is no other special area for protecting biodiversity in and around the island.
o Bay		✓	The island is situated within a large atoll (Kaafu Atoll). The project site is bordered by marine waters on its northern and southern boundaries. However, these coastal/marine waters are not regarded as sensitive or protected areas.
B. Potential Environmental Impacts Will the Project cause...			
▪ impacts associated with transport of wastes to the disposal site or treatment facility		✓	Not applicable. The project does not include component associated with transport of wastes.
▪ impairment of historical/cultural monuments/areas and loss/damage to these sites?		✓	There are no historical or cultural monuments in Thilafushi Island.
▪ degradation of aesthetic and property value loss?		✓	<b>Not anticipated.</b> The project will improve the existing situation in Thilafushi Island.
▪ nuisance to neighboring areas due to foul odor and influx of insects, rodents, etc.?		✓	<b>Not anticipated.</b> The current condition (dumpsite and unscientific waste management) will significantly improve due to the closing down and eventual rehabilitation of the existing dumpsite.
▪ dislocation or involuntary resettlement of people?		✓	<b>Not applicable.</b> The project will not cause or involve dislocation and involuntary resettlement of people.
▪ disproportionate impacts on the poor, women and children, Indigenous Peoples or other vulnerable groups?		✓	<b>Not applicable.</b> The project site is a newly built site in an industrial island (with no displaced humans or residential areas). The island is also not a host to any indigenous peoples or vulnerable groups.
▪ risks and vulnerabilities related occupational health and safety (OSH) due to physical, chemical, biological, and radiological hazards during project construction and operation?	✓		<b>Anticipated during construction and operation phases.</b> OHS risks are inherent to construction activities and WTE plant operations. These impacts will be mitigated by measures in the EMP and bidding documents following internationally recognized best practices and standards, such as the World Bank EHS Guidelines on Construction and Decommissioning Activities, and Guidelines on Waste Management Facilities.
▪ public health hazards from odor, smoke from fire, and diseases transmitted by flies, insects, birds and rats?		✓	<b>Not anticipated.</b> The project will improve the existing situation in Thilafushi Island.

Screening Questions	Yes	No	Remarks
<ul style="list-style-type: none"> <li>deterioration of water quality as a result of contamination of receiving waters by leachate from land disposal system?</li> </ul>	✓		<b>Anticipated during operation.</b> The project includes a residual wastes landfill that will accommodate bottom ash and fly ash. The residual waste landfill cells may produce leachates that could potentially impact water quality of groundwater and marine waters. As measure included in the EMP and bidding documents, the landfill cells will be designed following internationally recognized best practices and standards for bottom ash/fly ash landfills to ensure no leachate will seep into the ground or flow out to the marine waters surrounding the project site.
<ul style="list-style-type: none"> <li>contamination of ground and/or surface water by leach ate from land disposal system?</li> </ul>	✓		<b>Anticipated during operation.</b> The residual wastes landfill may produce leachates that could potentially impact water quality of groundwater and marine waters. However, as measure included in the EMP and bidding documents, the landfill cells will be designed following internationally recognized best practices and standards for bottom ash/fly ash landfills to ensure no leachate will seep into the ground or flow out to the marine waters surrounding the project site.
<ul style="list-style-type: none"> <li>land use conflicts?</li> </ul>		✓	<b>Not applicable.</b> The project will utilize land that has been newly developed for the purpose.
<ul style="list-style-type: none"> <li>pollution of surface and ground water from leachate coming from sanitary landfill sites or methane gas produced from decomposition of solid wastes in the absence of air, which could enter the aquifer or escape through soil fissures at places far from the landfill site?</li> </ul>		✓	<b>Not anticipated.</b> The project does not include any solid waste landfilling. During operation phase of the WTE plant, wastes that will be used as buffer will be baled and stored in storage areas protected with flooring and linings that will prevent seepage of leachate.
<ul style="list-style-type: none"> <li>inadequate buffer zone around landfill site to alleviate nuisances?</li> </ul>		✓	Buffer zone and greenery is included in the design for the WTE plant.
<ul style="list-style-type: none"> <li>road blocking and/or increased traffic during construction of facilities?</li> </ul>		✓	<b>Not anticipated.</b> The transport of construction materials will utilize an exclusive route being used by the government in transporting solid wastes to Thilafushi island. This route is different from the route being taken by locals, including private and commercial marine vehicles in the island.
<ul style="list-style-type: none"> <li>noise and dust from construction activities?</li> </ul>	✓		<b>Anticipated</b> , but duration is short-term, site-specific within a relatively small area. Measures to mitigate these impacts are included in the EMP and bidding documents following internationally recognized best practices and standards. Environmental monitoring is included in the EMP.
<ul style="list-style-type: none"> <li>temporary silt runoff due to construction?</li> </ul>	✓		<b>Anticipated</b> , but duration is short-term, site-specific within a relatively small area. Measures to mitigate this impact are included in the EMP and bidding documents following internationally recognized best practices and standards.
<ul style="list-style-type: none"> <li>hazards to public health due to inadequate management of landfill site caused by inadequate institutional and financial capabilities for the management of the landfill operation?</li> </ul>		✓	<b>Not applicable.</b> The project includes institutional and financial capabilities for the management of the facilities.

Screening Questions	Yes	No	Remarks
<ul style="list-style-type: none"> <li>emission of potentially toxic volatile organics from land disposal site?</li> </ul>	✓		<b>Anticipated.</b> The design of landfill for the bottom ash and fly ash includes cover and engineering measures to ensure no emissions of potentially toxic volatile organics.
<ul style="list-style-type: none"> <li>surface and ground water pollution from leachate and methane gas migration?</li> </ul>	✓		<b>Anticipated.</b> Leachate will be generated during operations. However, the leachate collection and treatment system will be lined to ensure groundwater and marine waters are not polluted. Generation of methane gas is not anticipated.
<ul style="list-style-type: none"> <li>loss of deep-rooted vegetation (e.g. tress) from landfill gas?</li> </ul>		✓	<b>Not applicable.</b> The project does not involve solid waste landfill operation.
<ul style="list-style-type: none"> <li>explosion of toxic response from accumulated landfill gas in buildings?</li> </ul>		✓	<b>Not applicable.</b> Generation of methane gas is not anticipated.
<ul style="list-style-type: none"> <li>contamination of air quality from incineration?</li> </ul>	✓		<b>Anticipated.</b> Air emission from the WTE plant will potentially contaminate the air and deteriorate ambient air quality in the island. However, this impact will be mitigated by the engineering design and requirements of the project. The DBO Contractor will be required to comply with a set of performance guarantees, which includes assurance that air emission will comply with internationally accepted emission standards for incinerator plants.
<ul style="list-style-type: none"> <li>public health hazards from odor, smoke from fire, and diseases transmitted by flies, rodents, insects and birds, etc.?</li> </ul>		✓	<b>Not anticipated.</b> The project will improve the situation in Thilafushi Island. The shutting down of operation and eventual rehabilitation of the existing dumpsite will reduce the proliferation of disease vectors affecting the island and other nearby islands. During operation phase, the EMP will define measures to mitigate hazards following internationally recognized best practices and standards, such as the World Bank EHS Guidelines on Waste Management Facilities.
<ul style="list-style-type: none"> <li>health and safety hazards to workers from toxic gases and hazardous materials in the site?</li> </ul>	✓		<b>Anticipated during construction and operation phases.</b> The EMP includes measures to mitigate impacts, such as the mandatory use of personal protective equipment by workers. Regular training will also be conducted to ensure that workers are aware of construction hazards and risks of chemicals during O&M.
<ul style="list-style-type: none"> <li>large population influx during project construction and operation that causes increased burden on social infrastructure and services (such as water supply and sanitation systems)?</li> </ul>		✓	<b>Not anticipated.</b> Similar to workers of other industries in Thilafushi island, most workers of the project are expected to be residents of nearby islands such as Gulhi Fahlu, Villingili and Male. For workers who will be staying at the project site, the DBO Contractor will be required to establish a workers' camp with complete facilities.
<ul style="list-style-type: none"> <li>social conflicts if workers from other regions or countries are hired?</li> </ul>		✓	<b>Not anticipated.</b> Priority in employment will be given to local residents of Maldives. Workers from other regions or countries will be considered only if no counterpart expertise is available locally.

Screening Questions	Yes	No	Remarks
<ul style="list-style-type: none"> <li>▪ risks to community health and safety due to the transport, storage, and use and/or disposal of materials such as explosives, fuel and other chemicals during construction and operation?</li> </ul>	✓		<p><b>Anticipated.</b> Fuels and other chemicals will be used during the construction and operation of the WTE plant, and these may raise risks of explosions or fires at the site. However, the EMP will define measures to manage these risks, including the implementation of proper handling and storage of these chemicals, following internationally recognized best practices and standards, such as the World Bank EHS Guidelines on Construction and Decommissioning Activities, and Guidelines on Waste Management Facilities.</p>
<ul style="list-style-type: none"> <li>▪ community safety risks due to both accidental and natural hazards, especially where the structural elements or components (e.g., landfill or incinerator) of the project are accessible to members of the affected community or where their failure could result in injury to the community throughout project construction, operation and decommissioning?</li> </ul>	✓		<p><b>Anticipated.</b> These risks are potential in the operation of the WTE plant. However, the EMP will define measures in order to manage these risks based on internationally accepted best practices and standards, such as the EHS Guidelines on Waste Management Facilities. Operational area will be clearly demarcated and access will be controlled. Only workers and project concerned members will be allowed to visit the WTE plant site.</p>

## A CHECKLIST FOR PRELIMINARY CLIMATE RISK SCREENING

Screening Questions	Score	Remarks <sup>1</sup>
<b>Location and Design of project</b>	2	Project location is in an island in Maldives that will likely be affected by floods due to rains or sea level rise.
	2	Project location is in an island in Maldives that will likely be affected by floods due to rains or sea level rise. Therefore, the project design needs to consider the impact of flooding and sea level rise.
<b>Materials and Maintenance</b>	0	No significant effect
	0	No significant effect
<b>Performance of project outputs</b>	0	No significant effect

Options for answers and corresponding score are provided below:

Response	Score
Not Likely	0
Likely	1
Very Likely	2

Responses when added that provide a score of 0 will be considered low risk project. If adding all responses will result to a score of 1-4 and that no score of 2 was given to any single response, the project will be assigned a medium risk category. A total score of 5 or more (which include providing a score of 1 in all responses) or a 2 in any single response will be categorized as high risk project.

**Result of Initial Screening (Low, Medium, High): High Risk**

Prepared by:



**Ninette Pajarillaga, Environment Specialist, SAUW**

<sup>1</sup> If possible, provide details on the sensitivity of project components to climate conditions, such as how climate parameters are considered in design standards for infrastructure components, how changes in key climate parameters and sea level might affect the siting/routing of project, the selection of construction material and/or scheduling, performances and/or the maintenance cost/scheduling of project outputs.



**Compliance with Terms of Reference Issued by the Maldives Environmental Protection Agency for the Conduct of EIA for the WTE Plant.**

<b>Scope of work — The EIA shall include but not necessarily be limited to the following tasks:</b>	<b>Compliance</b>
<b>Task 1. Description of the Proposed Project</b>	
<ul style="list-style-type: none"> <li>• Describe the RWMF (incinerator &amp; ash disposal cells) and associated infrastructure (harbor, fuel storage, power supply etc.) to be developed including location, plant layout and its position using maps and drawings where appropriate.</li> <li>• Describe the current operational condition of Thilafushi, including the tonnage of waste received, method of waste management, operator of the facility, number of staff employed, and difficulties faced.</li> <li>• Describe the need and justification for the proposed facility and the methodology employed.</li> <li>• Provide detailed description of the proposed facilities. Describe the level of waste treatment that will occur.</li> <li>• Describe the methodology for air quality measurement.</li> <li>• Describe how hazardous waste are going to be processed.</li> <li>• Describe how electronic waste is going to be processed.</li> <li>• Describe how plastic is going to be processed.</li> <li>• Describe how all organic and inorganic waste is going to be processed.</li> <li>• Describe the steps involved from waste collection to transport to delivery to final location.</li> <li>• Describe the lessons learnt that was adopted from current operations at regional waste management facility at Vandh00.</li> <li>• Describe the operations of the RWMF including waste catchment area to be serviced by the facility, and waste type, volumes and composition to be received at the facility. Indicate the project life span,</li> <li>• Identify the emission releases likely to be of concern and the environmental aspects of the project area which may potentially be impacted by the proposal.</li> <li>• Describe the type of incinerator plant to be installed including specifications, performance characteristics and operational flow diagrams. Provide details of the ash disposal cells including capacity, dimensions, design specifications and phased development plans.</li> <li>• Describe the lifetime of the sanitary landfill site, for how many years is the sanitary landfill designed.</li> <li>• Provide requirements for new infrastructure to service the project such as water supply and sewerage infrastructure. Describe details of all equipment and vehicles that are going to be procured for the new operations.</li> <li>• Provide details of the amount of energy that will be generated from the waste to energy component and how it will be utilized.</li> </ul>	<p>Task 1 refers to various requirements covered under Phase 1 and Phase 2, including rehabilitation of the existing dumpsite.</p> <p>The draft EIA is intended to be submitted for the ADB approval process. Therefore, Section I and Section II of the draft EIA report discuss items related to the WTE Plant only. The draft EIA does not include detailed discussions on the activities under Phase 1 and rehabilitation of the existing dumpsite (although background information is included).</p> <p>Since the project will be awarded as a DBO contract, many of detailed information required are not completely described.</p> <p>In a separate submission to Maldives EPA, Ministry of Environment may submit additional document that would discuss compliance with the other</p>

<ul style="list-style-type: none"> <li>• Describe the model of management that will be adopted for the operations.</li> <li>• Justify the final elevation of structures (including as ash disposal cells) with reference to the height above the mean high tide, highest annual tides and risk of flood inundations during seasonal high tide regimes.</li> <li>• Describe the existing condition of the site and how Thilafushi is going to be restored.</li> <li>• Describe all project inputs and outputs. Including equipment and resources required both for construction and operational phase. Provide a detailed schedule of the project.</li> <li>• Describe how this project facilitates to achieve the 3R concept of waste management. That is reduce, reuse and recycle concept.</li> </ul>	<p>required items under Task 1.</p>
<p><b>Task 2. Description of the Environment</b> - Assemble, evaluate and present baseline data on the relevant environmental characteristics of the study area, focused on the marine, terrestrial and air environment. Aspects of the environment shall be described to the extent necessary for assessment of the environmental impacts of the proposed development. The extent and quality of the available data shall be characterized indicating significant information deficiencies and any uncertainties associated with the prediction of impacts.</p> <p>This section should provide details of the environment in the vicinity of the proposed development site. Data collection methodology used to describe the existing environment shall be detailed. All survey locations, sampling points, reef transects, vegetation transects, manta tows and soil sampling sites shall be referenced with Geographic Positioning System (GPS). All marine water samples shall be taken at a depth of 1m below the mean sea level or mid water depth for shallow areas. Baseline data collection shall focus on key issues needing to be examined for the EIA Consideration of likely monitoring requirements shall be borne in mind during survey planning, so that the data collected is suitable for use as a baseline for impacts monitoring.</p> <p>All available data from previous studies, if available shall be presented. Information required includes the following:</p>	<p>Compliance in Section V.</p>
<p><u>Physical environment:</u></p>	

- Describe the meteorology (rainfall, wind, waves and tides), sea currents, surface hydrology, climatic and oceanographic conditions in the area, and bathymetry of the hot-water outfall location.
- Describe the existing air quality within project site at Thilafushi and at the nearest islands. Ambient Air Quality measuring the following parameters: Particulate matter (PM10, PM2), Sulphur dioxide (SO2), Oxides of nitrogen (NOx), Methane (CH4), Carbon monoxide (CO), Cadmium (Cd), Lead (Pb), Mercury (Hg), Hydrocarbons (HCs). Measurements should be made from all locations from which data was taken in 2011 ELA report.
- Dispersion model for air pollution taking into account wind direction.
- Describe noise sources contributing to ambient noise levels (day/night) at the nearest and adjacent islands.
- Sensitive noise receptors adjacent to all project components shall be identified and typical background noise estimated based on surveys at representative sites. A justification for an ambient noise baseline (dBA) at the nearest and adjacent inhabited islands shall be provided. Ambient Noise should be measured from the facility location, harbor location and also from the waste transfer road location.
- An indication of the quality and quantity of water resources in the vicinity of the project site should be given including spatial and temporal monitoring to accurately characterize baseline groundwater characteristics and present water uses. Groundwater quality measuring following parameters pH, color, odor, turbidity, Electrical Conductivity, nitrate, phosphate, chloride, total dissolved solids, mercury, lead, arsenic, manganese, cadmium, iron, Total Coliform and polyaromatic hydrocarbons. From all locations from which water quality was assessed in 2011 and from the reclaimed areas following 2011.
- Marine water quality should be assessed. The following parameters needs to be investigated. This includes Temperature, pH, salinity, Total Suspended Solids (TSS), phosphate, nitrate, ammonia, sulphate, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Arsenic and Total Coliform. Assessment should be undertaken at all waste transfer routes and from locations from which data was taken in 2011 report.
- Currents data should be measured from the harbor and channel locations and from the lagoon. Comparisons should be made with the data collected from 2011 EIA report. Dispersion model of waste in water should be presented, taking into account currents.

**Biological environment:**

<ul style="list-style-type: none"> <li>• Description of the terrestrial environment of the site including current condition of the site,</li> <li>• Assessment of the marine environment should be undertaken from all locations from which data was taken in 2011 ELA report. This assessment should cover coral cover and fish census information.</li> <li>• Plankton Assessment from 5 different locations around Thilafushi.</li> <li>• Areas of special sensitivity including coral reefs and marine protected areas near Thilafushi shall be marked on a map and described. This shall include environmentally sensitive areas, protected areas and significant dive sites.</li> </ul>	
<u>Socio-cultural environment:</u>	
<ul style="list-style-type: none"> <li>• Describe the natural features and landscapes of the project site which may have a cultural significance.</li> <li>• Describe the visual amenity from the nearest and adjacent islands to Thilafushi.</li> <li>• Describe any Structures on the project site which may have cultural or religious significance.</li> <li>• Provide details of the land use plan in Thilafushi. This shall refer to current and future envisioned development projects.</li> </ul>	
<u>Hazard Vulnerability</u>	
<ul style="list-style-type: none"> <li>• Vulnerability of proposed project area to flooding and storm surges need be described.</li> </ul>	
<p><b>Task 3. Legislative and regulatory considerations</b> — Identify the pertinent legislation, regulations and standards, and environmental policies that are relevant and applicable to the proposed project, and identify the appropriate authority jurisdictions that applies to the project. Outline the pertinent policies, regulations and standards governing project location, land use, environmental quality, and public health and safety. Relevant sections of the regulations need to be highlighted and how the project complies with these sections indicated. Specific attention needs to be given to the waste management regulation and waste policy and how the project complies with these documents and how the relevant approvals will be attained.</p>	Compliance in Section III.
<p><b>Task 4. Determination of Potential impacts of proposed project</b> — Identify the major issues of environmental and social concern and indicate their relative importance to the design of the project. Distinguish construction and postconstruction phase impacts, significant positive and negative impacts, and direct and indirect impacts. Identify impacts that are cumulative, unavoidable or irreversible. Particular attention shall be given to impacts associated with the following:</p>	Compliance in Section VI.

<u>Site preparation, construction and commissioning:</u>	
<ul style="list-style-type: none"> <li>• RWMF construction impacts including a description of the relevant parts and nature of the works, an indicative construction timetable, including expected commissioning and start-up dates and hours of operation, and a description of major work programs for the construction phase, including an outline of construction methodologies.</li> <li>• Commissioning impacts — including a description of the regional waste management facility commissioning process.</li> </ul>	
<u>Incinerator operation:</u>	
<ul style="list-style-type: none"> <li>• Describe solid waste management activities during operations, with particular reference to waste collection, transport, sorting, incinerator loading, and disposal of incinerator ash.</li> <li>• Characteristics of any hazardous materials resulting from or involved in the project, indicating appropriate management strategies (e.g. handling, storage, treatment, disposal).</li> <li>• Provide an inventory of projected annual emissions for each relevant greenhouse gas, with total emissions expressed in 'CO2 equivalent' terms.</li> </ul>	
<u>Air Quality:</u>	
<ul style="list-style-type: none"> <li>• Characterize the nature of emissions to air likely to be produced during the incineration process including flue gas composition, volumes, expulsion height, ejection velocity and temperature.</li> <li>• Describe the pollution control equipment, techniques and the features of the incinerator designed to suppress or minimize emissions to air.</li> <li>• Air dispersion modelling outcomes which estimate the effect of the expected emissions from the proposed incinerator on ambient air quality within the air shed with particular reference to the nearest and adjacent islands. The air dispersion modelling exercise shall evaluate the extent and concentration of following pollutants which are typical constituents of solid waste combustion: sulfur dioxide, nitrogen oxides (as nitrogen dioxide), TSP, PM2.5 and PM 10. Air emissions shall be stated in respect stack and ground level concentrations, using a dispersion model.</li> </ul>	
<u>Ground Water</u>	
<ul style="list-style-type: none"> <li>• Provide details of potential impacts on the quality of ground and marine waters. Reference shall be made to leachate from ash disposal, the potential of wastewater to contaminate ground and marine water, and impact on current and future potential groundwater usage from the Thilafushi.</li> </ul>	

<ul style="list-style-type: none"> <li>• Describe the pollution control equipment and design features of the proposed development for prevention and minimization of contamination of groundwater resources.</li> </ul>	
<u>Natural Environment</u>	
<ul style="list-style-type: none"> <li>• The proximity of the facility to any sensitive areas shall be described. Describe measures to be taken to avoid and minimize potential adverse impacts of the proposal on sensitive terrestrial and aquatic environments.</li> <li>• Describe potential issues relevant to sensitive areas, or areas which may have low resilience to environmental change arising from the construction, operation of the project including clearing, salvaging or removal of vegetation. Areas of special sensitivity include coral reefs, marine protected areas and communities. The capacity of the environment to assimilate discharges/emissions shall be assessed. Short-term and long-term effects shall be considered with comment on whether the impacts are reversible or irreversible. The discussion shall cover all likely direct and indirect environmental harm due to the project on flora and fauna particularly sensitive areas.</li> <li>• If construction and operation of the project are likely to cause adverse impacts on sensitive areas or areas which may have low resilience to environmental change describe environmental offsets that would counterbalance the impact on these values.</li> </ul>	
<u>Noise Amenity,</u>	
<ul style="list-style-type: none"> <li>• Describe the impacts of noise generated during the construction and operation of the proposed facility on nearest and adjacent islands. An analysis of noise impacts shall include the estimated noise levels generated by the proposed development assessed against typical background levels on the islands, and the impact of noise at all potentially sensitive receivers compared with an acceptable international standard.</li> <li>• If noise is likely to cause an adverse impact propose measures to minimize or eliminate these effects, including details of any screening, lining, enclosing or bunding of facilities, or timing schedules for construction and operations.</li> </ul>	
<u>Socio-cultural:</u>	

<ul style="list-style-type: none"> <li>• Describe the impacts of the proposed development on the natural features and landscapes of the project site which may have socio - cultural significance. Use sketches, diagrams, elevation drawings to portray the near views and far views of the completed structures and their surroundings from visually sensitive locations.</li> <li>• Describe measures to be taken to avoid and minimize potential adverse impacts of the proposal on visual amenity. Justify the proposed development with particular reference to potential for visual amenity.</li> <li>• Describe the impact of the proposed development on any structures which may have cultural or religious significance. Describe measures to be taken to avoid, manage or mitigate potential impacts on these structures during construction and operation of the proposed development.</li> <li>• The methods used to identify the significance of the impacts shall be outlined. One or more of the following methods shall be utilized in determining impacts; checklists, matrices, overlays, networks, expert systems and professional judgment. Justification shall be provided to the selected methodologies. The report shall outline the uncertainties in impact prediction and also outline all positive and negative/short and long-term impacts. Identify impacts that are cumulative and unavoidable.</li> </ul>	
<p><b>Task 5. Alternatives to proposed project</b> — Describe alternatives including the "no action option" should be presented. Determine the best practical environmental options. Alternatives examined for the proposed project that would achieve the same objective including the "no action alternative" which represents current conditions.</p> <p>This section shall include a comparison of the technologies and methods for management and control of contaminants which may potentially impact on the environment including alternatives for ash disposal. All alternatives shall be compared according to international standards and commonly accepted standards as much as possible. Mitigation options shall be specified for each component of the proposed project.</p> <p>A cost benefit analysis needs to be presented in this section for the different alternative methods of waste management proposed. Analysis from environmental, social and economic perspective needs to be presented.</p>	<p>Compliance in Section IV</p>
<p><b>Task 6. Environmental Management Plan (mitigation 'monitoring)</b> — The Project's environmental management plan (EMP) shall consists of a set of mitigation, monitoring, and institutional measures to be taken during implementation and operation to eliminate adverse environmental and social impacts, offset them, or reduce them to acceptable levels. In cases where impacts are unavoidable</p>	<p>Compliance in Section IX. However, specific details on institutional arrangements are yet to be agreed upon between ADB and the</p>

<p>arrangements to compensate for the environmental effect shall be given. The plan shall include off-set measures if mitigation measures are not feasible, cost-effective, or sufficient. Specifically, the EMP shall:</p>	<p>Government of Maldives.</p>
<p> </p>	
<p><u>Mitigation and management of negative impacts</u></p>	
<ul style="list-style-type: none"> <li>• Identify and summarize all anticipated significant adverse environmental impacts (coral reef and marine environment, air and groundwater (as applicable));</li> <li>• Describe each mitigation measure, including the type of impact to which it relates and the conditions under which it is required, together with designs, equipment descriptions, and operating procedures, including: <ul style="list-style-type: none"> <li>- General operating procedures for managing and mitigation risks to the environment from general facility, operations including waste collection, transport, incinerator loading, hazardous waste handling, fuel, transfer and storage, litter management disposal of incinerator ash and residues,</li> <li>- Manufacturer's operational guidelines specifically outlining safety and emission control procedures as well, as recommended maintenance practices.</li> <li>- General operating procedures for implementing back-up measures that will act in the event of failure of primary measures to minimize the likelihood of adverse air impacts.</li> </ul> </li> <li>• Estimate any potential environmental impacts of these measures;</li> <li>• Provide linkage with any other mitigation plans required for the project.</li> </ul>	
<p> </p>	
<p><u>Monitoring</u></p>	
<ul style="list-style-type: none"> <li>• Provide (a) a specific description, and technical details, of monitoring measures, including the parameters to be measured, methods to be used, sampling locations, frequency of measurements, detection limits (where appropriate), and definition of thresholds that will signal the need for corrective actions; and (b) monitoring and reporting procedures to; <ul style="list-style-type: none"> <li>- (i) Ensure early detection of conditions that necessitate particular mitigation measures, and</li> <li>- (ii) Furnish information on the progress and results of mitigation. Specifically, the plan shall address physical groundwater quality, air emissions, coral reef and marine environment (as applicable).</li> </ul> </li> </ul>	
<p> </p>	
<p><u>Capacity Development and Training</u></p>	
<p>Specifically, the EMP shall provide a specific description of institutional arrangements who is responsible for carrying out the mitigation and monitoring measures (e.g., for operation, supervision,</p>	



<p>enforcement, monitoring of implementation, remedial action, financing, reporting, and staff training). EMP shall cover steps to strengthen environmental management capability in the agencies responsible for its implementation.</p>	
<p><b>Implementation Schedule and Cost Estimates</b></p>	
<p>The EMP shall provide (a) an implementation schedule for measures that shall be carried out as part of the project, showing phasing and coordination with overall project implementation plans; and (b) the capital and recurrent cost estimates and sources of funds for implementing the EMP. This shall be presented for mitigation, monitoring, and capacity development required for the implementation of the EMP.</p>	
<p><b>Task 8. Stakeholder Consultation</b> — The stakeholder consultation process shall provide opportunities for stakeholders, community involvement and education. It may include interviews with individuals, public communication activities, interest group meetings, production of regular summary information and updates (i.e. newsletters), and other consultation mechanisms to encourage and facilitate active stakeholder consultation. Stakeholders consultation should cover Ministry of Environment and Energy, Greater Male' Investment Limited, WAMCO, EPA, STELCO, Maldives Energy Authority (MEA), Energy Department (MEE), Waste Department (MEE), nearby resorts, Male' City Council, Ministry of Housing and Infrastructure, existing businesses in Thilafushi, existing workers of the facility, NGOs and the general public shall be consulted. Stakeholder consultation processes (community engagement) for all parts of the EIA shall be integrated. Sufficient information about the development and the consultation process shall be provided to the community at an early stage and in accessible and culturally appropriate ways. Information about the development should inform the community about the benefits, disadvantages, trade-offs, potential issues and implications as required, enabling them to formulate their views. Information about the consultation processes conducted and their results shall be provided including:</p> <p>The methodology adopted, a list of stakeholders consulted during the program and how their involvement was facilitated,</p> <p>the processes conducted to date and the future consultation strategies and programs including those during the operational phase of the project,</p> <p>Recommendations on how the project might address concerns raised during public consultation.</p> <p>List of those who are consulted including their names and contacts should be provided in the EIA report,</p>	<p>Compliance in Section VII.</p>

<p><b>Task 8. Climate Change Risk Assessment</b> — Review of literature on climate change specific to the Maldives shall be carried out. Following this, climate change considerations shall be suggested for the project, including sea level rise, tropical cyclonic winds, storm surges, probable maximum precipitation. Climate change adaptation considerations for the design shall be discussed.</p>	<p>Compliance with this task is covered across the different sections of the EIA report, but not explicit because the assessment is yet to be undertaken through a CVRA.</p> <p>Since the project will be awarded under a DBO contract, the risks due to climate change will be integrated in the final detailed design that is to be undertaken during design phase.</p>
<p><u>Presentation</u>- The environmental impact assessment report, to be presented in digital format, shall be concise and focus on significant environmental issues. It shall contain the findings, conclusions and recommended actions supported by summaries of the data collected and citations of or any references used in interpreting those data. The environmental assessment report shall be organized according to, but not necessarily limited by, the outline given in the Environmental Impact Assessment Regulations, 2012 and relevant amendments.</p>	<p>Yet to be complied.</p>
<p>Timeframe for submitting the EIA report — The developer shall submit the completed EIA report within 6 months from the date of this Term of Reference.</p>	

## Comparative Analysis of Maldives Framework and ADB Safeguard Policy Statement

(A) ADB Safeguard Policy Statement	(B) Corresponding Legal Provisions of the draft of the Law on EIA <sup>1</sup>	(C) Extent of Equivalence <sup>2</sup>	(D) Recommended Gap-filling Measures
Policy Principle 1: Use a screening process for each proposed project, as early as possible, to determine the appropriate extent and type of environmental assessment so that appropriate studies are undertaken commensurate with the significance of potential impacts and risks.			
Key element (1) Use a screening process to determine the appropriate extent and type of environmental assessment	The <b>EIA regulations</b> , in particular Part III elaborates the process by which screening is used to identify proposals that have little or no environmental impact that are separated by projects that require an in-depth study. Schedule D of the EIA regulations list of projects that need to undertake an EIA because of likely severity of impacts. Proposals not listed in Schedule D are required to submit a Development Proposal Screening Form (Schedule C 1 of EIA Regulations) that is submitted to the Ministry of Environment where a decision is made either to approve the project or determine if further information is required through the preparation of an IEE needs (Schedule C 3 of EIA Regulations provides the Development Proposal Screening Decision Form). For projects falling under Schedule D an EIA application needs to be submitted along with TORs for the EIA to the Ministry of Environment for approval with or without proposed revisions. An EIA then should be prepared based on the TORs approved by the Ministry of Environment	Full Equivalence	None required
Policy Principle 2: Conduct an environmental assessment for each proposed project to identify potential direct, indirect, cumulative, and induced impacts and risks to physical, biological, socioeconomic (including impacts on livelihood through environmental media, health and safety, vulnerable groups, and gender issues), and physical cultural resources in the context of the project's area of influence. Assess potential trans-boundary and global impacts, including climate change. Use strategic environmental assessment where appropriate.			

<sup>1</sup> There are relevant provisions of the Environment Protection and Preservation Act of 1993, Environmental Protection Regulations of 2007 that deal with environmental assessment and management..

<sup>2</sup> "Full Equivalence" denotes that the Maldives legal requirement(s) are in complete harmony with the corresponding ADB Safeguard Objective, Scope and Trigger, Policy Principle or Key Element thereof. "Partial Equivalence" denotes that the Maldives legal requirement is in partial harmony with the corresponding ADB Safeguard Objective, Scope and Trigger, Policy Principle or Key Element; and "No Equivalence" denotes that no Maldives legal requirement can be found that corresponds to the particular ADB Safeguard Objective, Scope and Trigger, Policy Principle or Key Element.

(A) ADB Safeguard Policy Statement	(B) Corresponding Legal Provisions of the draft of the Law on EIA <sup>1</sup>	(C) Extent of Equivalence <sup>2</sup>	(D) Recommended Gap-filling Measures
Key element (1)  Identify indirect as well as direct impacts	<b>Schedule E of the EIA Regulations</b> requires that the direct and indirect environmental impacts on bio-physical, economic and human environment, including impacts on human well-being be assessed	Full compliance	None required
Key element (2) Identify cumulative impacts	The <b>EIA Regulations</b> , defines “EIA” as a means of identifying, predicting, evaluating and mitigating the biophysical, social, cumulative, economic and other relevant effects of a proposed development and “Cumulative Impacts” as the contained effect on the environment of two or more activities, or parts of projects, including synergistic projects  Similarly, the EIA Regulations require the project proponent to provide information on other similar projects in the area and IEEs and EIAs done for those projects	Full equivalence.	None required
Key element (3) Identify induced impacts	<b>The EIA Regulations</b> requires the assessment of indirect impacts, which are defined as “indirect results...as those caused by an action or actions and are later in time or further removed in distance, but are still reasonably foreseen, and includes growth-regulating effects and other effects to induced changes in the patterns of land-use, population density or growth rate and related effects on air, water and other natural systems, including ecosystems”	Full equivalence	None required
Key element (4) Identify physical impacts	<b>Schedule E of the EIA Regulations</b> requires that the direct and indirect environmental impacts on bio-physical, economic and human environment, including impacts on human well-being be assessed and that includes the description and direct and indirect impacts on the following: <ul style="list-style-type: none"><li>- Soil, relief, landforms, land use and drainage systems</li><li>- Surrounding infrastructure and drainage; and</li><li>- Beach systems, including composition, stability, tide and wave dynamics</li></ul>	Full Equivalence.	None required
Key element (5)	<b>Schedule E of the EIA Regulations</b> requires that the direct and indirect environmental impacts on bio-physical, economic and human environment, including the impacts on the following biological elements:	Full Equivalence.	None required

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Identify biological impacts	<ul style="list-style-type: none"> <li>- Flora, fauna, rare or endangered species, sensitive habitats of ecological importance, including mangroves and wetlands; and</li> <li>- Marine environment, including sandy and rocky bottoms, coral reefs and sea grass beds</li> </ul>		
Key element (6)  Identify socioeconomic impacts (including on livelihood through environmental health and safety, vulnerable groups, and gender issues)	<p>In the <b>EIA Regulations</b>, “EIA” is defined as a means of identifying, predicting, evaluating and mitigating the biophysical, social, cumulative, economic and other relevant effects of a proposed development and “the Human Environment” as the natural and physical environment and the relationships of people.</p> <p><b>Schedule C.1 of the EIA Regulations Part 3</b> requires the EIA to identify and assess the impacts on public well-being, public health, public safety, public transport, employment and economic status.</p>	<p>Partial Equivalence</p> <p>There is no reference in the EIA legislation regarding need to assess impacts on vulnerable groups and gender issues.</p>	<p>For full equivalence, the EIA Regulations should include assessment of the impact on vulnerable groups and gender related impacts.</p>
Key element (7)  Identify impacts on physical cultural resources	<p><b>Part II (2) of the EIA Regulations</b> requires EIAs and IEEs to consider effects of development programs on:.....(d) material assets and cultural heritage.</p> <p><b>Schedule E of the EIA Regulations</b> requires description of natural, economic and human environment, that includes among other things.....socio-economic characteristics....., including unique cultural characteristics.</p>	Full equivalence	None required
Key element (8)  Identify impacts in the context of the project’s area of influence	<p>There is reference to defining the boundaries of the area affected by the development project, but no specific reference to the context of the project’s area of influence, although the <b>EIA regulations</b> refers to induced impacts relating to changes patterns of land-use, population density or growth rate and related effects on air, water and other natural systems, including ecosystems, that might extend beyond the boundaries of the project area</p>	Full equivalence	None required
Key element (9)  Assess potential trans-boundary impacts	<p>There is no explicit reference to “assessment of trans-boundary impacts” in the legal framework.</p>	No Equivalence.	<p>For full compliance, new or revised legislation/regulations should require assessment of trans-boundary impacts</p>
Key element (10)  Assess potential global impacts, including climate change	<p><b>Part II Section 4 of the EIA Regulations</b> requires that project proponents take into account all policies and legislation, including commitments as Party to relevant International Conventions and Protocols</p>	Full Equivalence	None required

(A) ADB Safeguard Policy Statement	(B) Corresponding Legal Provisions of the draft of the Law on EIA <sup>1</sup>	(C) Extent of Equivalence <sup>2</sup>	(D) Recommended Gap-filling Measures
Key element (11) Use strategic environmental assessment	There is no explicit reference to conduct of strategic environmental assessment in the legislation	No equivalence	To achieve full compliance the EIA regulations or similar legislation should require the conduct of SEAs, including assessment of plans, programs and policies
Policy Principle 3: Examine alternatives to the project's location, design, technology, and components and their potential environmental and social impacts and document the rationale for selecting the particular alternative proposed. Also consider the no-project alternative.			
Key element (1) Examine alternatives to the project's location, design, technology.	<p><b>Schedule E of the EIA regulations</b> discusses the need for consideration of alternatives such as:</p> <ul style="list-style-type: none"> <li>(i) To identify and describe at least 3 alternatives, one of which should be the no-development option, define clear criteria to evaluate the alternatives, and determine the preferred alternative;</li> <li>(ii) Discuss whether the project be undertaken elsewhere, perhaps an alternate locations with less likely impacts; and</li> <li>(iii) Include discussion of alternative ways in which the project can may be carried out to cause less harm to the environment.</li> <li>(iv) Discuss the preferred alternative and why it was selected</li> </ul>	Full equivalence	None required
Key element (2) Consider the no-project alternative	<p><b>Schedule E of the EIA regulations</b> requires the need to:</p> <ul style="list-style-type: none"> <li>(i) To identify and describe at least 3 alternatives, one of which should be the no-development option, define clear criteria to evaluate the alternatives, and determine the preferred alternative;</li> </ul>	Full equivalence	None required
Policy Principle 4: Avoid, and where avoidance is not possible, minimize, mitigate, and/or offset adverse impacts and enhance positive impacts by means of environmental planning and management. Prepare an environmental management plan (EMP) that includes the proposed mitigation measures, environmental monitoring and reporting requirements, related institutional or organizational arrangements, capacity development and training measures, implementation schedule, cost estimates, and performance indicators. Key considerations for EMP preparation include mitigation of potential adverse impacts to the level of no significant harm to third parties, and the polluter pays principle.			
Key element (1) Avoid, and where avoidance is not possible, minimize, mitigate, and/or offset adverse impacts	<p><b>The EIA Regulations</b> recognizes the following explicit mitigation actions to emanate from the EIA process:</p> <ul style="list-style-type: none"> <li>(a) Avoiding the impact altogether by not taking a certain action or a part of an action</li> <li>(b) Minimizing negative impacts by limiting the degree and magnitude of the action and its implementation</li> </ul>	Full equivalence	None required

(A) ADB Safeguard Policy Statement	(B) Corresponding Legal Provisions of the draft of the Law on EIA <sup>1</sup>	(C) Extent of Equivalence <sup>2</sup>	(D) Recommended Gap-filling Measures
and enhance positive impacts by means of environmental planning and management	<ul style="list-style-type: none"> <li>(c) Optimizing the positive impacts of development</li> <li>(d) Rectifying the impact by repairing, rehabilitating or restoring the affected environment</li> <li>(e) Reducing or eliminating the impact over time by conservation operations during the life of the action; and</li> <li>(f) Compensating for the impact by replacing or providing substitute resources or environments</li> </ul>		
Key element (2) Prepare an environmental management plan (EMP)	<b>Schedule E of the EIA Regulations “Contents of an IEE of EIA study”</b> outlines the Content of an IEE study or EIA study report that development proponents are expected to prepare and submit to the Ministry of Environment for review and provision of environmental clearance of a development project, that includes a report with proposed measures to mitigate adverse environmental impacts.	Full equivalence	None required
Key Element (3) Prepare an environmental management plan (EMP) that includes the proposed... environmental monitoring and reporting requirements	<p><b>Schedule E of the EIA Regulations “Contents of an IEE of EIA study” under title “Environmental Monitoring”</b> requires the preparation of an environmental monitoring plan that includes provisions for on-site monitoring during (i) site preparation; (ii) construction/implementation and (iii) decommissioning phases, as well as the longer-term maintenance requirements</p> <p><b>Schedule M of the EIA Regulations “Format for Environmental Monitoring Reports”</b> requires the submission of summary reports at 2 monthly intervals and a final report at the end of the decommissioning phase or as specified in the Environmental Decision Statement to be submitted to the Ministry</p>	Full Equivalence	None required
Key Element (4) Prepare an environmental management plan (EMP) that includes... related institutional or organizational arrangements	<p><b>Schedule I of the EIA Regulations “Review of IEE or EIA study”</b></p> <p>Number 7: “Mitigation” requires the mitigation measures or “EMP” Plan to define in specific, practical terms the costs, manpower, equipment, timing and technology needed</p>	Partial Equivalence  While, the EMP is required to provide for manpower requirements for its implementation, it is not explicit in terms of requiring institutional or organization arrangements for its implementation	To attain full equivalence, the EMP should explicitly require the definition of institutional or organization arrangement
Key Element (5) Prepare an environmental management plan (EMP) that includes the	<p><b>Schedule I of the EIA Regulations “Review of IEE or EIA study”</b></p> <p>Number 7: “Mitigation” requires an assessment of institutional capacity to carry out mitigation measures</p>	Partial Equivalence  The requirement for capacity development and training for	To attain full equivalence, the legislation should made explicit reference for including capacity building and training

(A) ADB Safeguard Policy Statement	(B) Corresponding Legal Provisions of the draft of the Law on EIA <sup>1</sup>	(C) Extent of Equivalence <sup>2</sup>	(D) Recommended Gap-filling Measures
proposed... capacity development and training measures		implementation of EMP is implicit, rather than explicit in the legislation	needs in the EMP
Key Element (6) Prepare an environmental management plan (EMP) that includes the proposed ... implementation schedule	<b>Schedule I of the EIA Regulations “Review of IEE or EIA study”</b> Number 7: “Mitigation” requires the mitigation measures or “EMP” Plan to define in specific, practical terms the costs, manpower, equipment, <u>timing</u> and technology needed	Full Equivalence	None required
Key Element (7) Prepare an environmental management plan (EMP) that includes the proposed... cost estimates	<b>Schedule I of the EIA Regulations “Review of IEE or EIA study”</b> Number 7: “Mitigation” requires the mitigation measures or “EMP” Plan to define in specific, practical terms the <u>costs</u> , manpower, equipment, timing and technology needed	Full Equivalence	None required
Key element (8) Prepare an environmental management plan (EMP) that includes the proposed ... performance indicators	<b>Schedule M of the EIA Regulations “Format for Environmental Monitoring Reports”</b> is comprehensive, including requirements for monitoring and reporting on (i) implementation of mitigation measures; (ii) monitoring results, including date, time frequency and duration; (iii) presentation of environmental quality performance and standards; (iv) presentation of monitored parameters, etc.	Full Equivalence	None required
Key Element (9) Key considerations for EMP preparation include mitigation of potential adverse impacts to the level of no significant harm to third parties, and the polluter pays principle.	The legislation is implicit in terms of the requirement to avoid or minimizing the impact on the environment or human health and safety	Partial Equivalence  There is no explicit reference to the polluter play principle	To attain full equivalence, the legislation should explicitly made requirement for ensuring that the developer or polluter pay if there is damage to the environment or third party
Policy Principle 5: Carry out meaningful consultation with affected people and facilitate their informed participation. Ensure women’s participation in consultation. Involve stakeholders, including affected people and concerned nongovernment organizations, early in the project preparation process and ensure that their views and concerns are made known to and understood by decision makers and taken into account. Continue consultations with stakeholders throughout project implementation as necessary to address issues related to environmental assessment. Establish a grievance redress mechanism to receive and facilitate resolution of the affected people’s concerns and grievances regarding the project’s environmental performance.			
Key element (1) Carry out meaningful	<b>Schedule E of the EIA Regulations</b> lists the Public Consultation requirements as follows:	Partial equivalence	For full equivalence, the EIA Regulations should explicitly



(A) ADB Safeguard Policy Statement	(B) Corresponding Legal Provisions of the draft of the Law on EIA <sup>1</sup>	(C) Extent of Equivalence <sup>2</sup>	(D) Recommended Gap-filling Measures
consultation with affected people and facilitate their informed participation	<p>That the IEE and EIA process and report should include:</p> <ul style="list-style-type: none"> <li>(a) A list of persons consulted including persons in statutory bodies, atolls and island offices, community groups and NGOs, local residents, local fishermen, tourism operators and others likely to be affected by the proposed development</li> <li>(b) Information on how, when and where consultations were conducted, e.g. stakeholder meetings in affected area, individual meetings, questionnaires; and</li> <li>(c) Summary of outcome of consultations, including the main concerns identified.</li> </ul>	There is no clear timeline established when consultation should occur, if consultation should take place throughout project implementation and the means for resolution of any affected person's concerns	identifying the different stages at which consultation should take place (e.g. early in EIA process, before finalization of EIA and during project implementation and monitoring) as well as means to address people's concerns and grievances
Key element (2) Ensure women's participation in consultation	There is no explicit reference to women's participation in the consultative process, although reference to consultation in the EIA regulations.	No equivalence	For full equivalence the EIA Regulations should explicitly require consultation and participation of women in the EIA process and during project implementation
Key element (3) Involve stakeholders, including affected people and concerned nongovernment organizations, early in the project preparation process.	<p>While there is explicit reference in <b>Schedule E of the EIA Regulations</b> of the requirements for involving stakeholders and affected people as outlined below, it does not specify the stages (including early in project preparation process) that consultation is mandatory:</p> <p>That the IEE and EIA process and report should include:</p> <ul style="list-style-type: none"> <li>(a) A list of persons consulted including persons in statutory bodies, atolls and island offices, community groups and NGOs, local residents, local fishermen, tourism operators and others likely to be affected by the proposed development</li> <li>(b) Information on how, when and where consultations were conducted, e.g. stakeholder meetings in affected area, individual meetings, questionnaires; and</li> <li>(c) Summary of outcome of consultations, including the main concerns identified.</li> </ul>	<p>Partial equivalence</p> <p>There is no reference in the legislation to the stages and timing of consultations</p>	To attain full equivalence, the EIA Regulations should explicitly identifying the different stages at which consultation should take place, including early in the project preparation process
Key element (4) Establish a grievance redress mechanism	There is no explicit reference to establishment of a grievance redress mechanism at the project level.	No equivalence	For full equivalence the EIA Regulations should specify mechanisms for addressing people's grievances both during the EIA process and during project implementation
Policy Principle 6: Disclose a draft environmental assessment (including the EMP) in a timely manner, before project appraisal, in an accessible place and in a form and language(s) understandable to			

(A) ADB Safeguard Policy Statement	(B) Corresponding Legal Provisions of the draft of the Law on EIA <sup>1</sup>	(C) Extent of Equivalence <sup>2</sup>	(D) Recommended Gap-filling Measures
affected people and other stakeholders. Disclose the final environmental assessment, and its updates if any, to affected people and other stakeholders.			
Key element (1) Disclose a draft environmental assessment (including the EMP) in a timely manner, before project appraisal, in an accessible place.	The EIA Regulations require public consultations, and the invent that the project is complex and sufficiently controversial, the Ministry of Environment can request additional public consultation. This would take place before the EA report is finalized.	Partial equivalence  There is no guidance on the disclosure of draft EA (and EMP), including timing, location and language	To achieve full equivalence, the EIA Regulations should clearly specify the timing, location, language and other specifics regarding the disclosure of the draft EA (and EMP)
Key element (2) Disclose the final environmental assessment, and its updates if any, to affected people and other stakeholders	There is no guidance in the legislation regarding the disclose of the final EA report and EMP, although the decision of approval or environmental clearance has to be disclosed	No equivalence	For full equivalence, the EIA Regulation should explicitly specify the need for disclosure of the final EA and EMP reports in an accessible location and in a language that is understandable to the affected people and other stakeholders
Policy Principle 7: Implement the EMP and monitor its effectiveness. Document monitoring results, including the development and implementation of corrective actions, and disclose monitoring reports.			
Key element (1) Implement the EMP and monitor its effectiveness.	<b>The EIA Regulations, Schedule J “Environment Decision Statement”</b> issued to the developer by the Ministry of Environment, Item 2 (i) (ix) requires that all mitigation measures proposed in the EIA report for the construction phase and operational phase as outlined in page/s (as per the EIA Report) shall be fully implemented.	Full equivalence	None required
Key element (2) Document monitoring results, including the development and implementation of corrective actions, and disclose monitoring reports.	<b>The EIA Regulations, Part IV Item 13 “Environmental Monitoring and Mitigation</b> has the following instructions:  (i) The proponent shall fund and conduct environmental monitoring and implementing mitigation measures for the development proposal if specified and required by virtue of the Environmental Decision Statement  (ii) The proponent shall regularly submit summary environmental monitoring reports.....  (iii) The proponent shall maintain records of all monitoring data and on request make these available to the Ministry of Environment  (iv) The proponent shall submit a final environmental monitoring and mitigation report to the	Partial equivalence  There is no requirement for public disclosure of the monitoring results, disclosure is limited to submission to government agencies	For full equivalence, the EIA Regulations should specify requirement for public disclosure of monitoring results

(A) ADB Safeguard Policy Statement	(B) Corresponding Legal Provisions of the draft of the Law on EIA <sup>1</sup>	(C) Extent of Equivalence <sup>2</sup>	(D) Recommended Gap-filling Measures
	<p>Ministry of Environment when the project is completed or at such time as may be specified in the Environment Decision Statement</p> <p>(v) The Ministry of Environment may request to put in place necessary additional measures based on the finding of the monitoring reports</p>		
<p>Policy Principle 8: Do not implement project activities in areas of critical habitats, unless (i) there are no measurable adverse impacts on the critical habitat that could impair its ability to function, (ii) there is no reduction in the population of any recognized endangered or critically endangered species, and (iii) any lesser impacts are mitigated. If a project is located within a legally protected area, implement additional programs to promote and enhance the conservation aims of the protected area. In an area of natural habitats, there must be no significant conversion or degradation, unless (i) alternatives are not available, (ii) the overall benefits from the project substantially outweigh the environmental costs, and (iii) any conversion or degradation is appropriately mitigated. Use a precautionary approach to the use, development, and management of renewable natural resources.</p>			
<p>Key Element (1)</p> <p>Do not implement project activities in areas of critical habitats, unless (i) there are no measurable adverse impacts on the critical habitat that could impair its ability to function, (ii) there is no reduction in the population of any recognized endangered or critically endangered species, and (iii) any lesser impacts are mitigated.</p>	<p><b>The EIA Regulations</b> defines natural environment as:</p> <ul style="list-style-type: none"> <li>(i) Natural features consisting of physical and biological formations or groups of such formations</li> <li>(ii) Geological and physiological, geomorphical, lithostratigraphical, palaeontological and hydrological functions and precisely delineated areas which constitute the habitat of threatened species of fauna and flora; and</li> <li>(iii) Natural sites of precisely delineated areas of value from the point of view of science, scenic value, conservation or natural beauty.</li> </ul> <p><b>The EIA Regulations Schedule B</b> further requires development to ensure that economic development is sustainable and that any development project assess the “presence or absence of critical ecosystems” that would “Environmental Sensitive Areas” (ESA) that have been identified by the Ministry of Environment. If such an ESA has been identified in the development area, that that site should be either removed for consideration for future development or that development could take place, taking into consideration the conservation of the sensitive area, there by mitigating the negative impacts.</p>	Full Equivalence	None required
<p>Key Element (2)</p> <p>If a project is located within a legally protected area, implement additional programs to promote and enhance conservation aims of the protected area</p>	<p><b>The EIA Regulations Schedule B</b> further requires development to ensure that economic development is sustainable and that any development project assess the “presence or absence of critical ecosystems” that would “Environmental Sensitive Areas” (ESA) that have been identified by the Ministry of Environment. If such an ESA has been identified in the development area, that that site should be either removed for consideration for future development or that development could take place, taking into consideration the conservation of the sensitive area, there by mitigating the negative impacts.</p> <p>However <b>Schedule B of the EIA Regulations</b> clarifies that if a site/island or its surrounding reef is part of the island/reef ecosystem included in the ESA sites listed for special protection, such sites should not be</p>	Partial Equivalence	To attain full equivalence, the legislation should be explicit if development can take place in protected areas or ESAs, and if so under what conditions and what added measures are necessary for enhancing conservation of the area

(A) ADB Safeguard Policy Statement	(B) Corresponding Legal Provisions of the draft of the Law on EIA <sup>1</sup>	(C) Extent of Equivalence <sup>2</sup>	(D) Recommended Gap-filling Measures
	considered for any development. Also, any site/island selected for development must have at least a 20 m space (measured from the seaward edge inland) for maintenance of an undisturbed band of vegetation that could serve as a “no-development” buffer zone, or else it should be removed from any development activity		
Key Element (3) In an area of natural habitats, there must be no conversion or degradation, unless (i) alternatives are not available; (ii) the overall benefits from the project substantially outweigh the environmental costs, and (iii) any conversion or degradation is appropriately mitigated	While, the legislation recognizes the need to ensure that development is excluded from specially designed environmentally sensitive sites, <b>the EIA Regulations</b> calls for evaluation of alternatives ways to development that cause less harm of the environment (that is defined as fauna, flora and natural habitats....)	Partial equivalence  There is no explicit requirement for evaluating cost and benefits of damaging the environment (including natural habitats) in decision-making on conversion or degradation of natural habitats	To attain full equivalence, the legislation should specify the options for conversion and/or degradation of natural habitats including assessment of costs and benefits of conversion and mitigation options
Key Element (4) Use a precautionary approach to the use, development, and management of renewable natural resources	<b>Schedule B of the EIA Regulations</b> states that development that is in harmony with the natural environment is the preferred approach for the Maldives and environment is defined as the fauna, flora, natural habitat and the human environment. However, there is no specific reference to use of a precautionary approach to management of renewable natural resources	No Equivalence	To attain full equivalence, the legislation should require the explicit use of a precautionary approach to use and management of renewable natural resources
Policy Principle 9: Apply pollution prevention and control technologies and practices consistent with international good practices as reflected in internationally recognized standards such as the World Bank Group’s Environmental, Health and Safety Guidelines. Adopt cleaner production processes and good energy efficiency practices. Avoid pollution, or, when avoidance is not possible, minimize or control the intensity or load of pollutant emissions and discharges, including direct and indirect greenhouse gases emissions, waste generation, and release of hazardous materials from their production, transportation, handling, and storage. Avoid the use of hazardous materials subject to international bans or phaseouts. Purchase, use, and manage pesticides based on integrated pest management approaches and reduce reliance on synthetic chemical pesticides.			
Key element (1) Apply pollution prevention and control technologies and practices consistent with international good practices.	The main piece of legislation that provides regulations for the protection and prevention of pollution is the <b>Environment Protection and Preservation Act of 1993</b>  Under section 1 of Act, requires the Government and citizens to give special attention to the protection of its environment including both sea and the atmosphere. The relevant Government authorities shall also provide guidelines for the protection and preservation and everyone is required to respect such guidelines.  Under section 7(a), any type of wastes, oils, poisonous gases or any substance that may have harmful	Partial equivalence  While the EPPA does not make reference to international standards of pollution management	For full equivalence, guidelines are required as stipulated by the EPP Act to manage and deal with the pollution of air, water, land based on internationally recognized standards

(A) ADB Safeguard Policy Statement	(B) Corresponding Legal Provisions of the draft of the Law on EIA <sup>1</sup>	(C) Extent of Equivalence <sup>2</sup>	(D) Recommended Gap-filling Measures
	effects on the environment shall not be disposed of within the territory of the Maldives. In cases where the disposal of such substances becomes absolutely necessary, they shall be disposed of only within those areas designated for such purposes by the Government. If such waste is to be incinerated, appropriate precautions should be taken to avoid any harm to the health of the population. Similarly, the Act also states that wastes that are harmful to human health and the environment shall not be disposed of anywhere within the territory of the country and permission should be obtained from the relevant authority at least 3 months in advance of any trans-boundary movement of such wastes through the territory of the Maldives.		
Key Element (2) Adopt cleaner production processes and good energy efficiency practices	<b>Schedule E of the EIA Regulations “Project Description”</b> requires the project proponent to identify measures to be adopted to promote sustainable development, including cleaner production, renewable energy systems) during the implementation and operational phases of the project	Full Equivalence	None required
Key Element (3) Avoid pollution, or, when avoidance is not possible, minimize or control the intensity or load of pollutant emissions and discharges, including direct and indirect greenhouse gases emissions, waste generation, and release of hazardous materials from their production, transportation, handling, and storage.	<p><b>Environment Protection and Preservation Act</b> in Article 7 and 8 address the issues related to waste disposal and hazardous toxins.</p> <p><b>Article 7 “Waste disposal, Oil and Poisonous Substances”</b> states that</p> <ul style="list-style-type: none"> <li>(a) Any types of waste oil, poisonous gases or any substance that may be harmful on the environment shall not be disposed within the territory of the country</li> <li>(b) In case, where the disposal of substances stated in (a) becomes absolutely necessary, they shall be disposed within the areas designated by the government. If such wastes are incinerated, appropriate precautions should be taken to avoid harm to the health of the population</li> </ul> <p><b>Article 8 Hazardous/Toxic or Nuclear Wastes</b> states that such wastes that is harmful to human health and the environment shall not be disposed in the territory of the country, Permission is required for any transboundary movement of such wastes through the territory of the Maldives</p>	<p>Partial Equivalence</p> <p>There is no recognition of load minimization and control, including measures for generation, release, handling and storage</p>	To attain full equivalence, the legislation should require avoidance and control of emission and discharge loads and handling, production and storage of such materials
Key Element (4) Avoid the use of hazardous materials subject to international bans or phase-outs	The legislation (Environmental Protection and Preservation Act) refers to disposal of hazardous wastes and transboundary movement of such wastes, but is silent on its use and phase-outs	Partial Equivalence	To attain full equivalence, the legislation should deal explicitly with the use of hazardous materials on the basis of international norms and phase out schedules
Key Element (5) Purchase, use, and	There is no specific legislation that governs the purchase, use and management of pesticides in the	No Equivalence	To attain full equivalence, the legislation should provide

(A) ADB Safeguard Policy Statement	(B) Corresponding Legal Provisions of the draft of the Law on EIA <sup>1</sup>	(C) Extent of Equivalence <sup>2</sup>	(D) Recommended Gap-filling Measures
manage pesticides based on integrated pest management approaches and reduce reliance on synthetic chemical pesticides.	Maldives.  The Environment Protection and Preservation Act deals more broadly with the impacts of development related activities on the environment (fauna, flora, natural resources, etc.) and on the health and well being of the people. The direct and indirect impacts on air, water, and other natural systems (that likely refers to soil, renewable and non-renewable natural resources.		guidance on the purchase, use and management (production, transport, storage, handling, disposal) of chemicals use in agriculture
Policy Principle 10: Provide workers with safe and healthy working conditions and prevent accidents, injuries, and disease. Establish preventive and emergency preparedness and response measures to avoid, and where avoidance is not possible, to minimize, adverse impacts and risks to the health and safety of local communities.			
Key Element (1) Provide workers with safe and healthy working conditions and prevent accidents, injuries, and disease.	<p><b>Articles 73 -76 of The Employment Act of 2008</b>, provides coverage of measures for the safety and protection of employees at the work place..... Such measures shall include:-</p> <ul style="list-style-type: none"> <li>i. implementation of a safe work place and procedures, procurement of secure tools and machinery for carrying out work, and ensuring the continued safety of the same;</li> <li>ii. provide safe materials to work with;</li> <li>iii. provide protective equipment and safety equipment in the event that the nature of work is such that it is not possible to eliminate or control health hazards arising out of the work;</li> <li>iv. provide education and training to employees on the use of protective gear and safety equipment, and disseminate to employees information on all issues of related concern;</li> <li>v. conduct regular health checks for employees engaged in work involving chemical or biological materials that may cause a hazard to physical health or employees involved in any work that may cause physical ill health;</li> <li>vi. provide or arrange for appropriate medical care for employees injured while carrying out employment; and</li> <li>vii. arrange the facilitation of first aid to employees in emergencies or accidents.</li> </ul> <p>74. The following are duties imperative upon every employee:-</p> <ul style="list-style-type: none"> <li>i. maintenance of safe work practices at work to avoid danger to the safety and well being of the employee and co-workers which may be caused by inattentiveness to safety and security measures;</li> <li>ii. assist the employer and co-workers in maintenance of measures designed to ensure health and safety in the work place;</li> <li>iii. use safety equipment and protective gear as instructed in accordance with the training and education provided for use of such equipment and gear;</li> <li>iv. report to the employer any damage, loss of or destruction of protective gear or safety equipment;</li> <li>v. inform the employer or his designated supervisor immediately of the occurrence of any incident which the employee believes may cause danger and which the employee is unable to resolve;</li> <li>vi. inform the employer or his designated supervisor of any accidents or damage sustained occurring at</li> </ul>	Full equivalence	None required

(A) ADB Safeguard Policy Statement	(B) Corresponding Legal Provisions of the draft of the Law on EIA <sup>1</sup>	(C) Extent of Equivalence <sup>2</sup>	(D) Recommended Gap-filling Measures
	work or related to work.		
<p>Key Element (2)</p> <p>Establish preventive and emergency preparedness and response measures to avoid, and where avoidance is not possible, to minimize, adverse impacts and risks to the health and safety of local communities</p>	<p><b>The Disaster Management Act of 2006</b> recognizes that it is the state responsibility to protect its people, their property and the natural and built environment they live in from natural and man-made disasters as well as requiring the government to act to manage risks, ensure preparedness, relief and recovery through capacity building, and establishing partnerships with organized local communities and international organizations, as well as preparing a national disaster management plan and national emergency operations plan.</p> <p>The intent is to promote an integrated and coordinated system of disaster management with emphasis on prevention and mitigation, communication, public awareness, knowledge, community participation, etc.</p>	Full Equivalence	None required
<p>Policy Principle 11: Conserve physical cultural resources and avoid destroying or damaging them by using field-based surveys that employ qualified and experienced experts during environmental assessment. Provide for the use of “chance find” procedures that include a pre-approved management and conservation approach for materials that may be discovered during project implementation.</p>			
<p>Key Element (1)</p> <p>Conserve physical cultural resources and avoid destroying or damaging them by using field-based surveys that employ qualified and experienced experts during environmental assessment.</p>	The <b>EIA regulations</b> requires the need to conserve and protect cultural resources	<p>Partial equivalence</p> <p>The legislation lacks mention of the need to use field-based surveys and qualified experts during the EIA process</p>	To attain full equivalence, the legislation should require the use of field based surveys and qualified experts to assess impacts on cultural resources during EIA preparation
<p>Key Element (2)</p> <p>Provide for the use of “chance find” procedures that include a pre-approved management and conservation approach for materials that may be discovered during project implementation</p>	None	There is no guidance on how to deal with “chance finds”	For full equivalence, the EIA regulations or other legislation should provide for the use of “chance find” procedures

## **ENVIRONMENTAL AUDIT OF THE THILAFUSHI RECLAMATION PROJECT**

### **I. INTRODUCTION**

1. ADB Safeguard Policy Statement (SPS) requires that for projects involving facilities and/or business activities that already exist or are under construction, the borrower/client will undertake an environment compliance audit, including on-site assessment, to identify past or present concerns related to impacts on the environment. The objective of the compliance audit is to determine whether actions were in accordance with ADB's safeguard principles and requirements for borrowers/clients and to identify and plan appropriate measures to address outstanding compliance issues.

2. The proposed Waste-to-Energy (WTE) Facility Project at the island of Thilafushi in Maldives will be financed by ADB together with Asian Infrastructure Investment Bank (AIIB). This WTE Facility Project is part of Phase 2 of the Government of Maldives initiative to set up an integrated Regional Waste Management Facility (RWMF) for Zone 3. As part of the environmental impact assessment (EIA) of the WTE Facility Project, all past and present projects associated with the RWMF have been assessed if any of these is/are considered existing or associated facility/ies per definition of ADB SPS. Evaluation showed that the RWMF project component named as "Reclamation of 15 hectares of land at Thilafushi for development of the Regional Waste Management Facility (RWMF) for Zone 3" (Reclamation Project) has been identified as an existing facility relative to the WTE Facility Project. Therefore, an environmental audit is required.

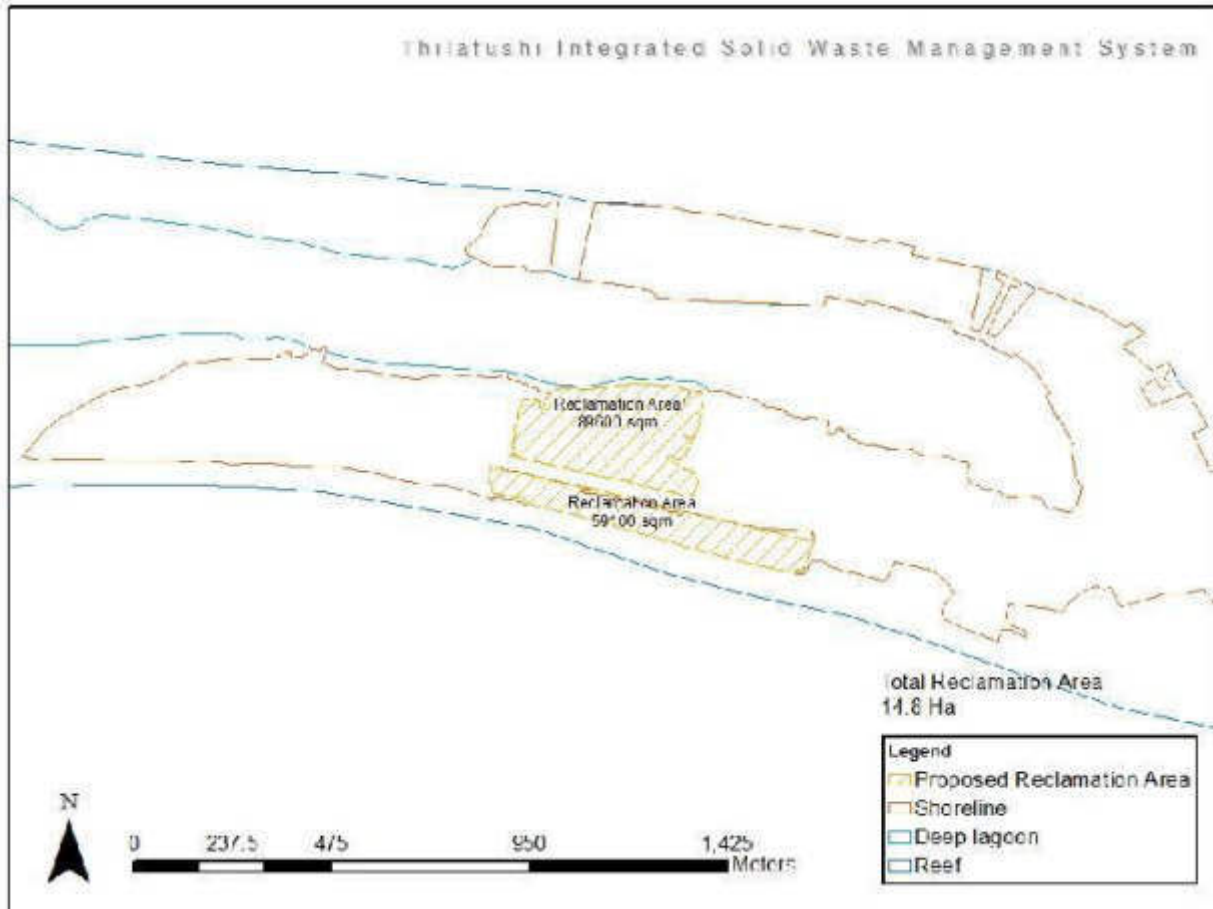
3. As such, an environmental audit has been carried out for the Reclamation Project. Since the Reclamation Project has been completed, the methodology adopted for this audit is documentary review in nature. The environmental safeguard documents of the project were reviewed to identify if it has complied with the relevant national laws, rules and regulations, and to determine if there were issues identified during the implementation of the project that remained outstanding or relevant to the present. The audit was also supplemented by visit to the completed project site (the reclaimed land) and interviews with the people who have been involved in the project implementation.

### **II. DESCRIPTION OF THE LAND RECLAMATION PROJECT**

4. The Reclamation Project involved a dredging and a reclamation component to create the additional land in Thilafushi Island. The reclaimed land is planned as additional site for the various components of the RWMF, including the WTE Facility Project, which this environmental audit has been carried out for.

5. The material for the reclamation was obtained from dredging in the deep seas around Thilafushi Island. The project was designed to reclaim a total area of 15 hectares with an estimated volume of 525,000 cubic meters of dredged materials. The project was also designed to elevate the reclaimed land to a height of +2.0m from mean sea level. The design of the Reclamation Project also included a coastal protection component to protect the created land from erosion. The coastal protection was built by building a revetment using geo-textile containers. Geo-textiles, bags and tubes were filled with sand and placed on the boundary of the reclaimed land as a revetment. The revetment was constructed to a height of +2.5 m from mean sea level. Figure below shows the area that was reclaimed.

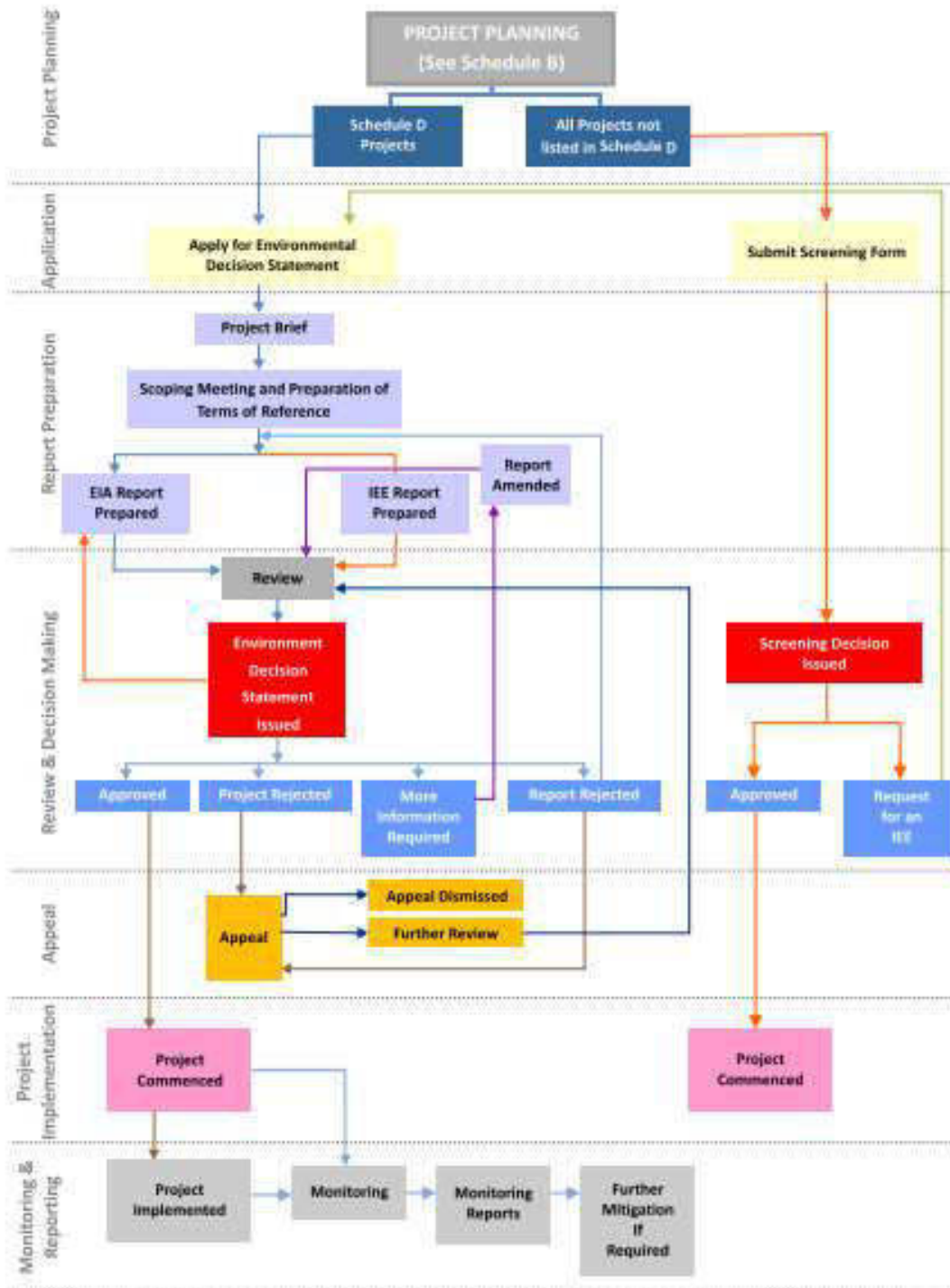




### III. ENVIRONMENTAL COMPLIANCE OF THE PROJECT

6. **Environmental Impact Assessment.** In 2017, an environmental impact assessment (EIA) was undertaken for the project. The EIA process was based on the requirements of EIA Regulation (2012/R-27), the Government of Maldives governing EIA regulation for all projects in the country. This regulation provides the detailed guidelines outlining the EIA process, including the roles and responsibilities of proponent (in this case the Ministry of Environment) and consultant undertaking the EIA. In summary, the project took all the necessary steps in order to finish the EIA and secure approval from the Maldives Environmental Protection Agency (EPA). The following illustration depicts the steps followed:

**FLOW CHART OUTLINING THE PROCESS FOR THE ISSUANCE OF AN ENVIRONMENTAL DECISION STATEMENT**



7. As a result, an EIA report was prepared and submitted to the Maldives EPA. A copy of the EIA report is available to public through the Maldives EPA website. The EIA report is also available from the Ministry of Environment. The front cover of this EIA report is attached as Annex 1 to this audit document.

8. On 17 December 2017, the Maldives EPA issued an approval of the EIA through Environmental Decision Statement No. 203-EIARES/438/2017/180. A copy of this approval document is attached as Annex 2 of this audit document.

9. On 21 February 2018, the contract for the project was awarded to Maldives Transport and Contracting Company Plc. After the award, significant development happened when the proposed methodology under the project was changed due to economic and technical issues. In particular, the initial plan to use Cutter Suction Dredger (CSD) was changed to use of Trailing Suction Hopper Dredger (TSHD). Accordingly, among many other reasons, use of TSHD was deemed more economical compared to use of CSD due to reduced reclamation time. Consequently, the reduction of reclamation time was also deemed as tantamount to having lesser environmental impacts arising from the activities. In view of this, an addendum to the EIA was prepared and submitted to Maldives EPA for approval.

10. On 07 May 2018, the Maldives EPA issued an approval of the First Addendum to the EIA through Environmental Decision Statement No. 203-EIARES/438/2018/87. Accordingly, the mitigation measures proposed in the initial EIA were sufficient for the project. The front cover of the Addendum to the EIA is attached as Annex 3 of this audit document. Also, a copy of the approval document of the First Addendum to the EIA is attached as Annex 4 of this audit document.

11. **Compliance with the conditions of the EIA.** The Environmental Decision Statement provides the conditions with which the proponent should comply with during the implementation of the Reclamation Project. Below is a summary of these conditions and the corresponding compliance by the proponent:

Conditions	Status of Compliance
1. In the event the project activity has not commenced within one (1) year from the date of issue, or if the duration of this Environmental Decision Statement has not been extended, this Environmental Decision Statement shall be considered null and void. In order to extend the duration of this Environmental Decision Statement, the Proponent shall write to the Minister for an extension according to Clause 14 of the 2 <sup>nd</sup> Amendment to the Environmental Impact Assessment Regulations 2012.	Complied. The project has been completed prior to the expiry of the Environmental Decision Statement.
2. In the event the project activities has been delayed for more than one (1) year due to unforeseen circumstances, the Ministry shall have the discretion to extend the duration of the Environmental Decision Statement, or to terminate it. In such circumstances the proponent shall write to the Minister for an extension clearly stating out the reasons for the delay.	Complied. The project has been completed prior to the expiry of the Environmental Decision Statement.
3. The Minister, or his designate, may issue a cessation order requiring persons working on	Complied.

<p>a Development Proposal to cease working until the order is withdrawn, if:  (a) This Environmental Decision Statement has been withdrawn or;  (b) There has been a breach of the conditions of this Environmental Decision Statement.</p>	
<p>4. It is the Developer's responsibility to undertake all project activities in accordance with the relevant laws and regulations of the Maldives.</p>	<p>Complied. The Developer has not been issued any notices or violation (or similar forms) and the project was completed without any breach of relevant laws and regulations.</p>
<p>5. The Developer shall submit environmental monitoring report as outlined in Paragraph viii of this Environmental Decision Statement. Failure to submit the requisite monitoring report may result in the suspension or revocation of the permit under this Decision Statement.</p>	<p>Complied. One Environmental Monitoring Report have been submitted and reviewed as part of this audit. The monitoring report confirmed that overall the environmental performance of the project is acceptable and further monitoring was recommended.</p>
<p>6. The Developer is aware that under the National Environment Protection Act (Law No. 4/93) and the Environmental Impact Assessment Regulations the Ministry reserves the right to terminate any activity without compensation if found that such an activity has caused significant, irreversible impacts on the environment.</p>	<p>Complied. No termination of activities happened.</p>
<p>7. All mitigation measures proposed in the EIA report for all the phases of the project shall be fully implemented.</p>	<p>Complied. No termination of activities happened. It is viewed that all mitigation measures have been implemented.</p>
<p>8. The environmental monitoring program outlined in the Environmental Impact Assessment Report shall be undertaken and implemented and summary environmental monitoring reports shall be submitted to the Ministry.</p>	<p>Complied. Environmental Monitoring Reports and Physical Progress Reports have been prepared and submitted to the Ministry.</p>
<p>9. The date of expiry stated in this Environmental Decision Statement is the duration given to commence the project activities approved under this Environmental Decision Statement.</p>	<p>Complied. The project was accomplished within the duration of the Environmental Decision Statement.</p>
<p>10. Once the project activities have started, the Proponent must inform the Environmental Protection Agency, the date of commencement of project activities.</p>	<p>Complied. Accordingly, this activity was monitored closely by the Maldives EPA.</p>

#### IV. CONCLUSION

12. The Reclamation Project has long been accomplished prior to this environmental audit. No actual dredging activities was observed as part of this 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.

Annex 1

## **ENVIRONMENTAL IMPACT ASSESSMENT**

Reclamation of 15 hectares of land at Thilafushi for development of  
the Regional Waste Management Facility for Zone 3

**DRAFT**

June 2017

Proposed by  
Ministry of Environment and Energy

Prepared by  
Ahmed Jameel (EIA P07/2017)  
Ibrahim Faiz (EIA P05/2017)  
Akeed Ahmed (EIA T/2017)

For Water Solutions Pvt. Ltd



## Annex 2











the Environmental Impact Assessment Regulations the Ministry reserves the right to terminate any activity without compensation if found that such an activity has caused significant, irreversible impacts on the environment.

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vii. All mitigation measures proposed in the EIA report for all the phases of the project shall be fully implemented.

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viii. The environmental monitoring program outlined in the Environmental Impact Assessment Report shall be undertaken and implemented and summary environmental monitoring reports shall be submitted to the Ministry.

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ix. The date of expiry stated in this Environmental Decision Statement is the duration given to commence the project activities approved under this Environmental Decision Statement.

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مقرر ٿيل سڀني ضابطن ۾ مقرر ٿيل  
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*[Handwritten signature]*



- x. Once the project activities have started, the Proponent must inform the Environmental Protection Agency, the date of commencement of project activities.

**Date of Issue:** 17<sup>th</sup> December 2017

تاریخ صدور: 17 دسامبر 2017

**Date of expiry:** 17<sup>th</sup> December 2018

تاریخ منتهی: 17 دسامبر 2018

**Name:** Yazeed Ahmed

اسم: یازید احمد

**Designation:** Director, Environment Assessment

مقام: مدیر تقييم البيئة

Signature:

موقع

## **FIRST EIA ADDENDUM TO**

**Reclamation of 15 hectares of land at Thilafushi for development of  
the regional waste management facility for zone 3, Kaafu Atoll,  
Maldives**

**PROPONENT**  
**MINISTRY OF**  
**ENVIRONMENT**  
**AND ENERGY**

**Prepared By:**  
Firdous Hussain: EIA  
P21/2016  
Maldives Transport and  
Contracting Company Plc

April 2018

## Annex 4









delay,

- iii. The Minister, or his designate, may issue a cessation order requiring persons working on a Development Proposal to cease working until the order is withdrawn, if:

  - a) This Environmental Decision Statement has been withdrawn or;
  - b) There has been a breach of the conditions of this Environmental Decision Statement.

iii. ބޯރީޔަނި ވިއަބަލާ ނާއިބާރުގެ ނިންމުމުގެ ދަށުން ދާއިރާއެއްގެ މަސައްކަތް ކުރަމުން ދަތުރުކުރުމަށް ބަންދުކުރާ ޕަރމިޓް ދީނީ ފަދަ ފުރުޞަތެއް ނެތް ނުވަތަ ފަދަ ފުރުޞަތެއް ހުރި ސަބަބުތަކާ ގުޅިގެން ވިއަބަލާ ނާއިބާރުގެ އަމުރު ނެތުމާއެކު ދަތުރުކުރުމަށް ބަންދުކުރުމަށް ނުދޭން ބަންދުކުރުމެވެ.

  - a) ޖަދުވަލުގެ ބަންދުކުރުމުގެ ޖަދުވަލުގެ ދަށުން ފަދަ ފުރުޞަތެއް ނެތް ނުވަތަ ފަދަ ފުރުޞަތެއް ހުރި ސަބަބުތަކާ ގުޅިގެން ވިއަބަލާ ނާއިބާރުގެ އަމުރު ނެތުމާއެކު ދަތުރުކުރުމަށް ބަންދުކުރުމެވެ.
  - b) ވިއަބަލާ ނާއިބާރުގެ އަމުރުގެ ޖަދުވަލުގެ ދަށުން ފަދަ ފުރުޞަތެއް ނެތް ނުވަތަ ފަދަ ފުރުޞަތެއް ހުރި ސަބަބުތަކާ ގުޅިގެން ވިއަބަލާ ނާއިބާރުގެ އަމުރު ނެތުމާއެކު ދަތުރުކުރުމަށް ބަންދުކުރުމެވެ.
  
- iv. It is the Developer’s responsibility to undertake all project activities in accordance with the relevant laws and regulations of the Maldives.

iv. ވިއަބަލާ ނާއިބާރުގެ ރިސްކަލުގެ ދަށުން ފަދަ ފުރުޞަތެއް ނެތް ނުވަތަ ފަދަ ފުރުޞަތެއް ހުރި ސަބަބުތަކާ ގުޅިގެން ވިއަބަލާ ނާއިބާރުގެ އަމުރު ނެތުމާއެކު ދަތުރުކުރުމަށް ބަންދުކުރުމެވެ.
  
- v. The Developer shall submit environmental monitoring report as outlined in Paragraph viii of this Environmental Decision Statement. Failure to submit the requisite monitoring report may result in the suspension or revocation of the permit under this Decision Statement.

v. ވިއަބަލާ ނާއިބާރުގެ ރިސްކަލުގެ ދަށުން ފަދަ ފުރުޞަތެއް ނެތް ނުވަތަ ފަދަ ފުރުޞަތެއް ހުރި ސަބަބުތަކާ ގުޅިގެން ވިއަބަލާ ނާއިބާރުގެ އަމުރު ނެތުމާއެކު ދަތުރުކުރުމަށް ބަންދުކުރުމެވެ.
  
- vi. The Developer is aware that under the National Environment Protection Act (Law no. 4/93) and

vi. ވިއަބަލާ ނާއިބާރުގެ ރިސްކަލުގެ ދަށުން ފަދަ ފުރުޞަތެއް ނެތް ނުވަތަ ފަދަ ފުރުޞަތެއް ހުރި ސަބަބުތަކާ ގުޅިގެން ވިއަބަލާ ނާއިބާރުގެ އަމުރު ނެތުމާއެކު ދަތުރުކުރުމަށް ބަންދުކުރުމެވެ.

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x. Once the project activities have started, the Proponent must inform the Environmental Protection Agency, the date of commencement of project activities.

x. دہشتہ شروع ہونے پر، ذمہ دار کو ایجنسی کو مطلع کرنا چاہئے۔

دہشتہ شروع ہونے پر، ذمہ دار کو ایجنسی کو مطلع کرنا چاہئے۔

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Signature:

مستعمل

Annex 5

Google Earth Photo Over Thilafushi Island





## Technical Assistance Consultant's Final Report

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Project Number: 51077-001

February 2019

### **Maldives: Greater Male Environmental Improvement and Waste Management Project - Market Study on the Reuse of Incinerator Bottom Ash and Construction and Demolition Waste in the Maldives**

This consultant's report does not necessarily reflect the views of ADB or the Government concerned, and ADB and the Government cannot be held liable for its contents. (For project preparatory technical assistance: All the views expressed herein may not be incorporated into the proposed project's design.

Asian Development Bank

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## ABBREVIATIONS

ADB	Asian Development Bank
CDW	Construction Demolition Waste
CIF	Cost, Insurance and Freight
IBA	Incinerator Bottom Ash
IBA (r-IBA)	Recycled Incinerator Bottom Ash
MSW	Municipal Solid Waste
MSWI	Municipal Solid Waste Incinerator
SWM	Solid Waste Management
tpd	Tons per day
WTE	Waste-to-Energy
TA	Technical Assistance
RCA	Recycled Concrete Aggregates
RC	Recycled Aggregates
STO	State Trading Organization



# 1. Project

## 1.1. Project Description

Greater Male' is centrally located in Maldives and is the capital city of the nation. The Male' island and its 32 inhabited islands are categorized as Zone 3 in the National Solid Waste Management Policy. Greater Male' Region lack a proper waste management system. For the last 30 years, waste has been collected, transferred by sea, dumped and burnt at an open dump site at Thilafushi, an island 6km away from Male'. The current practice of waste management poses an environmental and public safety issue. Some waste, often in plastic bags, are lost to the sea during transportation and toxic leachate from the Thilafushi dump site contaminate the ground water. The smoke from burning of waste causes air pollution. The current practice of waste management is not sustainable.

The Greater Male' region (Zone 3) produces 774 tons per day (tpd) of mixed solid waste. The breakdown of waste is given in Table 1 and Table 2 shows the composition of Municipal Solid Waste (MSW). Due to the rapid urbanization and tourism development in Zone 3, it is expected the waste generation would increase to 924 tpd by 2022.

*Table 1. Breakdown of Waste by Type*

<b>Type</b>	<b>Amount</b>	
	<b>(tons per day)</b>	
Construction Demolition		
Waste	530	68%
Household	149	19%
Resort	48	6%
Commercial	27	3%
Airport	9.3	1.2%
Industrial	6	0.8%
Market	2.5	0.3%
Hazardous	1.5	0.2%
End-of-life vehicles	0.65	0.1%

Table 2. Composition of Municipal Solid Waste

<b>Type of Municipal Solid Waste</b>	
Organic	53%
Paper and cardboard	12%
Plastic	11%
Hazardous (medical)	8%
Metal	3%
Glass	3%
Others	11%

As an alternative to the current unsustainable practice of burning mixed solid waste, Greater Male' Environmental Improvement and Waste Management Project (Project), supported by the Asian Development Bank (ADB), is going to strengthen the solid waste management (SWM) in Zone 3. The Project will establish an integrated SWM system including collection, transfer, treatment using advanced waste-to-energy (WTE) technology, disposal, recycling, dumpsite closure and remediation, public awareness in reduce-reuse-recycle (3R), and strengthening institutional capacities for service delivery and environmental monitoring. The Government will implement the Project in two phases;

**Phase 1** includes Construction Demolition Waste (CDW) processing facility (200 tpd capacity).

**Phase 2** will consist of a WTE incineration of 500 tpd of Municipal Solid Waste (MSW) and the flammable fraction of the CDW

The incineration process reduces the waste to energy, Incinerator Bottom Ash (IBA) and fly ash. The fly ash will be disposed in a landfill. The IBA can also be disposed in a landfill. However, it is expected 100 to 125 tpd of IBA would be generated and land scarcity in Zone 3 limits the disposal of IBA in landfills. Alternatively, IBA could be treated further to produce recycled IBA (r-IBA) and reused as a building material.

CDW is mixed waste generated from construction and demolition activities. Soil and sand is not considered as CDW in this report as it is usually reused as backfill material. Disposal of CDW in landfills is also challenging due to land scarcity. CDW can be processed as recycled aggregates that could be used in various applications in the construction industry.

## 1.2. Objective of Technical Assistance

The objective of this assignment is to assess the potential market for IBA and CDW reuse in the Maldives.

## 1.3. Scope of Technical Assistance

The scope of this Technical Assistance (TA) is to conduct a market assessment for potential IBA and CDW reuse in the Maldives. Current use of aggregates with the aim of identifying potential applications, required national standards, costs, and current and projected demand for recycled IBA and CDW in the Maldives is analyzed. Detailed tasks of this assignment include:

- (i) Identify suitable applications for treated IBA and CDW reuse in the Maldives through literature review and surveys.
- (ii) Review applicable national standards for the reuse of treated IBA and CDW for the potential applications as identified in (i) and summarize the required material characteristics (e.g. chemical, physical).
- (iii) Conduct interviews/surveys with key stakeholders to understand their views on potential reuse, product requirements, and willingness to pay for treated IBA and CDW.
- (iv) Collect information on cost and demand of similar construction materials (to IBA and CDW) currently used in the Maldives.

- (v) Conduct a market demand analysis for reusing treated IBA and CDW in the Maldives including projections for next 5, 10 and 15 years
- (vi) Recommend possible ways/alternatives for maximize IBA and CDW demand/reuse and sustainable business models for the Greater Male context.
- (vii) Prepare comprehensive report on the activities (i) to (vi) with key recommendations for IBA treatment and CDW plant design and operation

## 2. Suitable Applications for Incinerator Bottom Ash

Incineration of MSW releases the energy during combustion. The waste reduces in weight by about 70%. IBA accounts for about 80% of the incombustible residue left <sup>1</sup>. The remaining of the residue is fly ash. Incombustible metals, glasses, ceramics, slag and sand mixture form as IBA and is rich in heavy metals, chlorides, oxides and organic pollutants. IBA require removal of ferrous and non-ferrous metals and further treatment to enhance its reusability. The type of treatment process adopted affects the leaching property and consequently the reusability of r-IBA. Common oxides and heavy metals found in IBA are given in Table 3. The composition of the oxides and heavy metals depend on the characteristics of the MSW but SiO<sub>2</sub> is generally the most abundant oxide in IBA<sup>2</sup>.

IBA is similar in its size and appearance to aggregates and hence can be used as a substitute to aggregates in applications aggregates are required. The main factors affecting the reuse of IBA is the suitability of IBA for treatment and processing, the

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<sup>1</sup> Lynn, C., Dhir, R., & Ghataora, G. (2016). Municipal incinerated bottom ash characteristics and potential for use as aggregate in concrete. *Construction and Building Materials*, 504-517.

<sup>2</sup> Lam, C. H., Ip, A. W., Barford, J. P., & McKay, G. (2010). Use of Incineration MSW Ash: A Review. *Sustainability*, 1943-1968.

attainability of required properties for a given application, and the environmental impact from the reuse of IBA <sup>3</sup>.

Reuse of IBA has been studied for the past 40 years. Lynn, Dhir, & Ghataora (2016) studied 76 publications published since 1979 over 18 countries<sup>4</sup> (Figure 1). Reuse of IBA is most prevalent in Europe. In Asia, reuse of IBA is prevalent in Taipei,China, Singapore and Japan where land is scarce.

Table 3. Oxides and heavy metals in incinerator bottom ash<sup>2</sup>

Oxides		Heavy Metals	
SiO <sub>2</sub>	K <sub>2</sub> O	Ag	Mn
Al <sub>2</sub> O <sub>3</sub>	Na <sub>2</sub> O	As	Ni
CaO	SO <sub>3</sub>	Ba	Pb
Fe <sub>2</sub> O <sub>3</sub>	P <sub>2</sub> O <sub>5</sub>	Cd	Se
MgO	TiO <sub>2</sub>	Co	Zn
		Cr	Sn
		Cu	Sr
		Hg	V

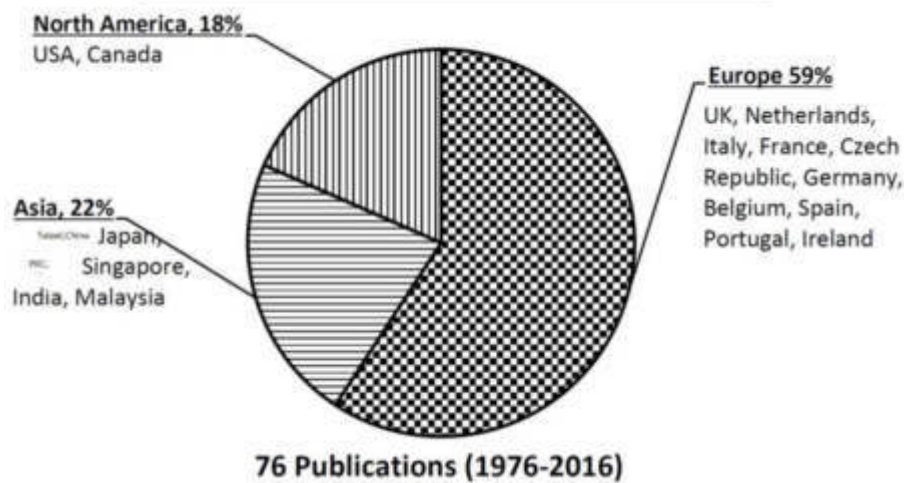


Figure 1. Global distribution of publications on MIBA in concrete applications<sup>4</sup>

<sup>3</sup> Lam, C. H., Ip, A. W., Barford, J. P., & McKay, G. (2010). Use of Incineration MSW Ash: A Review. *Sustainability*, 1943-1968.

<sup>4</sup> Lynn, C., Dhir, R., & Ghataora, G. (2016). Municipal incinerated bottom ash characteristics and potential for use as aggregate in concrete. *Construction and Building Materials*, 504-517.

There are two main literature that had collected the fragmented studies done and reviewed them in a single work. The work of Lam, Ip, Barford, and McKay<sup>5</sup> categorized the utilization of IBA and fly ash into seven different applications; cement and concrete production, road construction, glasses and ceramics, agriculture, stabilizing agent, adsorbents and zeolite production. Incinerator fly ash is utilized as a stabilizing agent and in zeolite production. Since the scope of this TA is only IBA, applications for incinerator fly ash will not be discussed. Lynn, Dhir, & Ghataora, (2016) had reviewed 76 publications and focused the work on the reuse of IBA as aggregates in concrete applications<sup>6</sup>. Additionally, there is literature that support the utilization of IBA in land reclamation works in Singapore and Japan. The utilization of r-IBA as raw materials in glass, ceramic and blasting grit production is supported by studies<sup>5</sup>. However, there is no glass and ceramic production industry in Maldives and hence reuse of r-IBA for glass and ceramic production is not a practical application in Maldives.

Existing literature was reviewed and the following utilizations of r-IBA are evaluated to determine their potential in Maldives.

- i. Cement manufacturing
- ii. Concrete production
- iii. Masonry and pavement block production
- iv. Road construction
- v. Land reclamation
- vi. Coastal protection systems

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<sup>5</sup> Lam, C. H., Ip, A. W., Barford, J. P., & McKay, G. (2010). Use of Incineration MSW Ash: A Review. *Sustainability*, 1943-1968.

<sup>6</sup> Lynn, C., Dhir, R., & Ghataora, G. (2016). Municipal incinerated bottom ash characteristics and potential for use as aggregate in concrete. *Construction and Building Materials*, 504-517.

## 2.1. Cement Manufacturing

Calcareous materials like limestone and argillaceous materials like shale and clay are raw materials for cement production. These raw materials provide the reactants CaO, SiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub> and Al<sub>2</sub>O<sub>3</sub> required for cement production. These oxides are also present in IBA (Table 3). Hence, IBA can be used as a substitute raw material in cement manufacturing<sup>7</sup>. However, corrosion of the cement kiln due to chloride ions and heavy metals in IBA can limit its reusability in cement manufacturing. Treatment of IBA is essential to reduce the effects of chloride and heavy metals. Pan, Huang, Kuo, and Lin used the washing treatment process and the cement produced conformed to the Chinese National Standards of Type II cement <sup>8</sup>, suggesting the technical feasibility of utilizing treated IBA in cement production.

Maldives does not have a cement manufacturing industry. However, exporting the treated IBA to a cement manufacturer in an Asia is a possible option that could be explored. The requirements of Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal should be met for exporting the treated IBA.

## 2.2. Concrete Production

Treated IBA can be used as coarse aggregates and fine aggregates in concrete. The physical characteristics of IBA is an important factor that defines the properties of concrete made using IBA.

One of the physical properties of IBA that influence other physical properties of IBA and consequently the properties of concrete made with treated IBA is porosity. The porosity of IBA is higher than that of natural aggregates. Consequently, the absorption of IBA is

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<sup>7</sup> Lam, C. H., Ip, A. W., Barford, J. P., & McKay, G. (2010). Use of Incineration MSW Ash: A Review. *Sustainability*, 1943-1968.

<sup>8</sup> Pan, J. R., Huang, C., Kuo, J.-J., & Lin, S.-H. (2008). Recycling MSWI bottom and fly ash as raw materials for Portland cement. *Waste Management*, 1113-1118.

higher. An averaged value of the water absorption is 9.7% and ranges over 2.4 – 15.0 %<sup>9</sup>. The porosity and absorption influence the bond between the cement paste and IBA. Aggregates are used as a fill material for concrete and can take up three quarters of the volume of concrete. Hence the high porosity and absorption of IBA used in concrete increases the porosity and absorption of the hardened concrete.

The high porosity of IBA contributes to the low specific gravity of IBA. The average specific density of IBA is 2.32<sup>8</sup>. This is comparably less than the typical specific density of natural aggregates. The specific density of natural aggregates is between 2.6 and 2.7<sup>10</sup>. The specific density depends on the treatment process as well.

Table 4 summarizes Lynn, Dhir, and Ghataora's review of the 76 publications focusing on the reuse of IBA in concrete<sup>9</sup>. As observed from Table 4, the performance of concrete produced with IBA is lower than concrete with natural aggregates. The workability is reduced due to high absorption of IBA. The compressive strength and tensile strength is lower. The current construction practices are very traditional in Maldives. It is a common practice to add water on site to the concrete mix to improve the workability. However, uncontrolled addition of water can further reduce the compressive strength of concrete. A reduction in compressive strength is translated to a reduction in flexural tensile strength of concrete. Concrete with lower tensile strength is susceptible to early cracking. Furthermore, the presence of chloride ions in IBA with close proximity to the reinforcing steel increases the risk of reduced durability. The existing literature lack a focus on long-term durability.

The practical utilization of IBA in concrete applications is in the early stages<sup>9</sup>. Due to the poor performance of concrete with IBA as aggregates, unreliable workmanship and the associated risks and lack of long-term durability studies, the reuse of r-IBA in structural concrete applications in Maldives is not recommended.

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<sup>9</sup> Lynn, C., Dhir, R., & Ghataora, G. (2016). Municipal incinerated bottom ash characteristics and potential for use as aggregate in concrete. *Construction and Building Materials*, 504-517.

<sup>10</sup> Neville, A. M., & Brooks, J. J. (2010). *Concrete Technology*. Harlow: Pearson Education Limited.



Table 4. Effect on properties of concrete when r-IBA replaced natural aggregates

Property of Concrete	Change in property when aggregates replaced with IBA
Slump	Reduces
Cohesiveness	Remains cohesive
Segregation	No segregation
Bleeding	Bleeding reduces
Setting time	Increases
Compressive strength	Decreases
Tensile strength	Decreases
Elastic modulus	Decreases
Shrinkage	Increases
Creep	No significant change
Absorption	Increases
Chloride corrosion	Higher risk
Sulfate attack	No expansion due to sulfate attack
Carbonation resistance	Carbonation depth decreases

### 2.3. Masonry and Pavement Block Production

Concrete masonry blocks are extensively used in the construction industry. They are mainly used in non-load bearing masonry walls. Concrete masonry blocks used for majority of projects are locally produced. Sand quarried from lagoons are used as fine aggregates in block production. Use of local quarried sand is not a sustainable use of natural resources. Furthermore, the chloride content of the blocks due to the sand quarried from the sea floor can be high. However, supply of local quarried sand is limited and hence some large-scale block producers depend on imported sand.

The unit weight of masonry blocks with IBA is less than normal masonry blocks. This is due to the lower specific gravity of IBA. Since, the absorption of IBA is higher, the water demand during production is higher. The compressive strength of masonry and pavement

blocks with IBA is lower. However, since the strength demanded from masonry products is lower, the target strength is achieved in non-load bearing, load bearing, paving and interlocking blocks<sup>11</sup>. Fire resistance performance is comparable to the products made with natural aggregates and no adverse shrinkage cracking is observed when IBA is used as a fine aggregate. Additionally, concrete paving blocks made with IBA exhibited excellent slip resistance and can be classified as having low potential for slip as per BS EN 1333<sup>11</sup>.

Furthermore, full-scale operations had been conducted with masonry and pavement blocks made with IBA. There has been reports of spalling in projects carried out in the nineties. This is due to corrosion of the ferrous metal in IBA. However, with advanced treatment methods, the problem of spalling can be easily resolved. Most of the full-scale operations can be deemed successful<sup>11</sup>.

Quality of masonry and pavement blocks made with IBA as aggregates is slightly inferior to similar products with natural aggregates. However, the requirements of masonry and pavement products is less than those of structural concrete. Therefore, review of literature suggests that the performance of the products with IBA can be of acceptable standards<sup>11</sup>.

Concrete masonry blocks are extensively used in non-structural applications in Maldives and the reuse of r-IBA is a more sustainable use of materials than the current use of chloride rich quarried sand. Therefore, utilization of r-IBA in concrete masonry and pavement block production has high potential in Maldives.

## 2.4. Road Construction

Reuse of IBA in road construction is one of the applications where IBA is utilized most in Europe. The research of IBA utilization in road construction is well progressed and

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<sup>11</sup> Lynn, C., Dhir, R., & Ghataora, G. (2016). Municipal incinerated bottom ash characteristics and potential for use as aggregate in concrete. *Construction and Building Materials*, 504-517.

translated to field applications in countries like Belgium, Denmark, Germany and Netherlands<sup>12</sup>.

A typical road cross-section has the wearing course as top surface, the base course and then the sub-base layer. Interlocking concrete blocks has been mostly used for the wearing course layer in Maldives though the use of bituminous asphalt in new roads is increasing. The sub-base layer is constructed on the subgrade, compacted natural soil as the foundation for the road. The base course and the sub-base is constructed with graded aggregates. Treated IBA can replace the natural aggregates used for the base course and sub-base layer<sup>12</sup>. IBA can be used in unbound form, hydraulically bound or bitumen bound form.

Hydraulically bound IBA is often stabilized with cement or lime when used in base layers. Singh and Kumar studied the geotechnical properties of MSWI ash mixed with cement<sup>13</sup>. The particle sizes of the MSWI ash used by Singh, et.al ranges from 75 microns to 1.18mm and suggests the study used IBA. Singh, et.al found that the California Bearing Ratio (CBR) value, Unconfined Compressive Strength (UCS) and Split Tensile Strength (STS) of MSWI increases when mixed with cement and suggests the MSWI mixed with cement can be used as an alternative material for road bases. However, the study of Singh, et.al did not focus on the environmental impacts of MSWI when used in ground works. A similar study in People's Republic of China also indicate the IBA mixed with cement satisfy the strength requirements for use on base and sub-base layers of heavy highway traffic<sup>14</sup>. However, the use of cement can increase the cost of the road construction.

Lynn, Ghataora, and Dhir had done an evaluation of the global experimental data on the use of IBA in road construction<sup>15</sup>. The analysis confirms that unbound IBA meets the grading requirement after standard processing and can be compacted well with

<sup>12</sup> Ip, A. W., Barford, J. P., & McKay, G. (2010). Use of Incineration MSW Ash: A Review. *Sustainability*,

Lam, G.,  
1998. Cement. *Journal of Rock Mechanics and Geotechnical Engineering*, 370-375.

<sup>13</sup> Singh, S. K., & Kumar, A. (2017). Geo-environmental application of municipal solid waste incinerator ash stabilized  
Waste Incineration Used in Roadbase. *Advances in Civil Engineering*.

<sup>14</sup> Lynn, C. J., Ghataora, G. S., & Dhir, R. K. (2017). Municipal incinerated bottom ash (MIBA) characteristics and  
potential for use in road pavements. *International Journal of Pavement Research and Technology*, 185-201.

performance similar to that of sandy gravel. Unbound IBA meets the requirements of a material suitable for sub-base and is widely used in Denmark and Netherlands. IBA bound with a stabilizing agent like cement or lime can be processed to satisfy the requirements of a sub-base or base-course material by adjusting the binder content. Laboratory results of hydraulically bound IBA shows low density and elastic modulus. However, performance measured in full-scale projects suggests hydraulically bound IBA can be satisfactorily used despite lower laboratory results. Additionally, there are full-scale projects that provides evidence that low contents of IBA can be used to form bituminous bound bases and wearing course layers.

Environmental impact of the IBA used in road construction is as important as the mechanical properties. Lynn, Ghataora, and Dhir, had done an evaluation of global literature published on the environmental impacts of IBA as a road construction material<sup>16</sup>. Lynn, Ghataora, and Dhir's analysis concluded that IBA in unbound form poses the highest risk of leaching heavy metals and contaminants to the ground water but the risk could be minimized by treatment prior to utilization<sup>16</sup>. However, IBA bound with cement or bitumen restricts the leaching and the leachate concentrations were below the utilization and water quality limits. Therefore, the environmental impacts of the reuse of IBA in road construction does not limit its utilization.

Roads in most islands in Maldives are not leveled and paved. Only the capital city Male', Hulhumale' and Villimale' have all the roads paved, either with interlocking concrete paving blocks or asphalt. Some of the larger islands like Laamu Atoll Gan, Seenu Atoll Gan and Fuvahmulah have the main road paved with asphalt. The islands without paved roads create an opportunity for the reuse of IBA. Currently, there are eight road development projects in eight different islands in the tender phase. Similarly, future airport developments are potential applications for the utilization of IBA. However, according to Regional Airports there are no long-term development plans and the recent increase in new airports was politically rationalized.

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<sup>16</sup> Lynn, C. J., Ghataora, G. S., & Dhir, R. K. (2018). Environmental impacts of MIBA in geotechnics and road applications. *Environmental Geotechnics*, 31-55.

## 2.5. Land Reclamation

The utilization of IBA in land reclamation is published in literature. However, this application is only limited to countries like Singapore and Japan where land is scarce.

In Singapore, IBA and marine clay originating from excavation works are solid wastes. It was proposed to use a mixture of stabilized IBA and marine clay as a fill material for land reclamation<sup>17</sup>. The mechanical properties and environmental impact assessments were tested. The literature concluded the reuse of IBA and marine clay matrix is feasible from both geotechnical and environmental perspective<sup>18</sup>. However, it should be highlighted that the polymer-based cementitious stabilizer Chemlink SS-331H is a proprietary product.

In Japan, approximately 78% of MSW that is disposed in coastal landfill sites is MSWI ash and 20% of the MSW is disposed in coastal landfills, mostly located in port areas of Tokyo, Nagoya and Osaka<sup>19</sup>. Various studies had showed the geotechnical properties of the landfills improved. Nguyen, Inui, Ikeda, and Katsumi had taken waste mixture samples just before being disposed at coastal landfill site in Osaka Bay area and studied the time dependent geotechnical properties of waste mixtures submerged in landfill leachate or seawater. The composition of the waste mixture was approximately 50% of MSWI ash, 30% of gravel materials like slags, and 20% surplus soil. The study concluded that the shear strength increases and deformation decreases with time and hence waste mixture layers studied could be used as foundation layers with adequate bearing capacity after closure of the coastal landfill sites<sup>20</sup>.

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<sup>17</sup> Guo, L., & Wu, D. -Q. (2018). Study of leaching scenarios for the application of incineration bottom ash and marine clay for land reclamation. *Sustainable Environment Research*, 396-402.

<sup>18</sup> Guo, L., & Wu, D.-Q. (2017). Study of recycling Singapore solid waste as land reclamation filling material. *Sustainable Environment Research*, 1-6.

<sup>19</sup> Nguyen, L. C., Inui, T., Ikeda, K., & Katsumi, T. (2015). Aging effects on the mechanical property of waste mixture in coastal landfill sites. *Soils and Foundations*, 1441-1453.

<sup>20</sup> Nguyen, L. C., Inui, T., Ikeda, K., & Katsumi, T. (2015). Aging effects on the mechanical property of waste mixture in coastal landfill sites. *Soils and Foundations*, 1441-1453.

Land reclamation activities had rapidly increased over the last five years with several islands being reclaimed as a solution to land scarcity. Sand for reclamation is quarried from borrow sites in lagoons.

The reuse of IBA as a landfill material can be a potential alternative to the use of natural sand dredged from the lagoons. However, large quantities of sediments are required for some land reclamation projects and IBA generated might not be adequate for a single project. However, there is the opportunity for blending stabilized IBA with natural sediments during land reclamation. Further research is required to support the reuse of IBA as a blended material in land reclamation.

The duration and frequency of land reclamation is different to IBA generation. Frequency of reclamation projects are discrete and the duration is relatively shorter compared to the large volume of sediments mobilized. However, IBA generation is more continuous and subjected to maturation period as well. If r-IBA is planned to use, large volumes of IBA might be required to be stored for a long period of time. Therefore, even though the reuse of IBA in land reclamation or land filling might be a technically potential application, there might be operational limitations.

## 2.6. Coastal protection systems

Maldives being a coastal country, reuse of IBA in coastal protection systems can be a potential application. However, literature review revealed that the reuse of IBA in coastal protection systems is an area where there is a gap in literature.

One of the applications for reuse of IBA can be in concrete for quay walls and jetties. However, these are structural applications and due to inadequate performance of concrete with IBA, reuse of IBA in construction of quay walls and jetties is not recommended.

Crushed rocks are commonly used as revetments and breakwaters in Maldives. Alternatively, tetrapods made from concrete can be used and since it is not a structural application IBA can be used as aggregates in tetrapod production. However, durability is a concern and require further research to fully validate this application. A solution to ensure durability can be to design a tetrapod with an inner core made of compacted and hydraulically bound IBA and a more durable shell made of concrete with natural aggregates.

An alternative to tetrapod could be geo-bags. Currently sand, often sourced close to the project site is used as a fill material. Since, IBA can be used in road base layers with acceptable leachate performances, stabilized IBA can potentially be used as a fill material for geo-bags. However, this application is subjected to further research and the intermittent frequency of coastal protection projections should be considered.

### 3. Suitable Applications for Construction Demolition Waste

Recycling of CDW is practiced widely in some countries. In some countries, approximately 90% of the CDW are recycled<sup>21</sup>. BS 8500 (2002) defines two types of aggregates; Recycled Concrete Aggregates (RCA) and Recycled Aggregates (RC). RCA should have minimum 95% crushed concrete and RC is defined as 100% masonry based crushed aggregates. The quality of both types of CDW aggregates is poor compared to natural aggregates. This is primarily due to the mortar adhered to the natural aggregates. The production method influence the quality and composition of CDW aggregates.

Acceptability of CDW aggregates depends on the properties of fresh and hardened concrete incorporating CDW aggregates more than the properties of CDW aggregates itself. Table 5 summarizes the properties of fresh and hardened concrete with CDW aggregates compared to concrete with natural aggregates. As observed from Table 5 the properties of concrete with CDW aggregates is lower than conventional concrete. However, Brito and Saikia had proved that when the partial replacement ratio is less than 30%, the properties of CDW incorporated concrete is comparable to that of conventional concrete and both normal and high-strength concrete could be prepared using CDW aggregates<sup>21</sup>. Furthermore, Brito and Saikia claim that properties of concrete with CDW aggregates could be improved through the mix design<sup>21</sup>.

Compared to IBA, CDW aggregates has more potential for reuse in structural concrete in Maldives. The majority of buildings have a concrete frame as the structural form and quay walls and jetties are made of concrete as well. RCA can be used to produce structural concrete and RC can be incorporated into concrete masonry block making. However, since construction of most residential buildings follow traditional methods and concrete is mostly batched volumetrically on site, the risk is high for the reuse of CDW as aggregates in concrete of residential buildings. The risk can be reduced when concrete mixes are designed and tested and batched using a batching plant. Currently, there are very few

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<sup>21</sup> Brito, J. d., & Saikia, N. (2013). *Recycled Aggregate: Use of Industrial, Construction and Demolition Waste*. London: Springer



ready-mix concrete producers. Additionally, many old buildings that are being demolished had used sand quarried from lagoons and coral fragments as aggregates. Consequently, the concrete is rich in chloride ions and had caused severe corrosion in old buildings and is one of the main reasons for demolition. Hence, reuse of aggregates made from old buildings constructed using coral fragments would lead to corrosion and would not be accepted by consultants in the industry. Therefore, CDW aggregates should be used in Maldives with caution.

*Table 5. Effect on properties of concrete when CDW replaced natural aggregates*

<b>Property of Concrete</b>	<b>Change in property when aggregates replaced with IBA</b>
Workability	Reduces
Density	Lower
Air-content	Increases
Bleeding	Reduces
Compressive strength	Lower
Split tensile strength	Lower
Flexural strength	Lower
Modulus of Elasticity	Lower
Creep	Increases
Drying shrinkage	Increases
Water absorption	Increases
Chloride permeability	Increases

#### 4. Review of national standards and required material characteristics

Construction Act of 2017 (Act No. 4/2017) and Environment Protection and Preservation Act of 1993 (Act No. 4/93) are the two legislations that could be related to IBA and CDW.

Environment Protection and Preservation Act confers power on a ministry responsible for environment to formulate policies and regulations. Environment Protection and Preservation Act briefly states in clause 7 and 8 that waste, oil and toxic material should be disposed in areas designated by the government, should not damage the environment and if waste burning is adopted it should not harm human health. Ministry of Environment has formulated a National Solid Waste Management Policy in 2008 and revised it in 2015. Ministry of Environment has also issued a Waste Management Regulation (Regulation No. 2013/R-58). Consultation with relevant staff of Ministry of Environment revealed that there are no specific environmental national standards related to IBA and CDW. However, clause 3.1 of Annex 1 of Waste Management Regulation states that International standards should be referred to in cases where there are no national standards. There are no universal standards. Standards differ in each country and reflect factors unique to the specific country. Table 7 shows European Union's minimum waste acceptance criteria for the different categories of waste<sup>22</sup>.

Construction Act sets the general principles and confers the power on the ministry to issue regulations to control production, import, testing and use of construction materials. However, currently there are no regulations formulated. Material testing and ensuring compliance to specifications is not widely practiced in Maldives. In circumstance where testing is conducted, only the grading of aggregates and compressive strength of concrete and sometimes masonry blocks is tested. However, when used in non-load bearing walls compressive strength of blocks is not critical. There is no specific standard followed by all the professionals in the construction industry. Some of the standards

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<sup>22</sup> Liu, A., Lin, W. Y., & Wang, J. Y. (2015). A review of municipal solid waste environmental standards with a focus on incinerator residues. *International Journal of Sustainable Built Environment*, 165–188.

followed include Australian Standards, British Standards, Indian Standards and standards of American Society for Testing and Materials (ASTM). There are no specific national standards on IBA or CDW. The grading requirements often followed in Maldives is given in Table 6.

*Table 6. BS 882:1992 grading requirement for fine aggregates*

<b>Sieve size</b>	<b>Percentage by mass passing sieve</b>
10 mm	100
5 mm	89-100
2.36 mm	60-100
1.18 mm	30-100
600 $\mu\text{m}$	15-100
300 $\mu\text{m}$	5-70
150 $\mu\text{m}$	0-150*

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



## 5. Stakeholder Product Acceptance and Product Requirements

Stakeholders were identified and interviewed individually. Maldives National Association of Construction Industry (MNACI), contractors, masonry block producers and consultants were interviewed. There were challenges in arranging interviews as some were not available for the interview. Twelve participants were interviewed. Three main questions were asked after a brief explanation of the project, potential applications of r-IBA and processed CDW, and the characteristics and performance of IBA and CDW in various applications. Figure 2 shows the results of the interview. The general response was good with 75% viewing the reuse of IBA and CDW as a good initiative and 65% were willing to buy and use the product. However, almost all the participants imposed a condition on the willingness to buy or use the product. The willingness of potential stakeholders was subjected to the compliance with standard requirements. Some of the participants (25%) view that if the performance of the product made using IBA or CDW satisfy the standards and is similar to the performance of product made with natural aggregates the price of IBA or CDW could be similar to that of natural aggregates. However, 35% of the participants believe the price of IBA or CDW should be 40 – 60% of the price of natural aggregates. A quarter of the participants did not respond to the price question.

It was observed that most of the contractors believe the use of IBA or CDW depend on the approval of consultants and did not suggest any product requirements, other than strength. However, consultants had given additional requirements such as absorption percentage and grading. In general, all participants believed that IBA and CDW aggregates should conform to international standards.

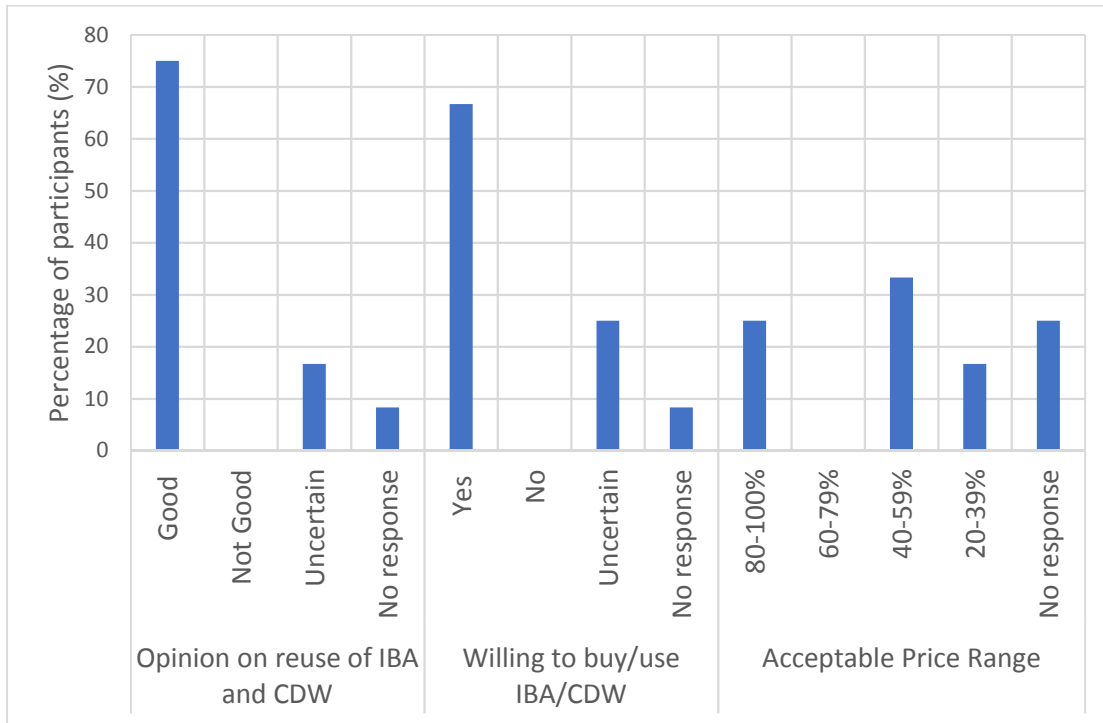


Figure 2. Results of stakeholder consultations on the reuse of IBA and CDW

## 6. Cost of similar construction materials and current demand

IBA and CDW are substitute products for coarse and fine aggregates used in construction industry. Hence, the demand for IBA and CDW products are expected to be similar to the demand for aggregates. Aggregates is one of the major materials used in construction. The current demand for aggregates should be reflected by the demand in the construction industry. Hence, the trends in the construction industry was first analyzed. The gauges used to determine the current demand is the construction related imports, loans to construction industry, and the building permits issued.

The construction industry is performing progressively as indicated by the gauges. In the first quarter of year 2018, loans for construction of residential housing, guest houses and new resorts observed an annual increase of 19%. During the first half of year 2018 the annual growth in credit to construction industry was registered as 23% and the growth maintained in the third quarter.

Construction related imports is another indicator of the demand in construction industry. The construction related imports increased 51% during the first half of the year 2018 and during the third quarter the growth was 39%. Statistics provided by Maldives Customs Service shows that about 792,800 tons of coarse aggregates and 495,300 tons of fine aggregates (sand) were imported to Maldives in year 2018 (Table 9). The value of imports of aggregate amounts to USD 48.9 million.

The demand for masonry blocks was captured through interviews. Maldives National Association of Construction Industry (MNACI), one of the largest contractors in Maldives and one of the current major suppliers of concrete masonry blocks to the Greater Male' Region were interviewed. Attempts to access archived information of Maldives Road Development Corporation was not successful. Maldives Road Development Corporation, before its recent liquidation, used to be one of the largest concrete masonry and pavement block production facility in the country. Currently, there are several block producers. Majority of block production facilities operate on a small scale and production is limited to approximately 1000 to 3500 blocks per day. Some of the large contractors operate their own production facilities and produce quantities sufficient for their own projects. Small scale block producers use local sand while in large-scale production, imported manufactured sand is used but local sand is also used to a limited extent.

The composition of the masonry block varies. Some production facilities had adopted a volumetric ratio of 1 units of cement to 5 or 6 units of sand while some production facilities can increase the sand content. Hollow rectangular blocks and solid rectangular blocks are manufactured in Maldives. The width of the blocks currently produced in the market is four inches.

The market rate of unit cost of local sand is approximately USD/kg 0.015. The typical market rate of four inch hollow blocks produced using local sand is USD 0.39 per block, though USD 0.34 per block is available from some of the large-scale producers. The unit price of four inch solid blocks produced using local sand is US 0.52. However, unit price of four-inch masonry hollow blocks produced using imported manufactured sand is USD

0.97. The average production rate of one of the major suppliers interviewed is 15,000 blocks per day. Considering the known masonry block producers in Male' and Hulhumale' and their observed production, it is estimated that approximately 83,000 blocks are produced per day in Male' and Hulhumale'. Estimating 3.5 kg of sand is required per block, production at this rate requires approximately 291 tpd of sand in Male' and Hulhumale'. Adopting 20% as the optimum aggregate replacement level<sup>23</sup>, it is estimated 58 tpd of r-IBA are required. The estimated IBA generation of 100 – 125 tpd is more than the quantity required as of year 2019. The demand for r-IBA could be increased through means of government controls on the use of local sand quarried from lagoons.

The current CDW generation is 530 tpd. The proportion that could be recycled and reused is 482 tpd<sup>24</sup>. However, the CDW processing facility proposed to be implemented has a capacity of 200 tpd. The composition of the CDW (Table 8) shows 42.6% of CDW arriving at Male' waste transfer station is concrete and 41% is sand and soil, and 8.1% is rock and gravel resulting from excavation<sup>23</sup>. It is assumed that sand and soil from excavation works will be reused for backfill and landscape works and thus is excluded from the scope of the TA. Therefore, the recycled concrete yield of the processing facility operating at maximum capacity can be estimated as 85 tpd (42.6% of CDW). However, to be conservative for demand estimation purposes, the yield of recycled aggregates is assumed to be same as 200 tpd, the maximum capacity of the processing plant.

There is no data in the feasibility study<sup>23</sup> that suggests concrete and masonry walls are identified separately. On the contrary it seems structural concrete and masonry walls are identified as a single group of concrete. The properties of aggregates derived from structural concrete and concrete masonry walls differ significantly and would influence the potential application for reuse of CDW and the corresponding demand. Additionally, many old buildings that are being demolished had used sand quarried from lagoons or

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<sup>23</sup> Lynn, C., Dhir, R., & Ghataora, G. (2016). Municipal incinerated bottom ash characteristics and potential for use as aggregate in concrete. *Construction and Building Materials*, 504-517.

<sup>24</sup> Water Solutions and Kocks Ingenieure. (2018). *Feasibility Study for an Integrated Solid Waste Management System for Zone III and Preparation of Engineering Design of the Regional Waste Management Facility at Thilafushi*.



beaches and coral fragments as aggregates. Consequently, the concrete is rich in chloride and had caused severe corrosion and cracking in old buildings. One of the main reasons for demolition is structural damage due to corrosion. Reuse of aggregates made from old buildings constructed using coral fragments would lead to corrosion. Given the uncertainty, it is recommended the concrete processed at the CDW processing plant to be crushed and used as sand for concrete masonry block making. Therefore, it can be assumed that 200 tpd of sand would be generated as recycled concrete.

Approximately 291 tpd of sand is required for block production in Male' and Hulhumale'. The current demand for sand (fine aggregates) in block production is less than the generation of 200 tpd of recycled aggregates and 100 – 125 tpd IBA, out of which 58 tpd can be used for replacement of sand.

Table 8. Estimated composition by weight of CDW<sup>25</sup>

### Estimated Composition by Weight for All Loads

<b>Paper</b>	<b>0.5%</b>		<b>Roofing</b>	<b>0.0%</b>	
Unwaxed OCC		0.5%	Roofing		0.0%
RC Paper		0.0%	RC Roofing		0.0%
<b>Plastic</b>	<b>0.5%</b>		<b>Insulation</b>	<b>0.0%</b>	
Non-bag Film		0.5%	Insulation		0.0%
Polystyrene Packaging		0.0%	RC Insulation		0.0%
Rigid Plastic		0.0%			
RC Plastic		0.0%	<b>Wood</b>	<b>7.1%</b>	
<b>Metal</b>	<b>0.2%</b>		Clean Recyclable Lumber, Pallets, Crates		7.1%
Major Appliances		0.0%	Other Untreated & Recyclable Wood		0.0%
HVAC Ducting		0.0%	Painted, Stained, Treated Wood		0.0%
Other Ferrous & Non-Ferrous		0.0%	RC Wood		0.0%
RC Metal		0.2%	<b>Gypsum</b>	<b>0.0%</b>	
<b>Organic</b>	<b>0.0%</b>		Clean Gypsum Board		0.0%
Prunings, Trimmings, Branches, Stumps		0.0%	Painted Gypsum Board		0.0%
RC Organic		0.0%	RC Gypsum		0.0%
<b>Carpet</b>	<b>0.0%</b>		<b>Misc. C&amp;D</b>	<b>0.0%</b>	
Carpet		0.0%	<b>Glass</b>	<b>0.0%</b>	
Carpet Padding		0.0%	<b>Electronics</b>	<b>0.0%</b>	
RC Carpet		0.0%	<b>HHW</b>	<b>0.0%</b>	
<b>Aggregates &amp; Dirt</b>	<b>91.8%</b>		<b>Special</b>	<b>0.0%</b>	
Dirt, Sand, Soil		41.0%	<b>Mixed Residue</b>	<b>0.0%</b>	
Concrete		42.6%			
Asphalt Paving		0.0%	<b>TOTAL</b>	<b>100.0%</b>	
Brick, Ceramic, Porcelain		0.0%			
Rock, Gravel		8.1%			
RC Aggregates & Dirt		0.0%			

<sup>25</sup> Water Solutions and Kocks Ingenieure. (2018). *Feasibility Study for an Integrated Solid Waste Management System for Zone III and Preparation of Engineering Design of the Regional Waste Management Facility at Thilafushi.*

## 7. Forecasted demand

The long-term demand is captured using the same three gauges; the construction related imports, loans to construction industry, and the building permits issued. Historic data was obtained and analyzed to see long-term trends. Future projections were done based on historic data and the current situation of the Greater Male' region.

Statistics published by Maldives Monetary Authority shows rapid growth in construction-related imports over last five years<sup>25</sup> (Figure 3). However, a sudden decline in imports was observed in year 2009. This is because of the Global Financial Crisis in year 2009. Despite global recovery from the financial crisis, significant growth in years 2011 to 2012 was not observed because of the restrictions imposed by India on imports of aggregates. Prior to year 2009, construction industry had been experiencing rapid growth for five to six years. The growth in the construction industry since year 2013 is due to numerous public sector investment programme (PSIP) infrastructure projects, private sector investment in real-estate and expansion in tourism sector. As observed from Figure 3, consumption of construction materials is increasingly observed in private and tourism sector. This suggests the growth in resort development and residential property construction.

Loans to construction industry over recent years exhibit industry growth and support the trend observed from construction-related imports. Credit to tourism sector and construction industry has been increasing since second quarter of year 2015 (Figure 4). Growth in tourism sector is mainly due to lending for construction of guesthouses and new resort development. The growth in lending to the construction industry is due to lending for residential and housing purposes<sup>26</sup>.

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<sup>26</sup> Maldives Monetary Authority. (2018). *Annual Report 2017*

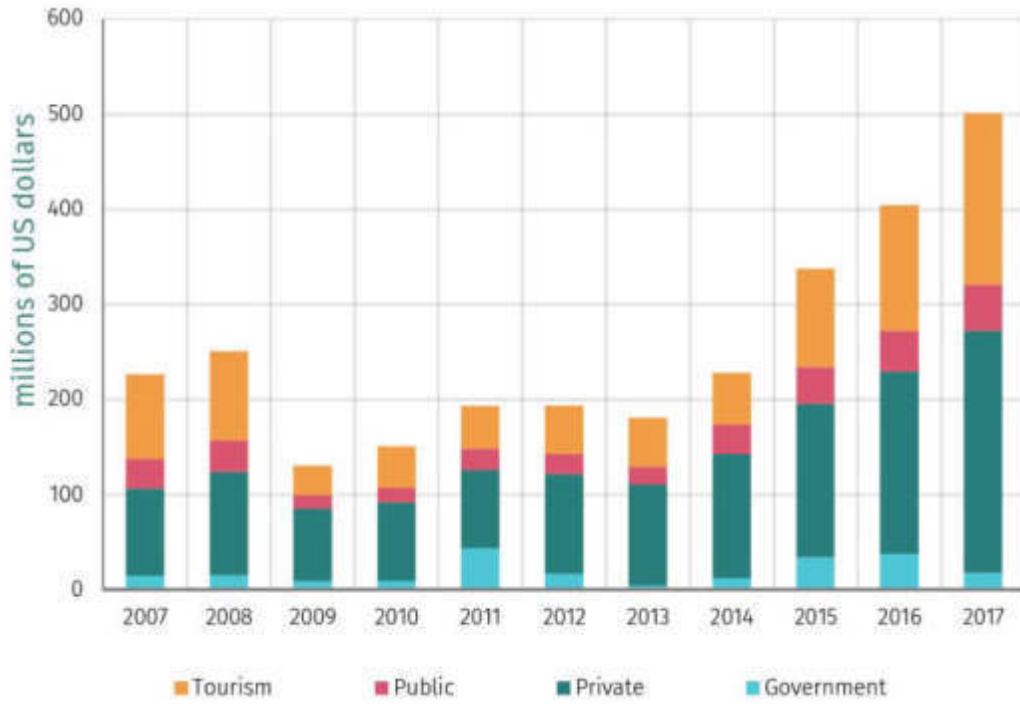


Figure 3. Construction related imports by sector<sup>27</sup>



Figure 4. Loans and Advances to the Private Sector by Major Sectors<sup>27</sup>

<sup>27</sup> Maldives Monetary Authority. (2018). Annual Report 2017

Building permits is a key indicator of activity in construction industry. There are two types of permits; a permit given to commence construction and a permit given to use the building following completion of construction. Permits are well documented in Male' and Hulhumale'. Building permits available for the last fifteen years is collected and historic trends analyzed (Figure 5). Construction industry prior to year 2009 was a very robust industry with construction permits more than 500 permits annually. The industry was experiencing double digit growth rates<sup>28</sup>. However, the industry came to a halt in year 2009 due to the Global Financial Crisis and it is estimated to have contracted sharply by 16% in 2009 due to delays in major resort development projects owing to declines in capital inflows. Growth for the five years following year 2009 may have been affected by political instability and restrictions in availability of aggregates from India<sup>29</sup>. Since year 2013, with the increase in supply of aggregates, construction of residential buildings has been rapidly increasing and construction activity is similar to the trend observed before the financial crisis.

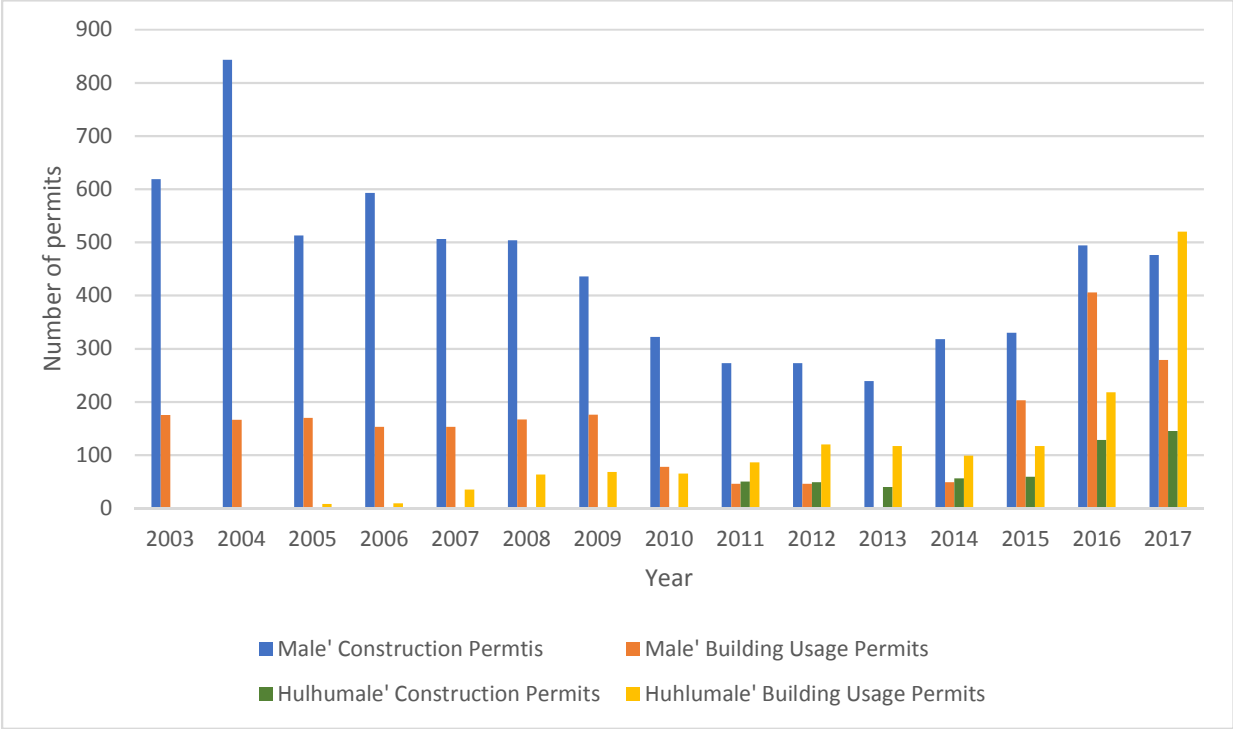


Figure 5. Building permits<sup>30</sup>

<sup>28</sup> Maldives Monetary Authority. (2010). *Annual Report 2009*.

<sup>29</sup> Maldives Monetary Authority. (2014). *Annual Report 2013*.

<sup>30</sup> National Bureau of Statistics, 2004 - 2017

Table 9. Imports of course aggregates and fine aggregates (sand)<sup>31</sup>

Year	Aggregates		Sand	
	Quantity (t)	CIF (MVR)	Quantity (t)	CIF (MVR)
2004	159,426	59,094,523	186,889	57,867,960
2005	191,518	76,128,976	245,979	86,542,799
2006	184,765	82,932,844	258,055	88,612,134
2007	355,762	186,032,748	432,665	200,161,633
2008	327,331	162,881,687	368,997	166,039,942
2009	184,180	86,776,242	165,230	63,140,895
2010	204,082	85,637,549	120,016	53,566,753
2011	267,540	136,810,147	153,877	88,147,309
2012	242,781	138,694,729	84,535	59,297,401
2013	180,492	147,359,782	133,699	105,190,451
2014	270,519	201,915,402	185,217	151,766,876
2015	536,523	344,320,685	226,981	155,857,347
2016	555,891	315,681,933	474,183	168,811,604
2017	803,326	425,625,230	330,156	177,082,708
2018	792,798	413,483,330	495,321	340,574,712

Historic data suggests that the construction industry has been a robust industry. The industry has potential growth due to the undeveloped reclaimed Gulhifalhu island and the recently reclaimed Hulhumale' phase 2. The relative annual growth rates of the last decade, (Figure 6) shows a positive growth. The exception is the year following Global Financial Crisis, where industry experienced a decline. The rate of growth is estimated by finding the average of the percentage growth of the three key indicators in years 2013 – 2017 (Table 10). Over the recent five years, the construction activity in Greater Male' Region has been restored close to the situation before the financial crisis. This is observed from the number of building permits in Figure 5. The average growth in construction related imports, credit to construction industry and construction permits is 22%, 26% and 17%, relatively. The average growth of these three key indicators is 22%.

<sup>31</sup> Maldives Customs Service (2018)

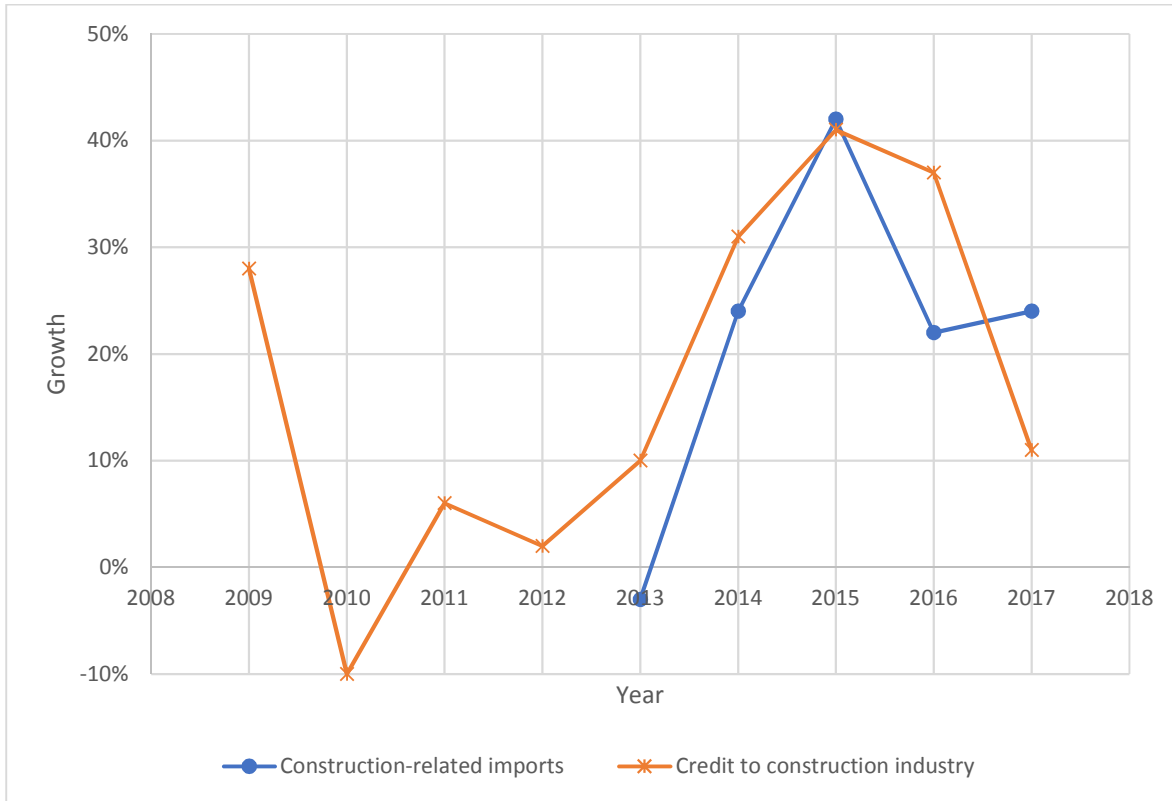


Figure 6. Growth of construction industry relative to preceding year

Table 10. Growth of key indicators of construction industry

Year	Construction-related imports	Credit to construction industry	Construction Permits	Building usage Permits
2017	24%	11%	0%	28%
2016	22%	37%	60%	95%
2015	42%	41%	4%	116%
2014	24%	31%	34%	26%
2013	-3%	10%	-13%	-30%
2012	-	2%	0%	26%
2011	-	6%	0%	-8%
2010	-	-10%	-26%	-41%
2009	-	28%	-13%	6%

Future total demand in aggregates were estimated based on historic import quantities. The data was obtained from Maldives Customs Services. Quantities of aggregates and sand (fine aggregates) imported to Maldives over last 15 years is shown in Figure 7. It is

believed the import quantity of sand obtained is only for river or natural sand and there might be quantities imported in various other names. The trend observed in aggregate imports mirrors the trend observed in the key indicators of the construction industry.



Figure 7. Imports of course aggregates and fine aggregates (sand) over 15 years <sup>32</sup>

Future demand projections are estimated based on historic values using exponential smoothing. Data since year 2011 is taken because Global Financial Crisis is an considered as an extreme and rare event and considering the two years following year 2009 would have affected the accuracy of the forecast. Figure 8 and Table 11 shows the demand forecast of aggregates in the industry for the next 15 years. Figure 9 and Table 12 shows the demand forecast of sand in the industry for the next 15 years. These are the total demand of the industry for aggregates and sand.

<sup>32</sup> Maldives Customs Service (2018)



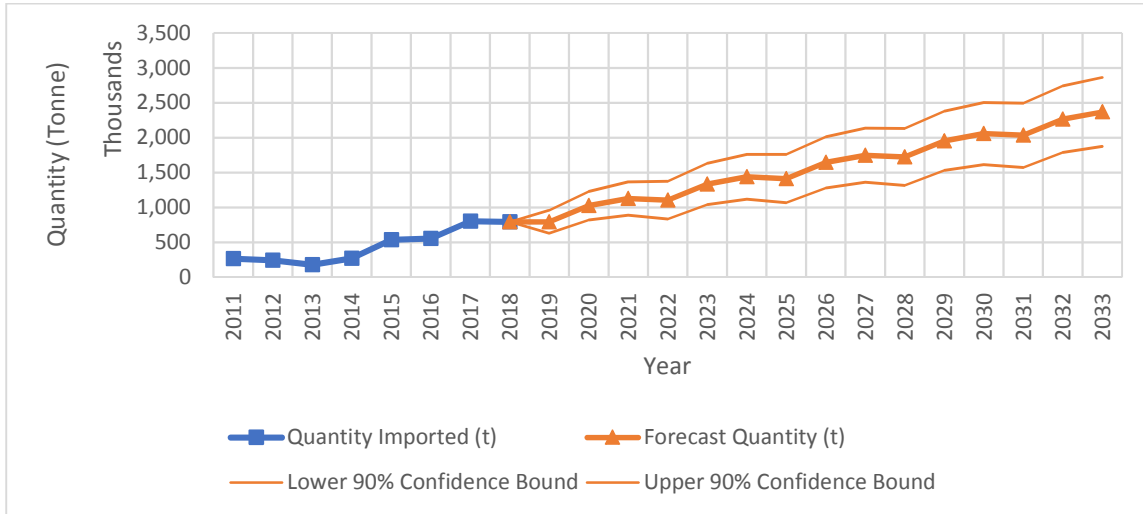


Figure 8. Forecast of course aggregates for 15 years (2018 - 2033)

Table 11. Forecast of course aggregates for 15 years (2018 - 2033)

Year	Quantity Imported (t)	Forecast Quantity (t)	Lower 90% Confidence Bound (t)	Upper 90% Confidence Bound (t)
2011	267,540			
2012	242,781			
2013	180,492			
2014	270,519			
2015	536,523			
2016	555,891			
2017	803,326			
2018	792,798	792,798	792,798	792,798
2019		794,590	630,542	958,638
2020		1,025,770	820,513	1,231,027
2021		1,128,784	889,223	1,368,346
2022		1,104,500	834,815	1,374,185
2023		1,335,679	1,038,913	1,632,446
2024		1,438,694	1,117,056	1,760,333
2025		1,414,410	1,069,571	1,759,249
2026		1,645,589	1,279,015	2,012,163
2027		1,748,604	1,361,461	2,135,747
2028		1,724,320	1,317,546	2,131,094
2029		1,955,499	1,529,999	2,380,999
2030		2,058,514	1,615,032	2,501,996
2031		2,034,230	1,573,378	2,495,082
2032		2,265,409	1,787,819	2,743,000
2033		2,368,424	1,874,620	2,862,227

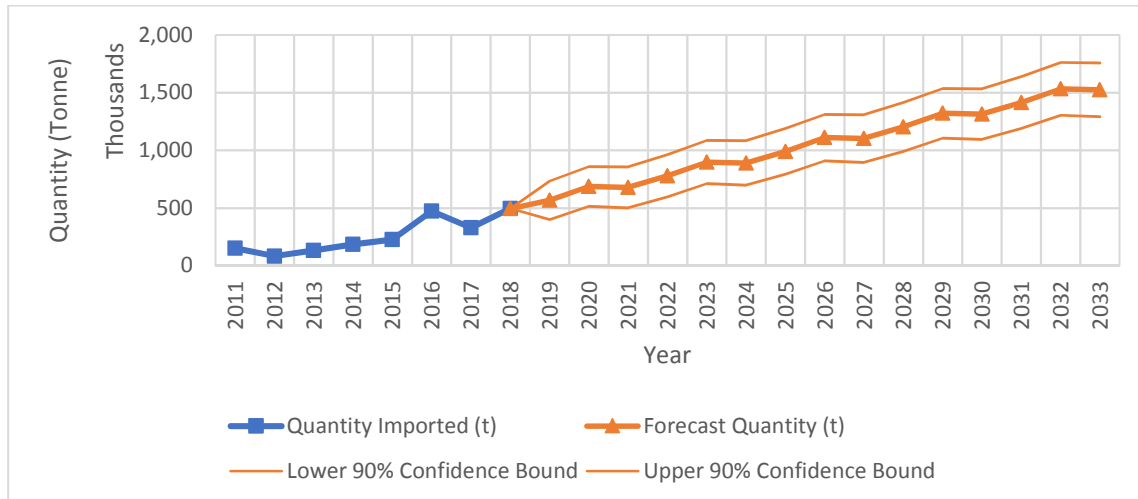


Figure 9. Forecast of fine aggregates (sand) for 15 years (2018 - 2033)

Table 12. Forecast of fine aggregates (sand) for 15 years (2018 - 2033)

Year	Quantity Imported (t)	Forecast Quantity (t)	Lower 90% Confidence Bound (t)	Upper 90% Confidence Bound (t)
2011	153,877			
2012	84,535			
2013	133,699			
2014	185,217			
2015	226,981			
2016	474,183			
2017	330,156			
2018	495,321	495,321	495,321	495,321
2019		568,631	401,394	735,869
2020		688,224	515,758	860,690
2021		680,146	502,565	857,726
2022		779,772	597,143	962,401
2023		899,364	711,822	1,086,906
2024		891,286	698,919	1,083,653
2025		990,912	793,766	1,188,059
2026		1,110,505	908,692	1,312,317
2027		1,102,427	896,018	1,308,835
2028		1,202,053	991,080	1,413,026
2029		1,321,645	1,106,204	1,537,086
2030		1,313,567	1,093,715	1,533,419
2031		1,413,193	1,188,952	1,637,434
2032		1,532,786	1,304,240	1,761,332
2033		1,524,708	1,291,904	1,757,511

There is no historic data available to use exponential smoothing to forecast the sand required for concrete masonry block making. The current demand is approximately 291 tpd of sand for block production in Male' and Hulhumale'. The demand of sand required for concrete masonry block making in the next 15 years is forecasted by assuming a linear growth equal to the estimated industry growth rate of 22%. However, computing growth at a rate of 22% for 15 years result in an exponential growth and is not realistic. Hence, linear growth at 22% is only computed for five years and used as historical values to use exponential smoothing to forecast for the next 10 years. The forecasted demand is shown in Figure 10 and the quantities are given in Table 13. The projected quantity of IBA and recyclable CDW is estimated in the feasibility study (Table 14). The projected IBA and recyclable CDW quantities are compared with the forecasted demand of sand required in block production (Figure 11). The quantity of CDW aggregates is initially more than the forecasted demand of sand used in block production. However, since year 2021, the demand of sand, including the lower bound, is more than the total IBA and CDW recyclables generated.



Figure 10. Demand forecast of fine aggregates (sand) required in concrete masonry block production for 15 years (2018 – 2033)

Table 13. Demand forecast of fine aggregates (sand) required in concrete masonry block production for 15 years (2018 – 2033)

Year	Forecast Quantity (t)	Lower 90% Confidence Bound (t)	Upper 90% Confidence Bound (t)
2018	90,210		
2019	110,056		
2020	134,269		
2021	163,808		
2022	199,845	199,845	199,845
2023	223,809	214,076	233,542
2024	251,494	240,607	262,380
2025	279,178	267,246	291,110
2026	306,862	293,965	319,760
2027	334,547	320,748	348,346
2028	362,231	347,583	376,880
2029	389,916	374,462	405,370
2030	417,600	401,377	433,823
2031	445,285	428,325	462,244
2032	472,969	455,301	490,637
2033	500,653	482,301	519,006

Table 14. Projection of IBA and CDW aggregates generation (Feasibility Study, 2017)

Year	Recyclables of CDW	IBA generated
2018	151572	
2019	153664	
2020	155787	
2021	157944	
2022	160134	
2023	162358	43125
2024	164617	43125
2025	166911	43125
2026	169242	43125
2027	171608	43125
2028	174012	43125
2029	176454	43125
2030	178934	43125
2031	181453	43125
2032	184012	43125
2033	186611	43125

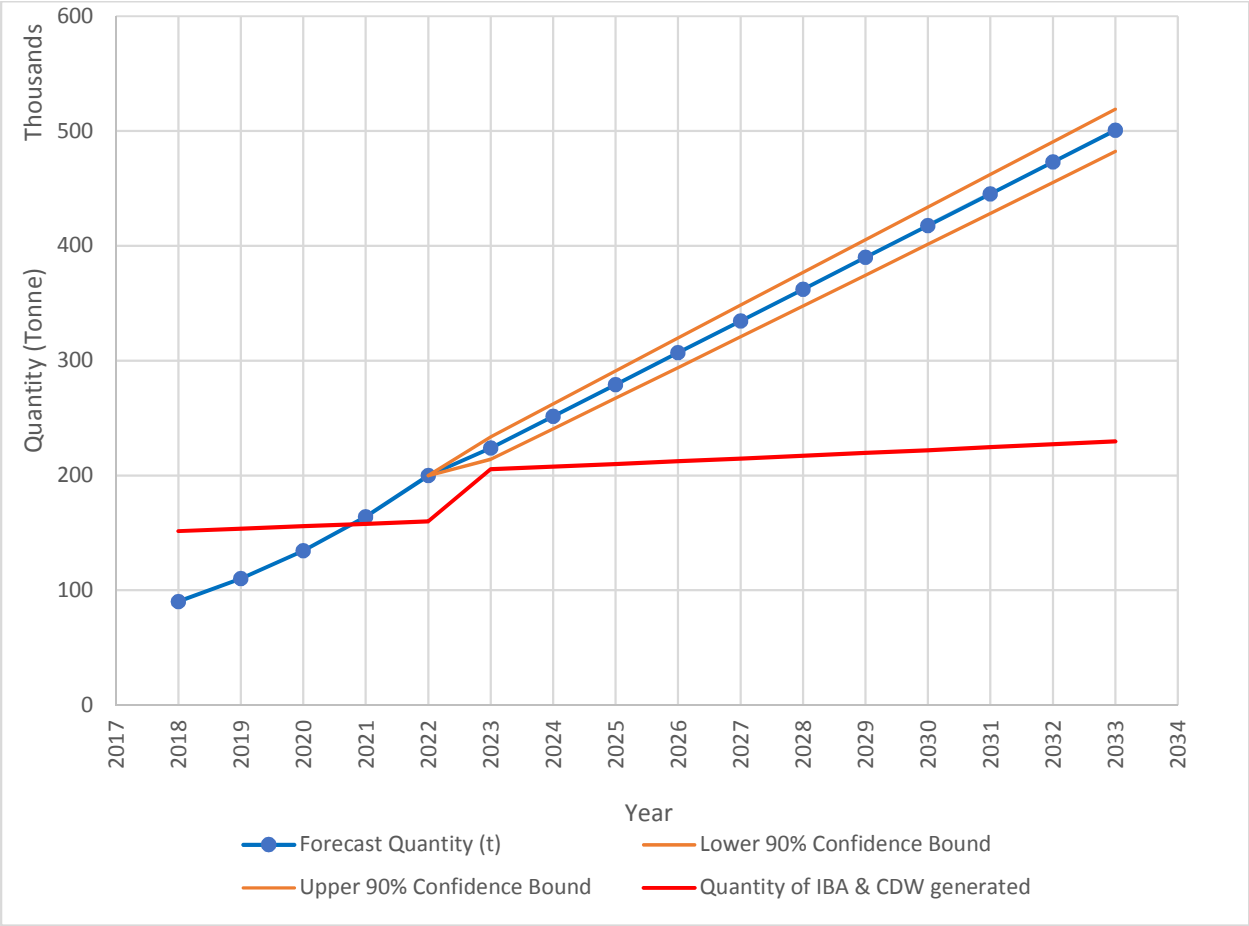


Figure 11. Comparison of forecasted sand required for concrete block production against IBA and CDW generated

A sensitivity analysis was done to evaluate consumption of IBA and CDW in various market share scenarios. The Figure 11 represents IBA and CDW consumptions when 100% market penetration is adopted. Three alternative scenarios were considered; 90%, 80% and 60% of the market share (Figure 12 and Table 15), instead of the 100% market share represented in Figure 11. When 100% market penetration is possible, all the IBA and CDW generated can be consumed by the block production industry. However, when market share reduces to 90% of the forecasted demand, not all IBA and CDW that is generated is consumed in year 2023. Similarly, when market share reduces to 80% of the forecasted demand, there are some IBA and CDW left over in years 2023 and 2024. When the market share reduces to 60% of the forecasted demand, there are some IBA and CDW left over in years 2023 to 2028. The left over IBA and CDW could be used for

other purposes like screeds as suggested by the participants interviewed. It is recommended to try to achieve 100% market share. This can be achieved easily by drastically reducing the price of IBA and CDW. IBA and CDW are substitute products to natural aggregates and price is the driving factor that drives demand in substitute products.

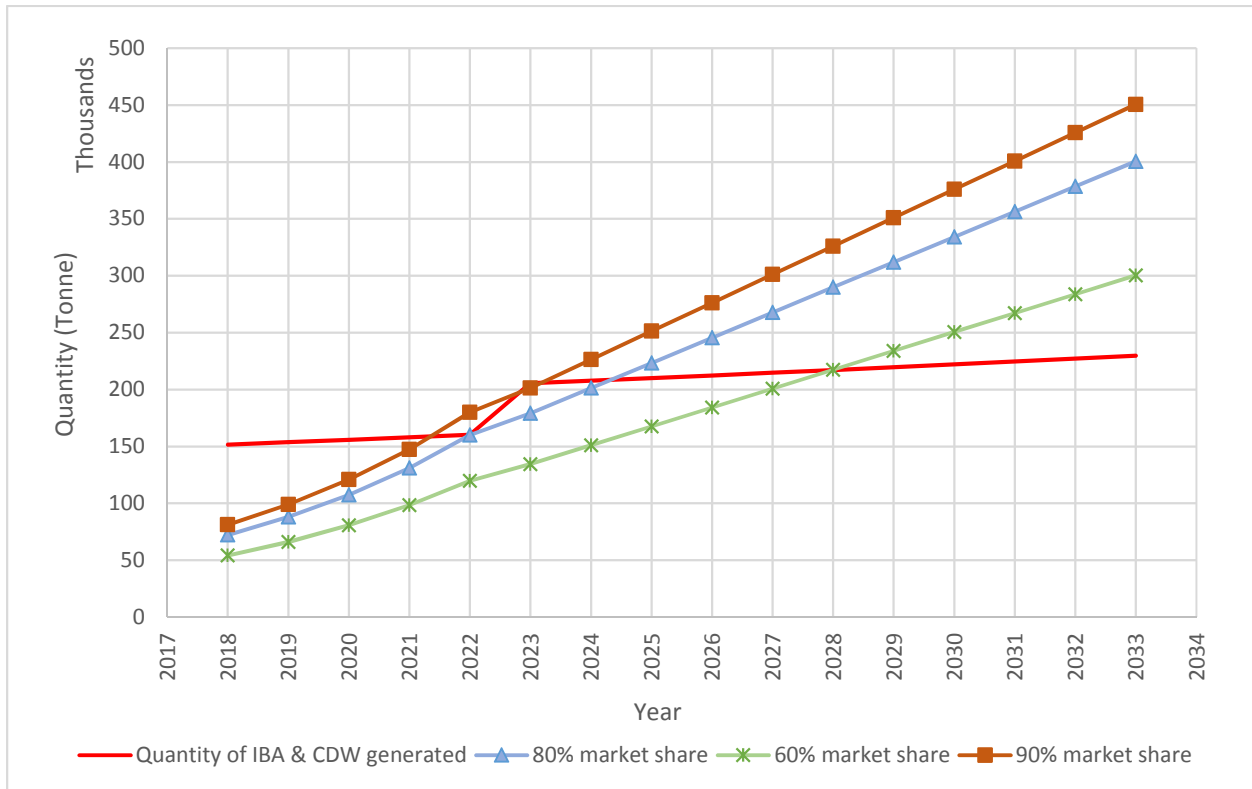


Figure 12. Sensitivity analysis of demand for IBA and CDW in concrete masonry block production

Table 15. Sensitivity analysis of demand for IBA and CDW in concrete masonry block production

Year	90% market share				80% market share				60% market share			
	20% IBA (t)	Unused IBA (t)	80% CDW (t)	Unused CDW (t)	20% IBA (t)	Unused IBA (t)	80% CDW (t)	Unused CDW (t)	20% IBA (t)	Unused IBA (t)	80% CDW (t)	Unused CDW (t)
2018			81,189	70,383			72,168	79,404			54,126	97,446
2019			99,051	54,613			88,045	65,619			66,034	87,630
2020			120,842	34,945			107,415	48,372			80,561	75,226
2021			147,427	10,517			131,046	26,898			98,285	59,659
2022			179,861	0			159,876	258			119,907	40,227
2023	40,286	2,839	161,143	1,215	35,809	7,316	143,238	19,120	26,857	16,268	107,428	54,930
2024	45,269	0	181,075	0	40,239	2,886	160,956	3,661	30,179	12,946	120,717	43,900
2025	50,252	0	201,008	0	44,668	0	178,674	0	33,501	9,624	134,005	32,906
2026	55,235	0	220,941	0	49,098	0	196,392	0	36,823	6,302	147,294	21,948
2027	60,218	0	240,874	0	53,527	0	214,110	0	40,146	2,979	160,582	11,026
2028	65,202	0	260,807	0	57,957	0	231,828	0	43,468	0	173,871	141
2029	70,185	0	280,739	0	62,387	0	249,546	0	46,790	0	187,160	0
2030	75,168	0	300,672	0	66,816	0	267,264	0	50,112	0	200,448	0
2031	80,151	0	320,605	0	71,246	0	284,982	0	53,434	0	213,737	0
2032	85,134	0	340,538	0	75,675	0	302,700	0	56,756	0	227,025	0
2033	90,118	0	360,470	0	80,105	0	320,418	0	60,078	0	240,314	0

## 8. Sustainable Business Model

The reuse of IBA and CDW as an exported alternative raw material in cement manufacturing, in structural concrete, as a fill material for road bases and sub-base layers, and fill material for land reclamation can be technically feasible as suggested by literature review. However, the financial feasibility or technical uncertainties in the Maldives context limits the reuse of IBA and CDW in many applications that might be viable in other countries.

Considering the logistics involved, the quantity of IBA available for exporting to a cement manufacturer is too small to achieve economies of scale. Similarly, uncertainties in the characteristics of CDW and low performance of IBA replaced concrete limits the reuse of IBA and CDW in structural concrete. The reuse of IBA in road construction is practiced widely in Europe and IBA is used for land reclamation in Japan port areas. However, due to the intermittent frequency and the large volumes of materials required for road and reclamation projects, the reuse of IBA or CDW is not viable for such projects in Maldives.

Concrete masonry block making is an application that has potential for the reuse of IBA and CDW aggregates in Maldives. Based on literature review, the replacement of sand with IBA is technically feasible. The performance of the blocks with r-IBA meets the required standards. Moreover, the demand forecast of sand required in 2023, the planned year to commence incineration of waste, is greater than the amount of IBA generated. Hence, all the IBA produced can be utilized. Similarly, it is recommended to crush CDW to sand size particles and reuse it for masonry block making. The forecasted demand of sand required for block production and the CDW aggregates generated become equal in year 2020, and then the demand is higher than supplied by CDW aggregates. Hence, all the CDW produced can be utilized in the block making industry, assuming 10% market penetration.

There are two business options. The first option is the CDW processing plant operator adopting forward integration and become either a supplier of IBA and CDW aggregates as raw materials to the market or starting a block production business. The consultant



does not recommend the first option because the amount of IBA and CDW aggregates generated is much less than the market demand. To create a demand for the product, the operator should ensure reliability of the availability of the product in quantities demanded by the market. This concern was raised by one of the large contractors interviewed. The contractor noted he would be willing to purchase IBA and CDW at a lower cost for his block production if a continuous stream of raw materials is ensured. The contractor highlighted that IBA and CDW depends on the availability of waste, which can be variable, and hence questioned the reliability of the availability. Furthermore, IBA and CDW would probably be used to replace part of the natural sand used. Hence, contractors or block producers would like to get all the required sand from one place. In such cases, the operator might be required to get into the business of importing sand.

The second option is to use an intermediately aggregate supplier like State Trading Organization (STO) instead of directly selling it to the market. This option is more recommendable because it eliminates the risks and costs associated with trading with the market directly. STO is one of the major aggregates supplier and has established customer bases and distribution networks. Hence, adopting the second option is financially more attractive.

Table 16 shows the price comparison of different types of sand used for block production. The price of IBA and CDW aggregates are the prices suggested by the consultant in the feasibility study. As observed the unit price of IBA and CDW aggregates are significantly cheaper. Since the materials are substitute goods, a drastic reduction in price would increase the demand for the IBA and CDW aggregates, provided the performance is assured.

*Table 16. Price comparison of sand used for concrete masonry block production and IBA and CDW*

	<b>Price (MRV/Mg)</b>	<b>Price (USD/Mg)</b>
Sand (fine aggregates)	794.18	51.5
Local sand	225	14.59
IBA	77.1	1 – 5
CDW aggregates	33.55	1 – 2.18

## 9. Recommendations

Concrete masonry block and pavement block production is a potential application for utilization of IBA and CDW in Maldives. Use of IBA and CDW in non-structural applications such as use in floor screed concrete could be a potential market too.

The demand forecast shows the generation of IBA and CDW could be less than the demand required by the block production industry, provided 100% market penetration is possible. It is recommended that Government should promote the use of IBA and CDW through campaigns to assure the technical and safety suitability of the waste products.

The general response of stakeholders consulted is promising and many are willing to accept the product if the price is significantly lower than natural aggregates and the performance of the product meets the standards, often international standards.

There are no existing local standards directly related to IBA or CDW, mainly because these are new products in the Maldivian market. However, new regulations governing the reuse of IBA and CDW should be expected soon as Ministry of Environment is in the process of formulating environmental regulations to IBA and CDW. Hence, it is suggested that treating of IBA and CDW is critical to ensure the characteristics and performance confirms to international best practices and consequently the acceptance of r-IBA and processed CDW as a building material in Maldives.

It is recommended to introduce the products to the market through intermediately aggregates supplier. Additionally, the price should be significantly lower than natural aggregates to drive the demand for IBA and CDW.

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## Fly Ash Management Plan (Handling of Air Pollution Control Residues) Greater Male Waste-to-Energy Project

### 1 Generation of Air Pollution Control Residues

As per Employer's Requirements (ERQ) of the envisaged DBO Contract, the Air Pollution Control (APC) system shall consist of a semi-dry or dry system that will generate hazardous residues containing the acid and organic flue gas components and heavy metals in a soluble form which require careful handling. The volume of APC residues depends on the type of absorbent used to clean the flue gases. According to a preliminary mass balance prepared during the feasibility study around 50 kg APC residues per tonne of waste will be generated. In total, approx. 8,500 tonnes are expected to be generated every year if the facility runs at full capacity. According to the European BAT Reference Document for Waste Incineration (BREF) Document that is to be applied, APC residues including the fly ash that is retained by the APC system must not be commingled with the boiler ash and the bottom ash.

APC residues are regarded in all countries that are incinerating waste as hazardous due to their heavy metal content in an easily leachable form. Subject to the absorbent and, of course, the type of waste incinerated, the composition of the APC residues may be characterised as listed in Table 1 (heavy metals highlighted in dark grey).

Table 1: Components of the residues of a semidry/dry APC system<sup>1</sup>

Element	Content in mg/kg
Ca	110,000 – 350,000
K	5,900 – 40,000
Mg	5,000 – 14,000
Na	7,600 – 29,000
Si	36,000 – 120,000
Cl	62,000 – 380,000
S	1,400 – 25,000
Al	12,000 – 83,000
Fe	2,600 – 71,000
As	18 – 530
Ba	51 – 14,000
Cd	140 – 300
Cr	73 - 570
Cu	16 – 1,700
Hg	0.1 – 51
Mn	200 – 900
Mo	9 – 29
Ni	19 – 710
Pb	2,500 – 10,000
Sb	300 – 1,100
V	8 – 62

<sup>1</sup> according to Chandler, Eighmy, Hartlém, Hjelmar, Kosson, Sawell, von der Sloot, Vehlow: Municipal solid waste incinerator residues (1997), cited in Management of APC residues from WtE Plants, ISWA 2008

Zn	7,000 – 20,000
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Besides the combustion conditions in the furnace (2 sec, 850°C), the homogeneity of the conditions across the furnace cross section and a sufficient turbulence in the post combustion chamber is an important parameter to control the dioxin and furan contents of the APC residues. Measurements in UK from 2004 revealed concentration between 800 and 1,750 ng TEQ/kg while eluates did not show a significant level above background contamination which was between 0.4 and 2 pg/l<sup>2</sup>.

## 2 Envisaged APC residue treatment and other nations current disposal practices

Because no worldwide methodology or guideline on how to deal with APC residues in an environmentally sound and technically feasible manner has been established, most nations do follow their own approach which again is subject to the local conditions such as availability of disposal sites, national legislation and the costs of the APC residue treatment.

In Germany, APC residues from dry/semi-dry system are usually stored in old salt mines as backfilling material (only if water ingress can be ruled out). Facilities in France with bicarbonate as absorbent apply an extraction of heavy metals at pH 9 and thus try to reuse the bicarbonate (which yet contains chloride) from the so obtained brine. As disposal option for the heavy metals, hazardous waste landfills are used. Dutch facility uses big bags with inlet liners and douses the APC residues during unloading with water to trigger pozzolanic reactions. By this, the APC residues solidify while the inlet liners of the big bags prevent water seepage into the big bags.

In the USA, APC residues are stored mostly in hazardous waste landfills. Some facilities use the bottom ash to stabilise the APC residues (due to pozzolanic effect of bottom ash after dousing with water).

Some Japanese facilities (appr. 30) vitrify both the bottom ash and APC residues, thus obtaining a highly concentrated and salt-rich residue (which is difficult to handle though). Costs for this kind of treatment are significant and can be as high as \$500/tonne of residue.

Deliberately, a stabilisation/solidification of the APC residues or any other treatment method was not explicitly prescribed to allow the DBO Contractor to develop a solution that meets the local requirements. Adding cement, for example, can, subject to the absorbent used in the APC system, triple the amount of residues to be landfilled which may be a costly undertaking in the Maldives. Hence, other pozzolanic reaction inducing additives have to be selected if the Contractor opts for such a solution. Space requirements for storing the stabilised bricks while they undergo the transformation was another factor which cannot be ignored. A plant to process around 25 tonnes per day requires 40mx20m, most of the space for storage to allow the bricks to solidify – up to 8 weeks.

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<sup>2</sup> Testing of residues from incineration of municipal solid waste, UK Environment Agency, 2004

Whether and to what extent, the DBO Contractor will use the residues after the bottom ash treatment to trigger a pozzolanic reactions, shall be left to the sole discretion of the Contractor which is in line with the general principles of a DBO contract to stimulate the competition of the bidders to present the technically most robust but an economically attractive solution.

Because the Maldives do not have a comprehensive environmental regulatory framework yet, the European standards that according to the BREF Document do require a separate handling of the bottom ash and the APC residues are regarded as the best option to maximise the reuse of the bottom ash and to concentrate the toxic substances within the smallest volume of residues, i.e. the APC residues. Since the BREF Document does not define the landfilling and the treatment of the APC residues and a DBO Contractor may have a preference for the one or other treatment option, it shall be left to the DBO Contractor to develop the solution against the standards that are defined in the ERQ.

During the design review, the Contractor has to provide the full documentation of for the APC residue handling. In the event it does not meet good international industrial practice or does not achieve the desired design standards, the Employer has any right to request modification.

### 3 Design Build Requirements as per ERQ

To avoid any impact to the environment and to the Contractor's personnel safety, the Contractor's design shall consider the following for conveying and loading APC residues:

- APC residues shall not be mixed with bottom or boiler ash prior to the bottom ash treatment.
- APC residues shall be conveyed in closed conveying systems that end up in storage silos whose exhaust air can be dedusted via a central dedusting system.
- 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).
- Discharging the APC residues from the silos into water-tight jumbo bags (with inlet) or into the transfer vehicles shall be carried out via dust-tight discharging chutes.
- APC residues shall be treated by either stabilization/solidification or via triggered pozzolanic reaction prior to landfilling to limit the leachability of heavy metals.

The ERQ request the Contractor to design and construct the landfill for the APC residues according to the European Landfill Directive 1999/31/EC and its latest amendment 2018/850/EC. The design of the landfill – i.e. whether a single compartment or different compartments for the APC residues and the remaining bottom ash – shall be subject to the design considerations of the Contractor. In any case, the Contractor shall take account of the following:

- The barrier system shall encompass an artificially completed/reinforced geological barrier (thickness shall be not less than 0.5 m) that can offer an equivalent protection as defined in the European Landfill Directive 1999/31/EC for hazardous wastes. An impermeable artificial liner for at least the compartment that is designated for the APC residues shall be provided. Given that Maldivian soils do not offer a geological barrier having a hydraulic conductivity of less than  $10^{-9}$  m/s and a thickness of more

than 5 m, the artificial geological barrier is the only way to apply to multi-barrier system.

- The compartment, if any, for the residues from the bottom ash processing shall be provided with an artificially completed geological barrier. Its thickness shall not be less than 0.5 m and shall meet the hydraulic resistance requirements for non-hazardous waste as stipulated in the European Landfill Directive.
- The barrier system shall be designed to allow minimizing the leachate generation by dividing the compartments into cells that will accommodate waste subsequently according to the filling plan of the landfill.
- The lower 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;
- Prior to construction, the Contractor shall prepare a test pad to demonstrate the effectiveness of the proposed engineered barrier.
- In the design of the Contractor, a composite cover system shall be included (see also operational requirements).

For the leachate management, the Contractor shall take into consideration the following:

- The design shall warrant a minimized leachate generation applying means, such as, but not limited to, 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.
- The design of the Contractor shall take account of that 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.
- The Contractor shall design and build or organize a system for the safe collection, transport and disposal of the LTP concentrate.
- Subject to its design, the Contractor shall 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.
- Monitoring wells to detect any potentially escaping leachate shall be installed.

## 4 Requirements during Operation Service Period

Focusing on the APC residues, during landfilling the Contractor shall consider:

- APC revenues shall be disposed safely to landfill meeting the European standards (1999/31/EC) as defined for hazardous waste. Safe disposal means that APC residues shall be unloaded either into water-tight jumbo bags in a semi-solid state (after dousing with water) or shall be stabilized/solidified. Given that APC residues are the only type of hazardous waste, no acceptance tests are needed.
- The Contractor shall dispose of all APC residues and any other residual wastes (i.e. excluding bottom ash for recycling and valuable wastes to be exported for reuse) to the dedicated landfill cells located within the Site, in accordance with the approved

Environmental and Social Impact Assessment for the Regional Solid Waste Management Facility (RSWMF) Thilafushi

## Marine Survey Report



Thilhafushi house reef. Photo by: Water Solutions

**Prepared by:** Abdul Aleem (EIA P03/2019), Mohamed Umar (EIA P02/2019) & Abdulla Fazeel



23<sup>rd</sup> September 2019



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## 1 Introduction

The marine environment survey of Thilafushi covered the shallow lagoon, deep lagoon, reef-flat, and reef slope of the house reef of areas of Thilafushi Island. 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.

## 2 Scope of work

The marine survey at Thilafushi has been conducted to cover the marine component of the TOR for the EIA for the Establishment of the Regional Waste Management Center for Zone III issued by EPA. Hence the TOR requested to assemble, evaluate and present baseline data on the relevant environmental characteristics of the study area, focused on the marine environment. Aspects of the environment shall be described to the extent necessary for assessment of the environmental impacts of the proposed development. The extent and quality of the available data shall be characterized indicating significant information deficiencies and any uncertainties associated with the prediction of impacts.

All available data from previous studies, if available shall be presented. Information required includes the following:

*Assessment of the marine environment should be undertaken from all locations from which data was taken in 2011 EIA report. This assessment should cover coral cover and fish census information. Plankton Assessment from 05 different locations around Thilafushi. Areas of special sensitivity including coral reefs and marine protected areas near Thilafushi shall be marked on a map and described. This shall include environmentally sensitive areas, protected areas and significant dive sites.*

## 3 Methodology

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.

Site selection for the marine survey was based on the location of the WTE, existing dumpsite, and proposed hotwater outfall and seawater intake and as well as control sites for future monitoring purposes. At survey sites M1 to M7 benthic composition and fish abundance was surveyed at depths of 5 meters and 10 meters and at survey sites M8 to M10, surveys were done to a depth of 30 metres along the reef profile. A Manta Tow survey was conducted along 500 metres from M9 to M10 along the reef edge on the southern side of Thilafushi at both 5 and 10 metres. The inner lagoon was not surveyed as the area is not of ecological importance.

The marine benthic and fish surveys at Thilafushi Island was focused on 10 sites. Plankton tows and water samples were done at 7 sites on 23<sup>rd</sup> – 24<sup>th</sup> April 2018. Marine surveys were done at marine sites M1 to M7 on 23<sup>rd</sup> – 24<sup>th</sup> April 2018. Three sites, M8 to M10 were surveyed on 1<sup>st</sup> September 2019 as more detail marine survey was requested to locate the hot water discharge location on southern side of Thilafushi. These three sites were chosen within a 500 m zone on the southern side of Thilafushi as shown in Figure 3. M8 was one of the potential site to locate the hot water discharge outfall.

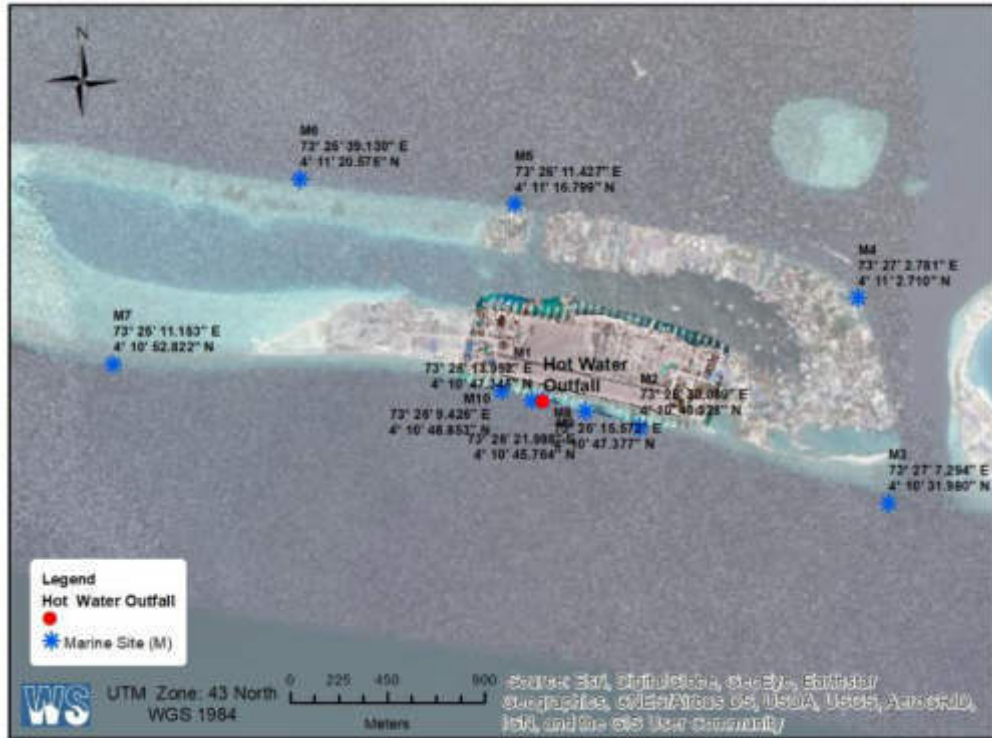


Figure 1: Marine surveyed locations with coordinates in 23<sup>rd</sup> – 24<sup>th</sup> April 2018 and 1<sup>st</sup> September 2019



Figure 2: Marine surveyed locations with coordinates in 23<sup>rd</sup> – 24<sup>th</sup> April 2018 and 1<sup>st</sup> September 2019

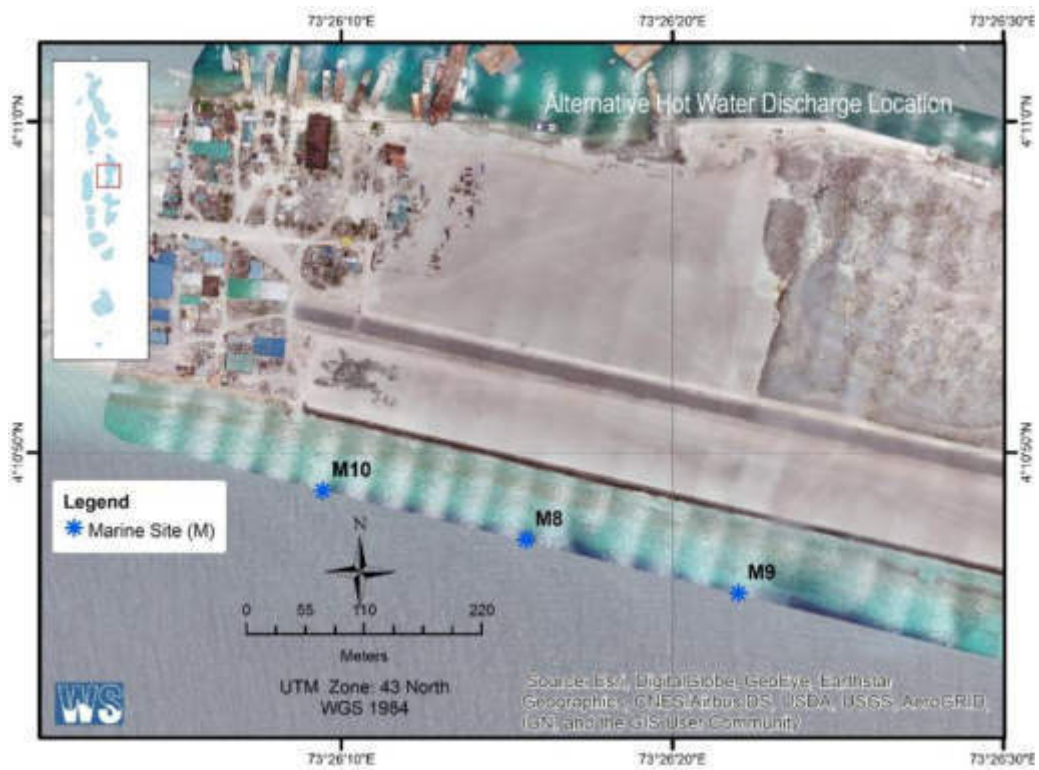


Figure 3: Marine surveyed locations on 1<sup>st</sup> September 2019

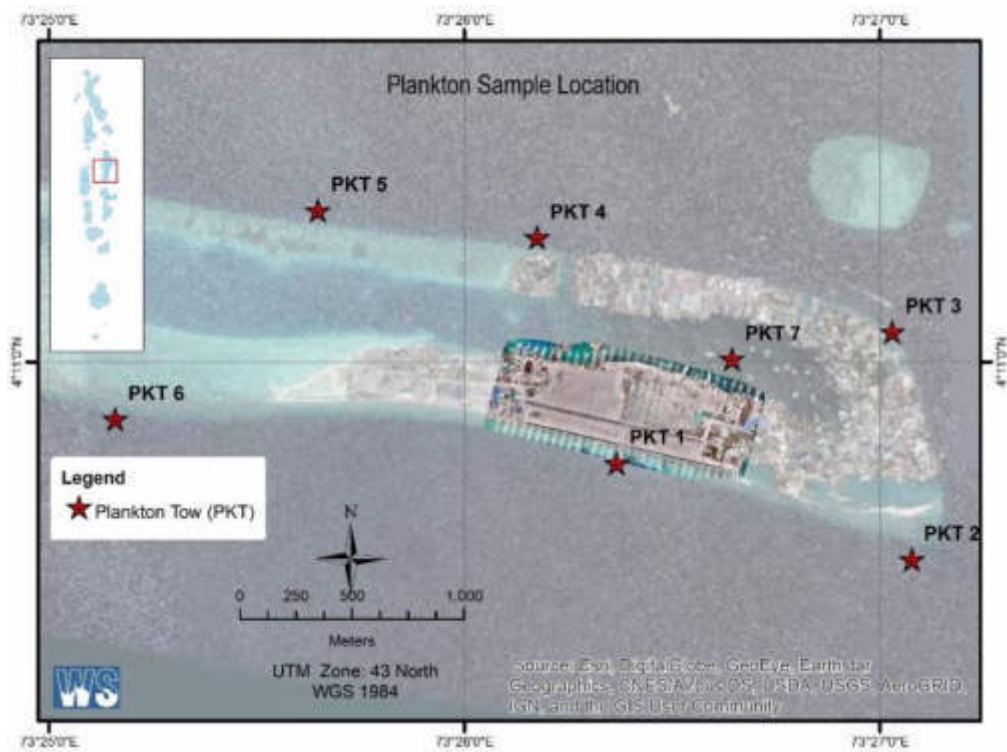


Figure 4: Plankton tows and water sampled location on 23<sup>rd</sup> – 24<sup>th</sup> April 2018

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### **3.1 Benthic Survey**

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 10 sites (M1-M10) located on areas on the outer reef around Thilafushi island. At the survey sites M1 to M7 benthic composition and fish abundance was surveyed at depths of 5 meters and 10 meters. At survey sites M8 to M10, marine surveys were done to a depth of 30 metres along the reef profile.

#### **3.1.1 Surveys in April 2018**

The photo quadrat surveys were undertaken at marine site M1 to M7. A transect line of 20 metres at each site is set out, the surveyor then places a half a metre 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 placed in two depths (5 & 10m). The surveys were undertaken on 23-24 April 2018.

#### **3.1.2 Reef profile Survey in September 2019**

Marine survey sites M8 to M10, were three additional sites surveyed using photo quadrat methods. Unlike the conventional reef transect surveys, the three sites were assessed for benthic composition by undertaking photo quadrates from the top reef up to 30 metres, along the reef profile.

Before start of the survey, the starting points were marked using a plastic bottle tied with a rope and weight at its end. The weight rested at the top reef, approximately 5 metres from the reef slope. This allowed the divers to descent from the exact required location up to 30 metres.

Photos were taken using the half metre 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 m below the first photo. In this manner, photos are taken along the transect line.

#### **3.1.3 Manta Tow survey in September 2019**

A Manta Tow survey was conducted along 500 metres from M9 to M10 along the reef edge on the southern side of Thilafushi at both 5 and 10 metres. Manta towed was conducted by swimming along the stretch and recording the observations on an underwater slate. The tow at 5 metres was undertaken with the help of a boat which towed the swimmer along the survey stretch using a rope.

The parameters observed include percentage cover of live coral, other benthic organisms, substrate diversity of the reef in terms of benthic and pelagic life. Overall status of the reef along this stretch was determined based on this survey and the results are outlined below.

## **4 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 world to assess the benthic composition of the reefs. In this programme, 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 categories. 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.

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

- **HC:** All living coral including bleached coral; includes fire, blue and organ pipe corals
- **SC:** Include zoanths but not anemones (OT)
- **DC:** Coral that has died within the past year; appears fresh and white or with corallite structures still recognizable
- **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.
- **SP:** All erect and encrusting sponges (but no tunicates).
- **RC:** Any hard substrate; includes dead coral more than 1 year old and may be covered by turf or encrusting coralline algae, barnacles, etc.
- **RB:** Reef rocks between 0.5 and 15cm in diameter
- **SD:** Sediment composed of particles of less than 0.5cm in diameter; in water, falls quickly to the bottom when dropped.
- **SI:** Sediment that remains in suspension if disturbed; recorded if color of the underlying surface is obscured by silt.
- **OT:** Any other sessile organism including sea anemones, tunicates, gorgonians or non-living substrate.
- **SG:** All types of sea grass observed categorized in the field SG.

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 analysed, the results are displayed on a table.

## 5 Results of the marine survey

### 5.1 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 centre. The substrate at the site is dominated by rock at depths of 5 ( $58 \pm 14.2\%$ ) and 10 ( $64.5 \pm 2.78$ ) meters respectively. Hard coral cover was observed to be moderate at the site at depths of 5 ( $19.5 \pm 5.91$ ) and 10 ( $21 \pm 2.68$ ) 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 butterfly fishes. 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.

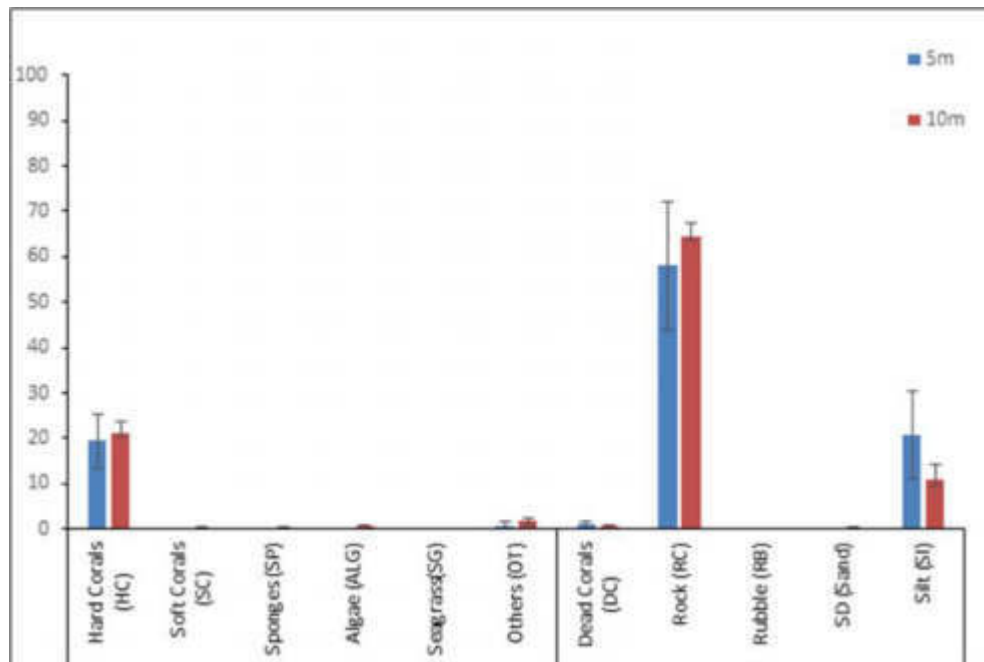


Figure 5: Percentage benthic composition at site 1(M1) at depths of 5 and 10 meters  $\pm$  Standard Error (SE) (23<sup>rd</sup> April 2018).

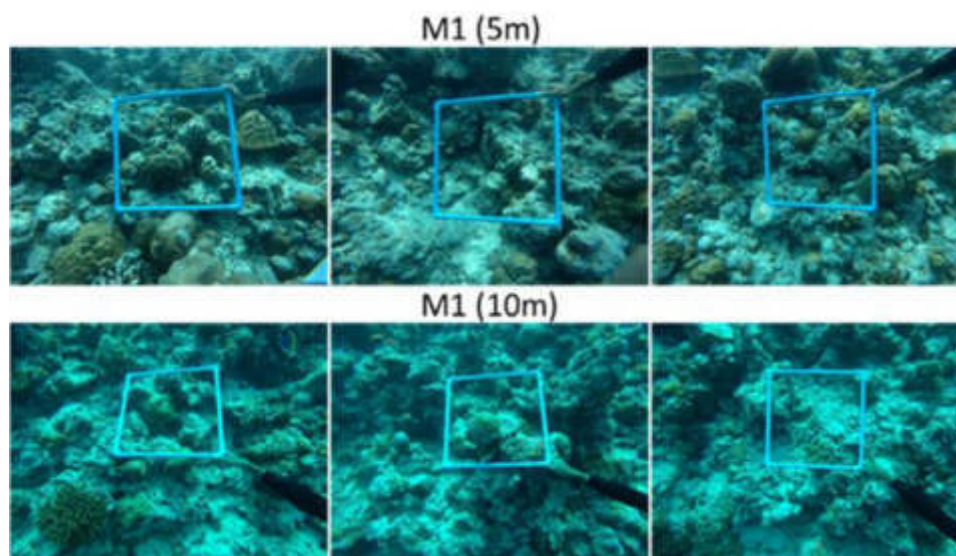


Figure 6: Photos taken from site 1 at depths of 5 and 10 meters (M1) (23<sup>rd</sup> April 2018).



## 5.2 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 centre. The substrate at the site is dominated by rock at depths of 5 ( $71.25 \pm 3.86\%$ ) and 10 ( $63 \pm 6.14$ ) meters respectively. Hard coral cover was observed to be moderate at the site at depths of 5 ( $22.25 \pm 2.95$ ) and 10 ( $23.25 \pm 5.17$ ) 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 butterfly fishes. Fishes observed to be abundant at depth of 10 meters were anthias, damselfishes, butterfly fishes and triggerfishes. The following graph outlines the status of site 2(M2) at depths of 5 and 10 meters.

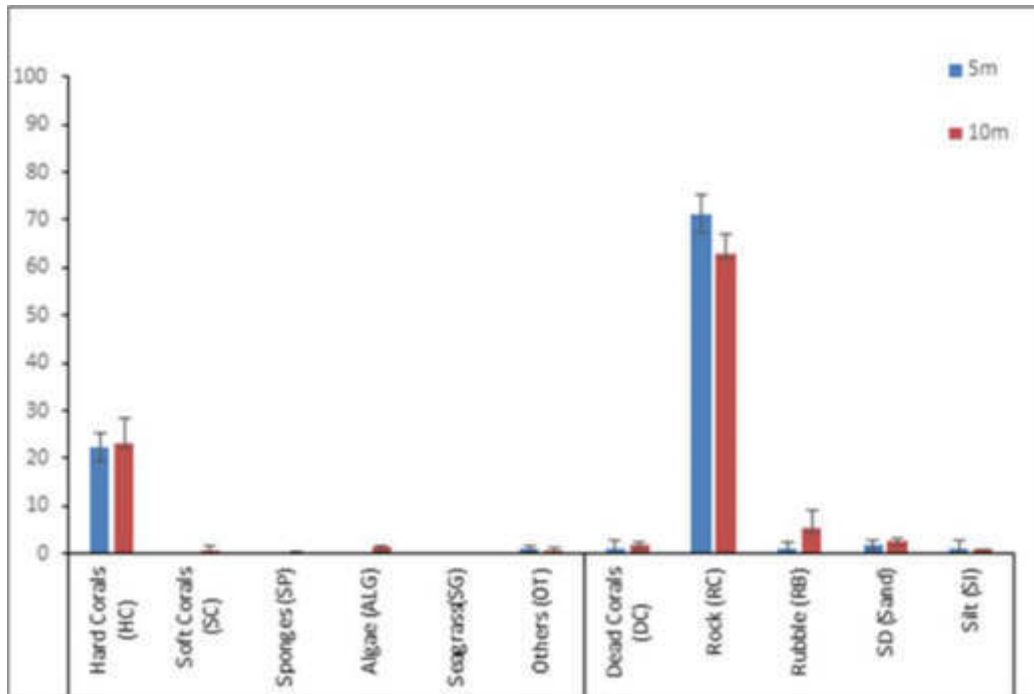


Figure 7: Percentage benthic composition at site 2 (M2)  $\pm$  SE (24<sup>th</sup> April 2018).

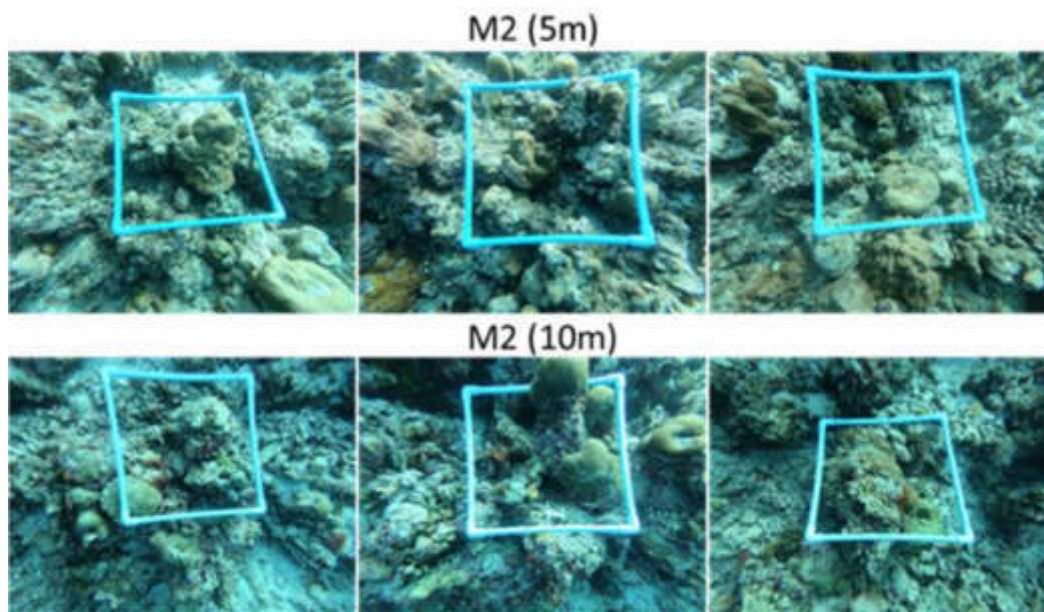


Figure 8: Photos taken from site 2 (M2) (24<sup>th</sup> April 2018).

### 5.3 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 ( $76.25 \pm 2.10\%$ ) and 10 ( $65.75 \pm 2.46\%$ ) meters respectively. Hard coral cover was observed to be moderate at the site at depths of 5 ( $17 \pm 2.48$ ) and 10 ( $16.5 \pm 0.65$ ) 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.

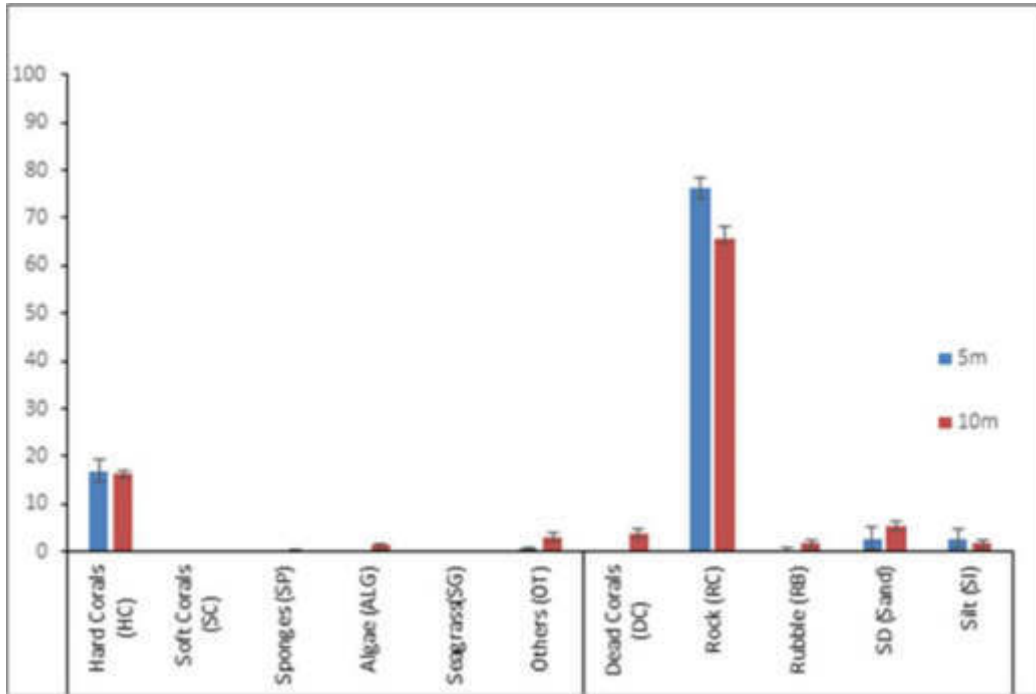


Figure 9: Percentage benthic composition at site 3 (M3) ± SE (23<sup>rd</sup> April 2018).

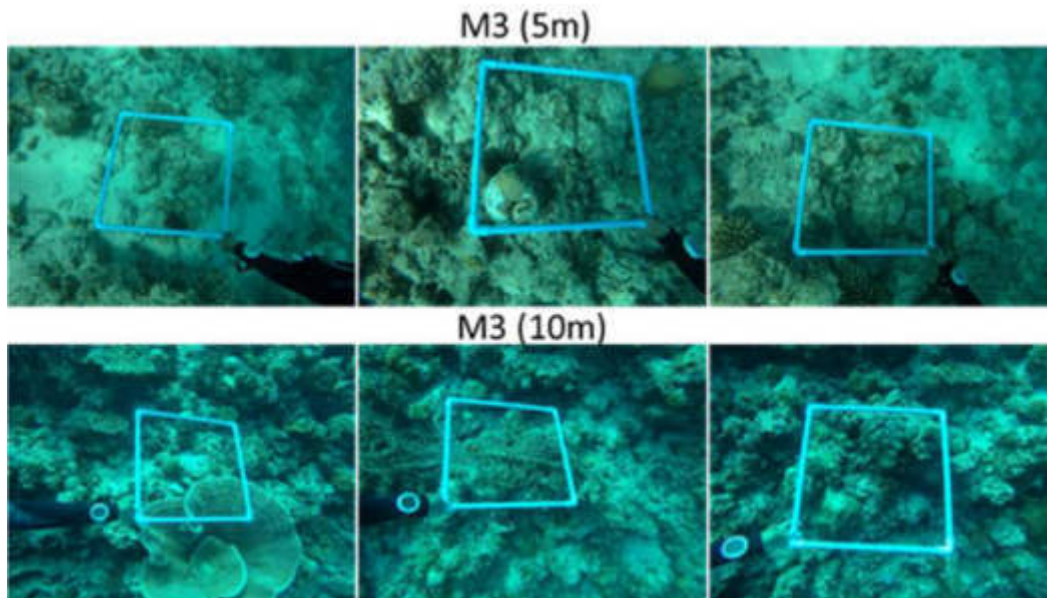


Figure 10: Photos taken from site 3 (M3) (23<sup>rd</sup> April 2018).

#### 5.4 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 ( $67 \pm 4.49\%$ ) and 10 ( $60 \pm 6.42\%$ ) 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.

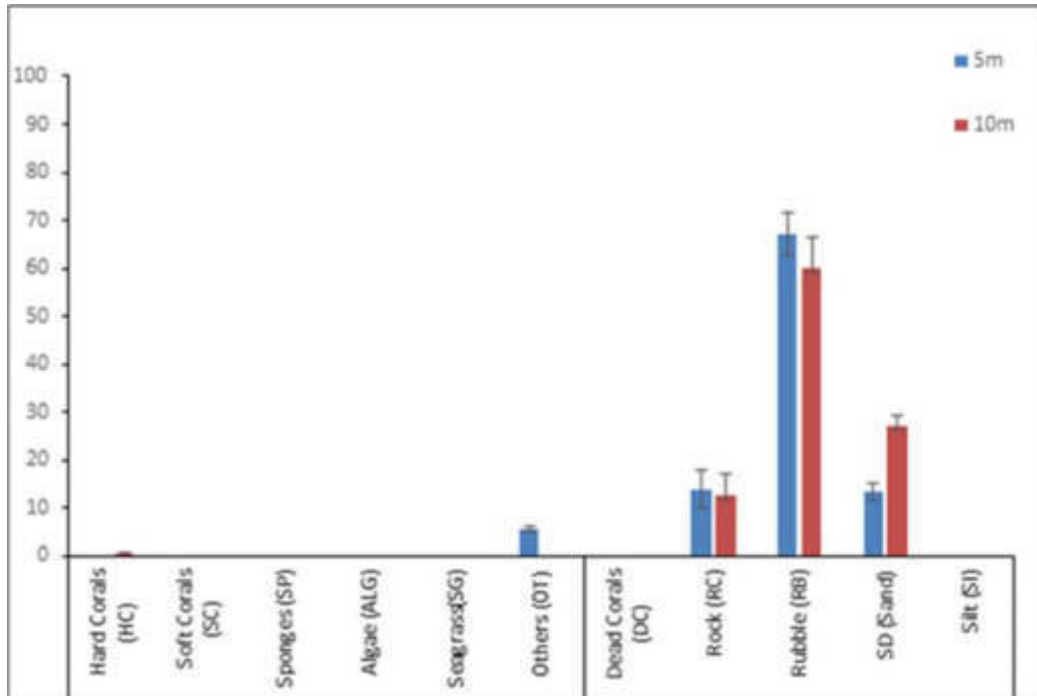


Figure 11: Percentage benthic composition at site 4 (M4)  $\pm$  SE (24<sup>th</sup> April 2018).

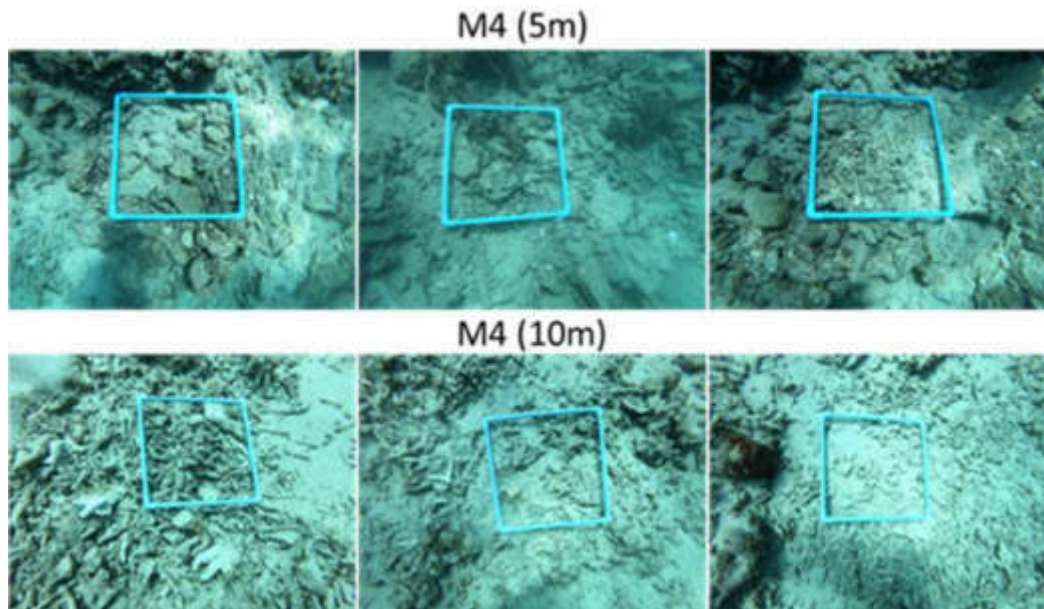


Figure 12: Photos taken from site 4 (M4) (24<sup>th</sup> April 2018).

### 5.5 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 ( $46.75 \pm 6.28\%$ ) and 10 ( $51.5 \pm 5.81\%$ ) meters respectively. Hard coral cover was observed to be low at the site at depths of 5 ( $5 \pm 1.58$ ) and 10 ( $4.25 \pm 0.75$ ) 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.

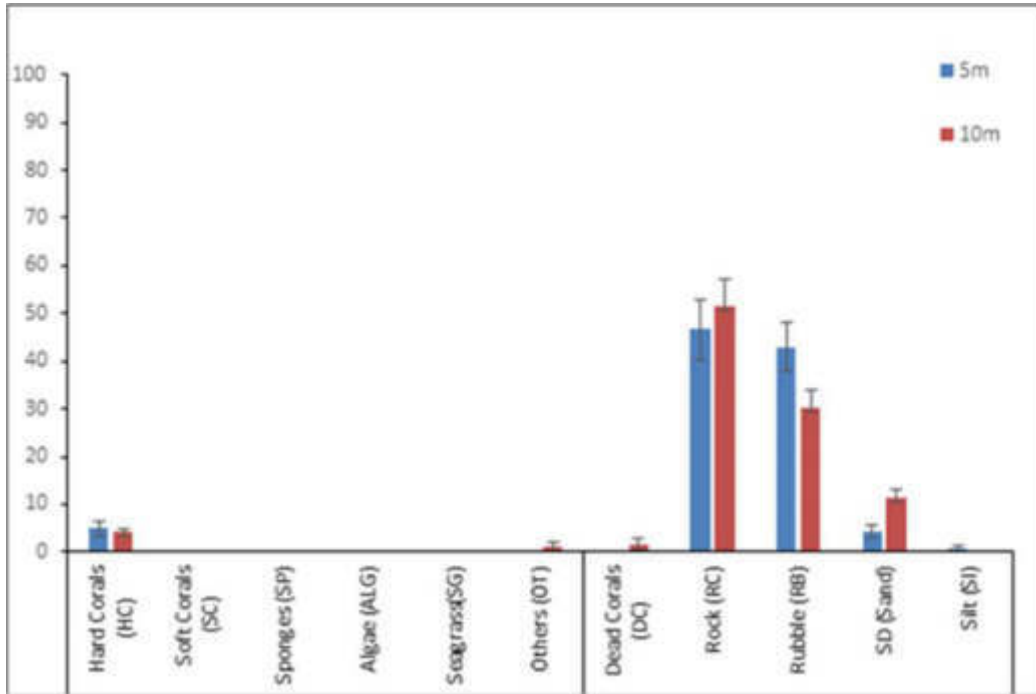


Figure 13: Percentage benthic composition at site 5 (M5)  $\pm$  SE (24<sup>th</sup> April 2018).

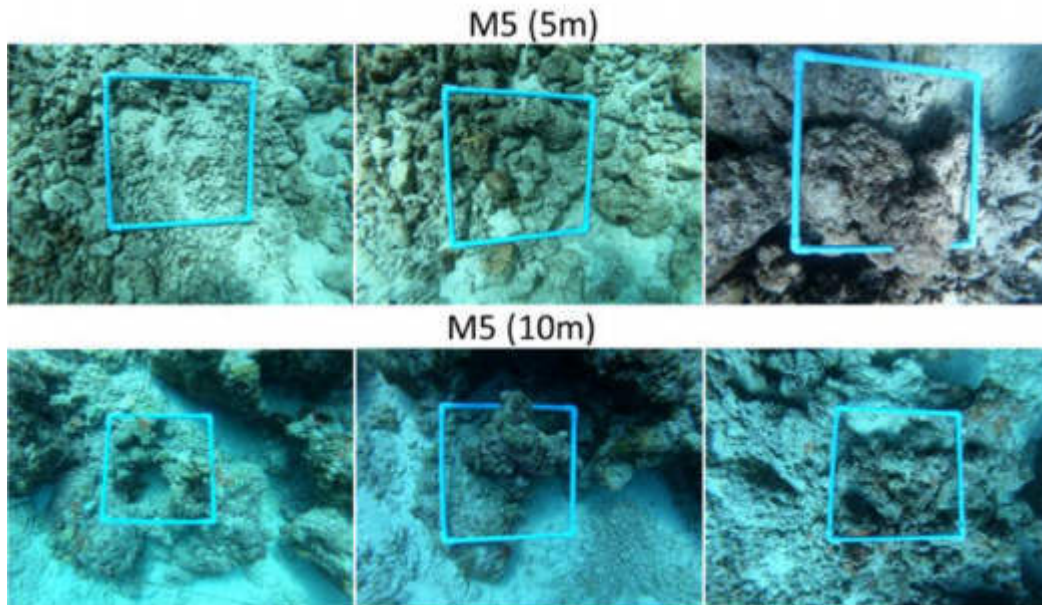


Figure 14: Photos taken from site 5 (M5) (24<sup>th</sup> April 2018).

## 5.6 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 ( $80.5 \pm 4.19\%$ ) and 10 ( $36.5 \pm 5.85\%$ ) meters respectively. Hard coral cover was observed to be low at the site at depths of 5 ( $8.75 \pm 2.53$ ) and 10 ( $14 \pm 2.58$ ) 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.

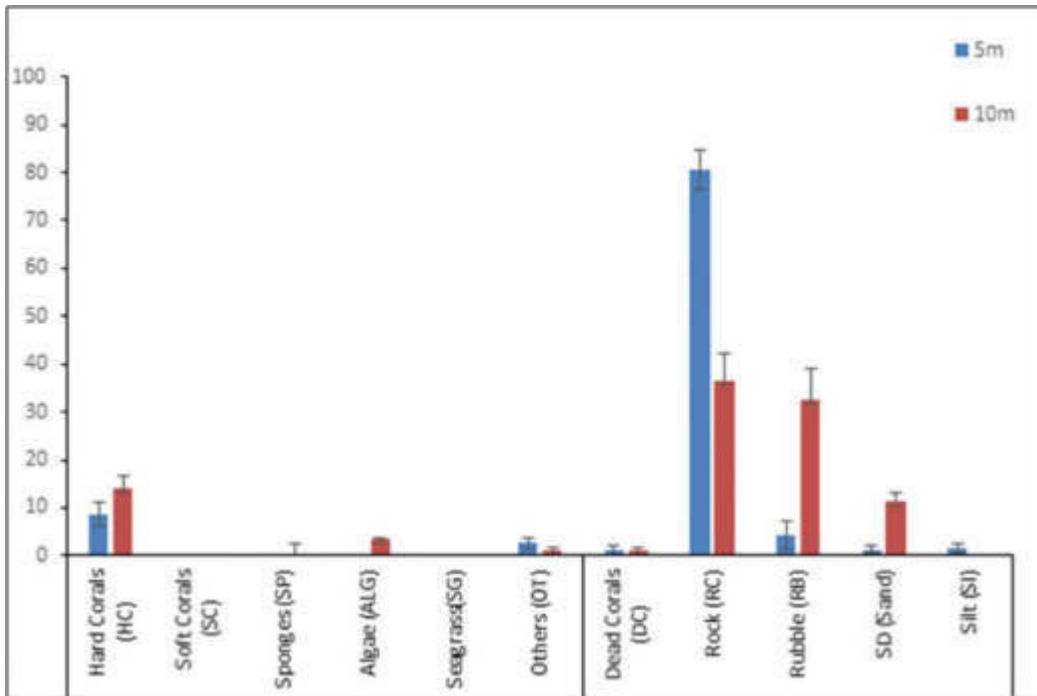


Figure 15: Percentage benthic composition at site 6 (M6)  $\pm$  SE (24<sup>th</sup> April 2018).

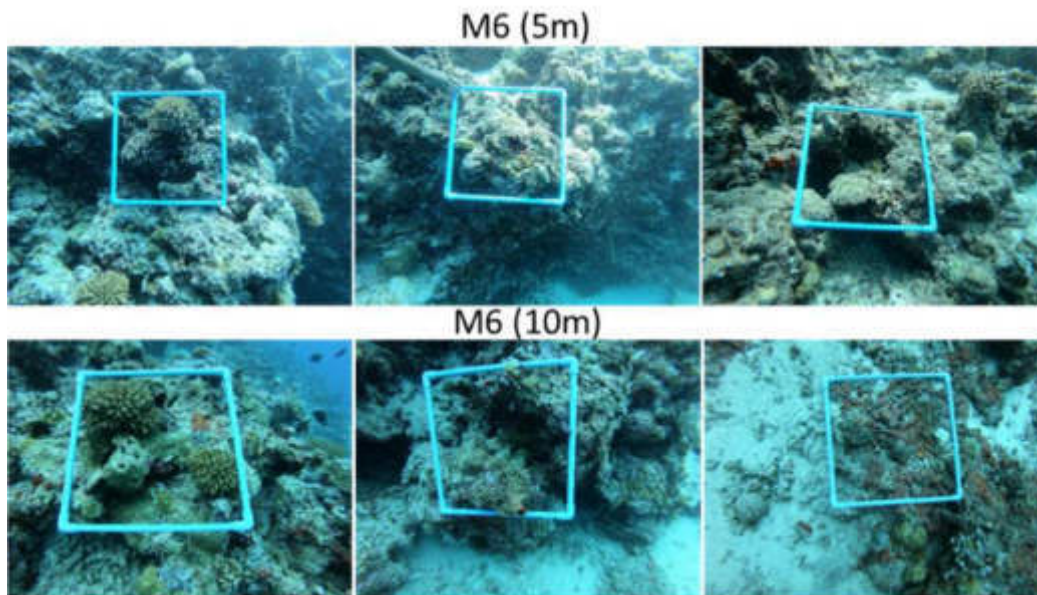


Figure 16: Photos taken from site 6 (M6) (24<sup>th</sup> April 2018).

### 5.7 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 ( $76 \pm 5.87\%$ ) and 10 ( $77.75 \pm 3.33\%$ ) meters respectively. Hard coral cover was observed to be low at 5 meters ( $5 \pm 1\%$ ) and moderate in 10 meters ( $17.5 \pm 3.2\%$ ). 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.

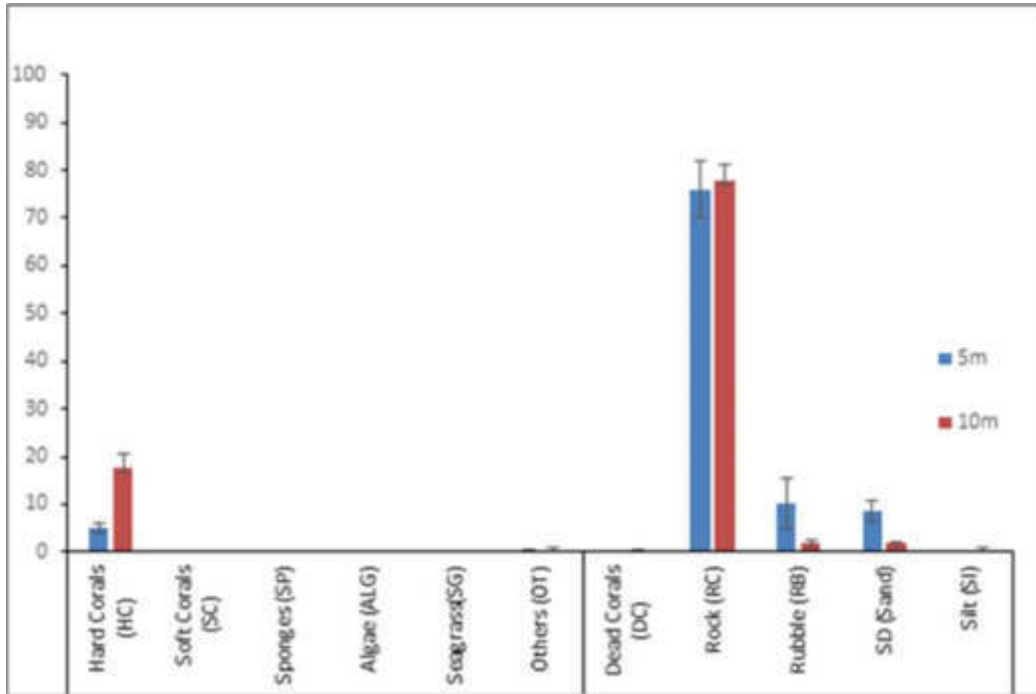


Figure 17: Percentage benthic composition at site 7 (M7)  $\pm$  SE (23<sup>rd</sup> April 2018).

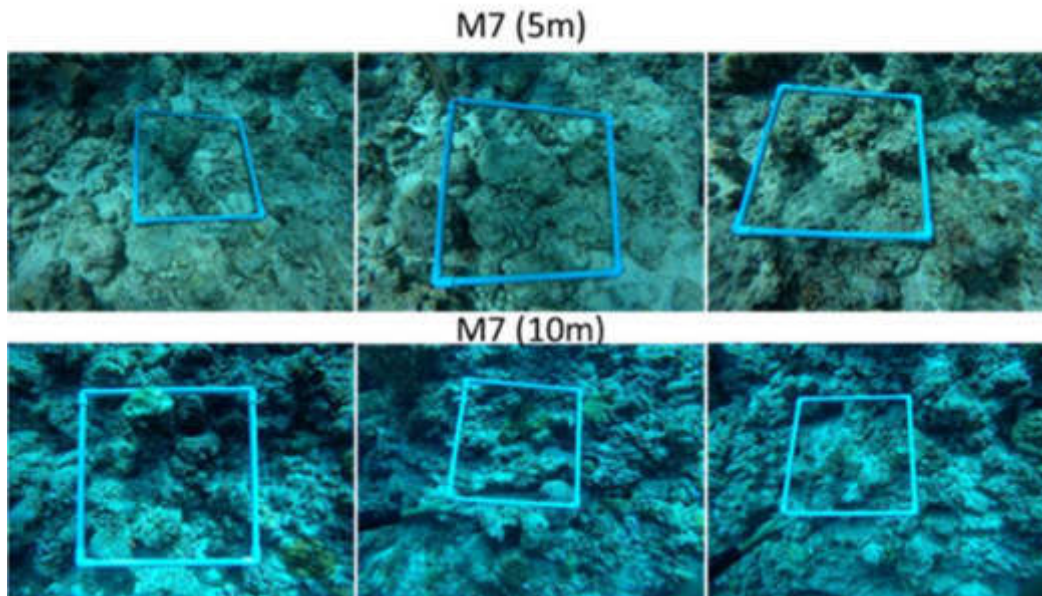


Figure 18: Photos taken from site 7 (M7) (23<sup>rd</sup> April 2018)

### 5.8 Observation during the marine survey in 2019

The highest coral cover was observed at the depth of 10 meters in site M2 adjacent to the current waste dumping area. The results are highlighted in the figure below. Therefore there is the possibility the leachate from land fill are not having negative impacts on the reef at site M2.

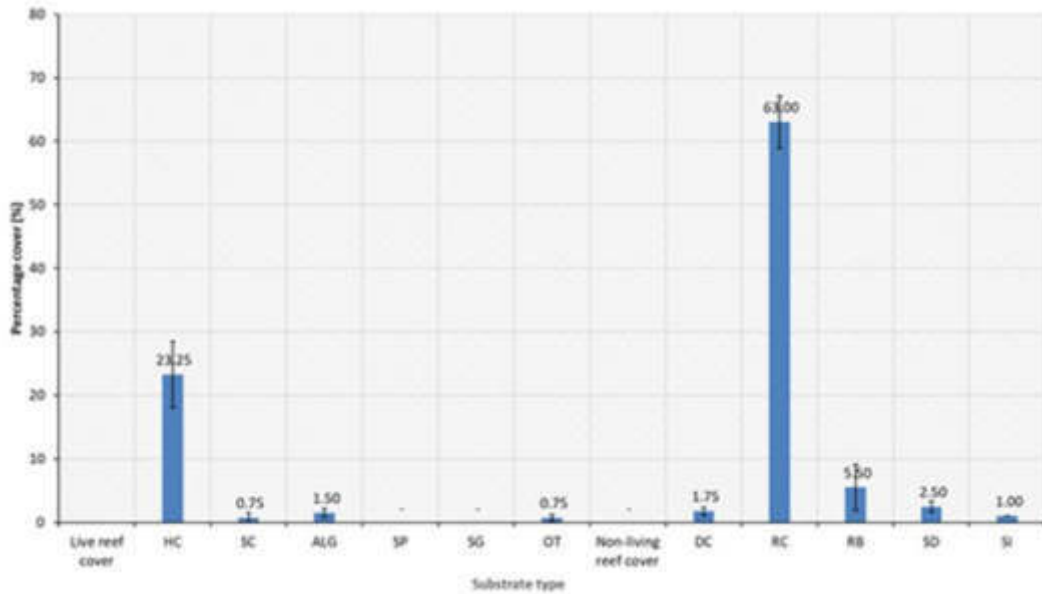


Figure 19: Percentage benthic composition at site 2(M2) at a depth of 10 meter  $\pm$  standard error (SE).

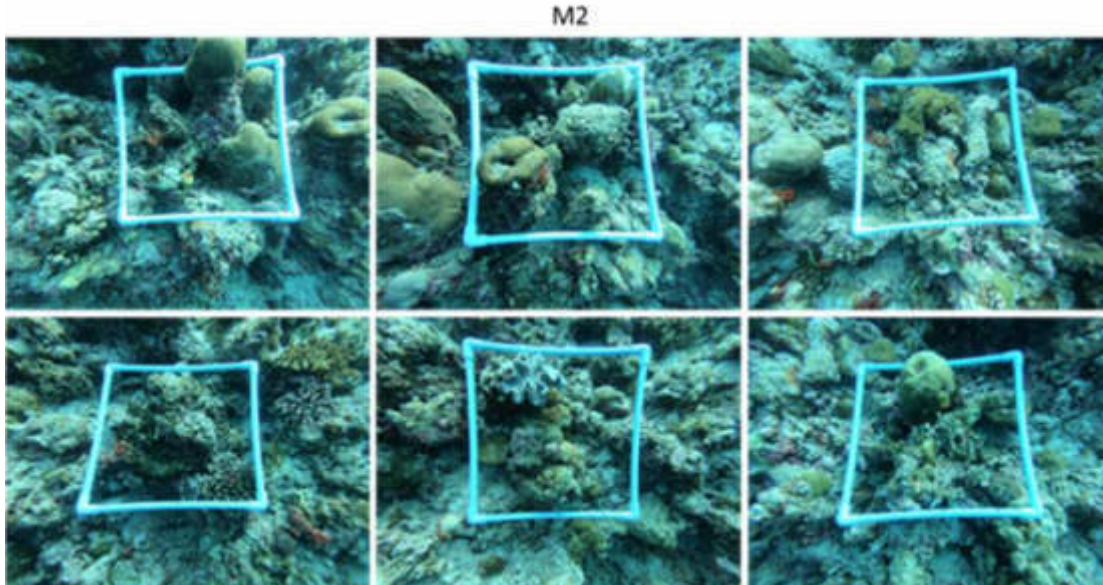


Figure 20: Photos compiled from site 2 (M2) at a depth of 10 meters.

## 5.9 Status of site M8

Site M8 was selected from the Southern rim of the island reef. The site was chosen as this is the proposed location for the hot water discharge outfall. The substrate at the site is dominated by silt along the entire transect line ( $43 \pm 11.69\%$ ). Hard coral cover was observed to be low ( $8 \pm 2.71$ ). 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 Thilafuhi to be spread along most part of the southern side. This has resulted in large areas of the reef being covered with silt. The following image illustrates the reef slope characteristics at site M10.

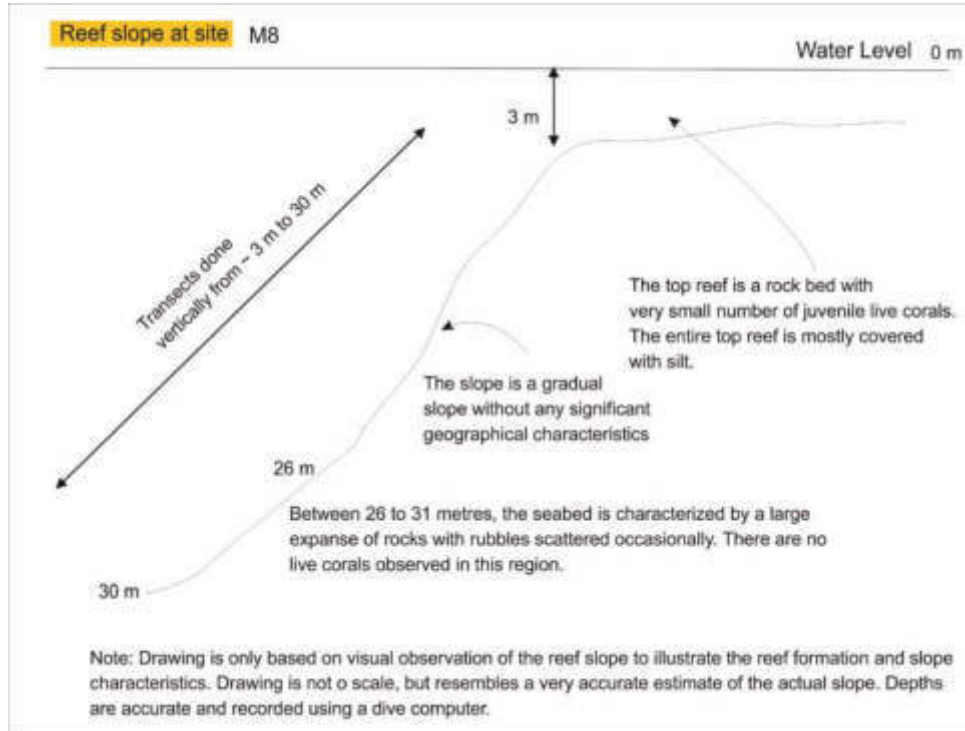


Figure 21: Reef slope characteristics at M8 (1st September 2019).

The following graph outlines the status of site M8.

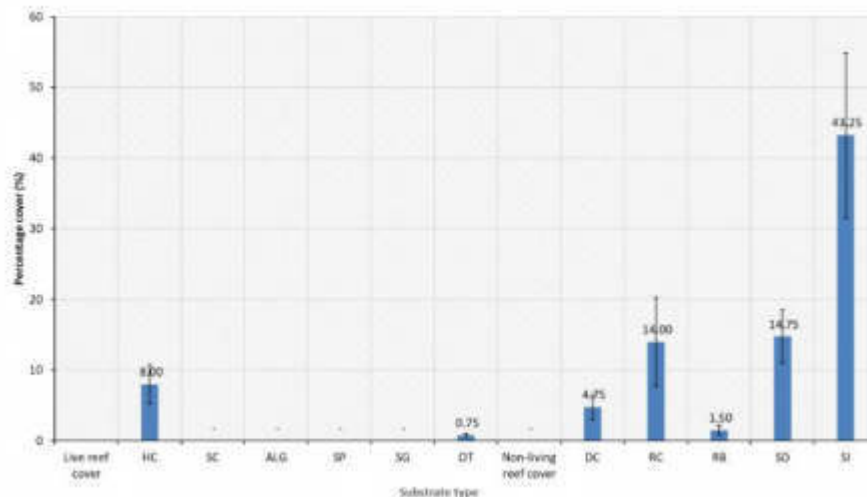


Figure 22: Percentage benthic composition at site M8 at depths from ~ 3 to 30 meters  $\pm$  Standard Error (SE) (1<sup>st</sup> September 2019).



### 5.10 Status of site M9

Site M9 was also selected from the Southern rim of the island reef east of site 1. 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 metres (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.

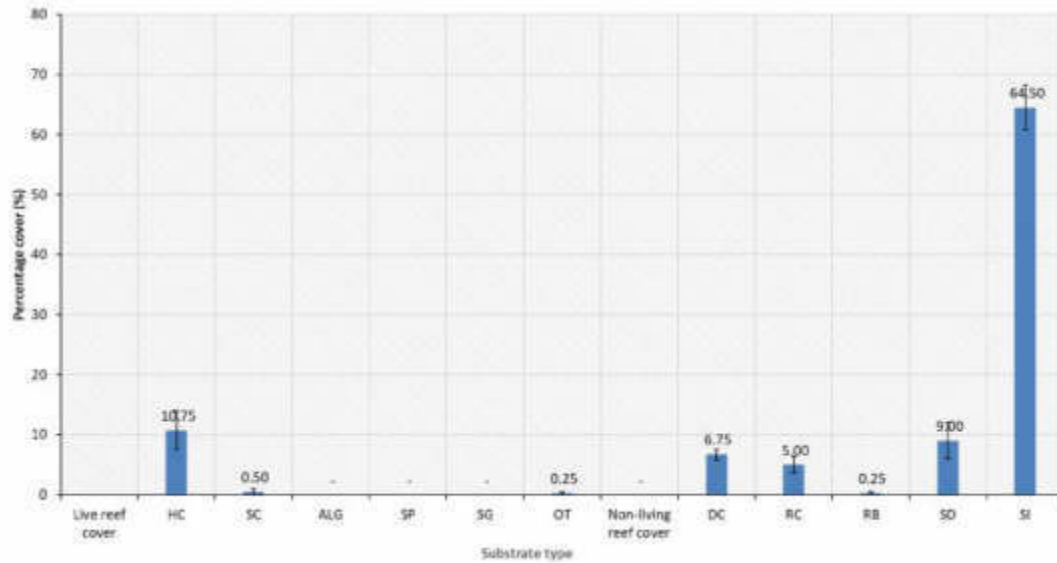


Figure 23: Percentage benthic composition at site M9 at depths from ~ 3 to 30 metres ± SE (1 September 2019). The following image illustrates the reef slope characteristics at site M9.

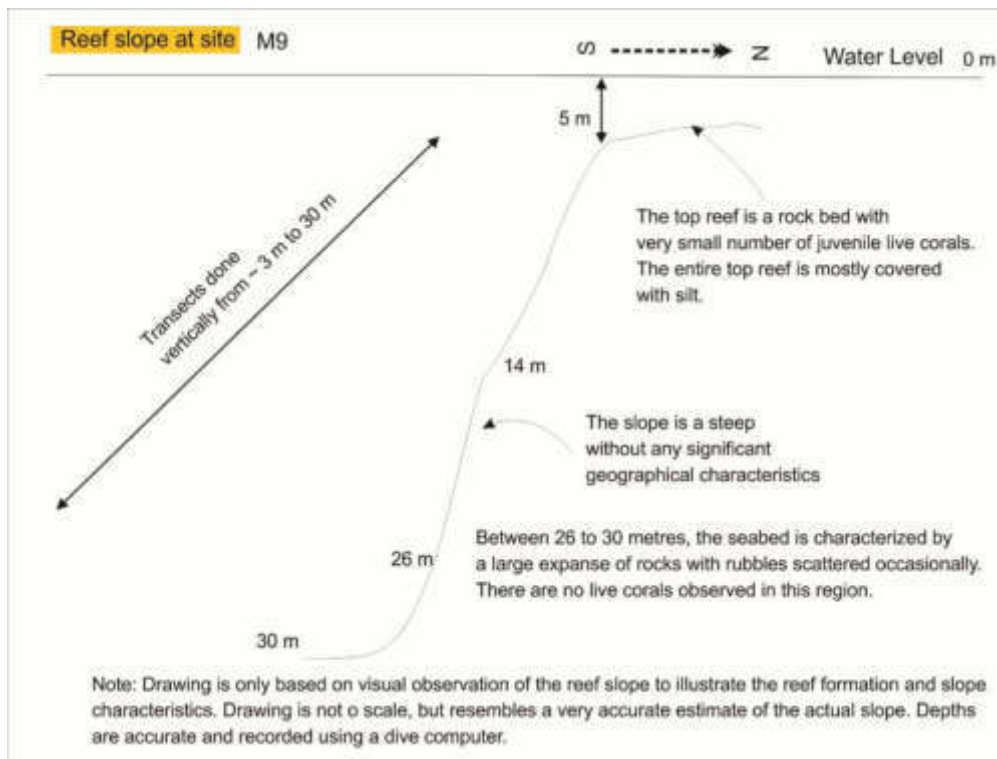


Figure 24: Reef slope characteristics at M9 (1 September 2019).

### 5.11 Status of site M10

Site M10 was also selected from the Southern side of the island reef. The following image illustrates the reef slope characteristics at site M10.

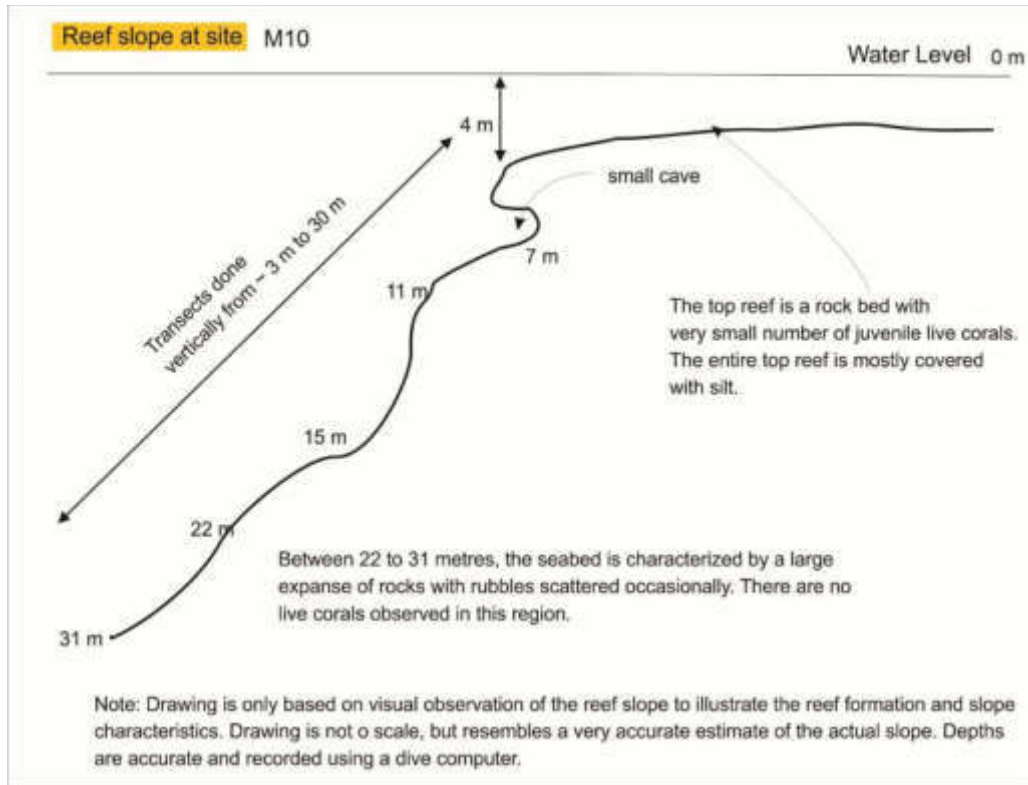


Figure 25: Reef slope characteristics at M10 (1 Sept 2019).

The substrate at the site is dominated by silt ( $58.50 \pm 4.57\%$ ). Hard coral cover was observed to be moderate ( $23.75 \pm 7.43$ ). 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.

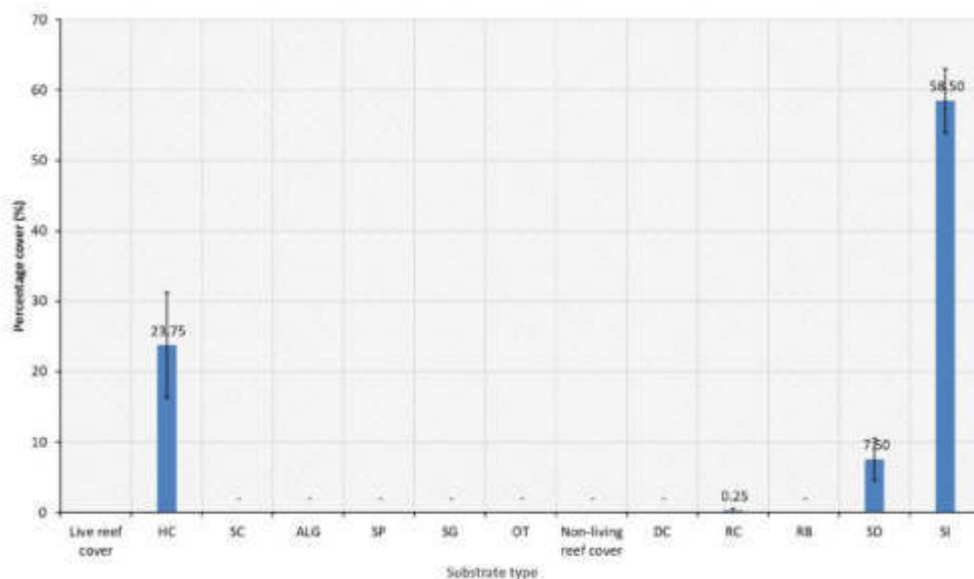


Figure 26: Percentage benthic composition at site M10  $\pm$  SE (1 Sept 2019).

## 5.12 Manta Tow between M9 and M10

The following table outlines the results of the Manta Tow survey that was carried out on 1<sup>st</sup> September from M9 to M10

Table 1: Manta Tow survey results of approximate substrate cover around the reef edge

	Live Coral cover %	Dead coral cover %	Soft corals cover %	Rock cover %	Rubble cover %	Silt cover %	Benthic diversity	Fish diversity
<u>5 metres</u>								
	5	8	-	15	2	70	low	low
<u>10 metres</u>								
	10	6	-	27	7	50	Low	low

The Manta Tow survey showed that coral reef system along the surveyed stretch 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 metres and approximately 10% at 10 metres. 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 metres. The corals in most abundance were massive type coral head belonging to the genus Porites.

### 5.12.1 Protected marine species

During the Manta tow survey, no protected marine species such as sharks or were observed and recorded.

### 5.12.2 Reef Aesthetics

This attribute was assessed by visual observations based on the observer's judgment and experience of the relative merits of a reefs 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:

- a. Very poor (mostly dead corals, pelagic life not abundant and diversity very low, structure uniform).
- b. b. Poor (Lot of dead corals, pelagic life not abundant and diversity low, some differences in structure).
- c. c. Average (Live corals about 10%, pelagic life abundant, diversity low, some structural variations exists).
- d. d. Good (Live corals about 20% pelagic life abundant, diverse, structural variations exists).
- e. e. Very good (Live corals about 30%, pelagic life abundant, diverse, overhangs, and other structures).
- f. f. Excellent (Live corals over 40%, pelagic life very abundant, very diverse, lots of different structures, overhangs, caves, gullies, and different habitat types exists).

Reef aesthetics of Thilafushi's coral reef system (along the 500 metres) 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.

## 5.13 Fish Diversity and Abundance (April 2018)

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. The following table outlines the fish count survey at all the sites.

Table 2: Fish abundances observed at sites 1 to 7 at a depth of 5 and 10 meters.

<b>Family/Subfamily</b>	<b>Site M1</b>		<b>Site M2</b>		<b>Site M3</b>		<b>Site M4</b>		<b>Site M5</b>		<b>Site M6</b>		<b>Site M7</b>	
<b>Depth</b>	<b>5m</b>	<b>10m</b>	<b>5m</b>	<b>10m</b>	<b>5m</b>	<b>10m</b>	<b>5m</b>	<b>10m</b>	<b>5m</b>	<b>10m</b>	<b>5m</b>	<b>10m</b>	<b>5m</b>	<b>10m</b>
Anthias (Anthiadae)	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 brems (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	
	5m	10m	5m	10m	5m	10m	5m	10m	5m	10m	5m	10m	5m	10m
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 ( <i>Cheilinus undulatus</i> )	-	-	-	-	-	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)

### 5.14 Fish Diversity and Abundance (September 2019)

The following table outlines the results of the fish counts along the survey points which was conducted from approximately 3 meters up to 30 meters at each site.

Table 3: Fish abundances observed at sites M8, M9 & M10 on 1<sup>st</sup> September 2019.

Family/Subfamily	Site M8	Site M9	Site M10
Anthias (Anthiadae)	-	C	R
Surgeonfishes (Acanthuridae)	R	C	R
Wrasses (Labridae)	-	-	-
Parrotfishes (Scaridae)	R	-	R
Triggerfishes (Balistidae)	-	-	-
Boxfishes (Ostraciidae)	-	-	-
Damselfishes (Pomacentridae)	-	-	-
Groupers (Serranidae)	-	-	-
Moorish idol (Zanclidae)	-	-	-
Butterflyfishes (Chaetodontidae)	-	-	-
Goatfishes (Mullidae)	-	-	-
Hawkfishes (Cirrhitidae)	-	-	-
Threadfin and Whiptail breems (Scolopsis)	-	-	-
Octopus (Octopodidae)	-	-	-
Fusiliers (Caesionidae)	R	-	R
Rabbitfishes (Siganidae)	-	-	-
Gobies (Gobiidae)	R	-	R
Pipefishes and seahorses (Syngnathinae)	-	-	-
Puffers (Tetraodontidae)	-	-	-
Emperors or scavengers (Lethrinidae)	-	-	-
Jacks and Trevallies (Carangidae)	-	-	-

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).

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### **5.14.1 Plankton tows**

Plankton are the base of the marine food chain. The phytoplankton and zoo plankton 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.

#### **5.14.1.1 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.

#### **5.14.1.2 Data processing methodology**

##### **5.14.1.2.1 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,  $Abundance = \frac{\text{Total Count in the Sample}}{\text{Distance towed} \times \text{Opening area}}$ . 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.

##### **5.14.1.2.2 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,  $Abundance = \frac{\text{Total Count in the Sample}}{\text{Distance towed} \times \text{Opening area}}$ .

#### **5.14.1.3 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.

#### **5.14.1.4 Plankton abundance**

##### **5.14.1.4.1 Zooplankton**

###### **5.14.1.4.1.1 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 4: Abundance of common phyla of zooplankton from sites PKT 1 to PKT 7.

Phyla	Abundance at sites (Individuals/m <sup>3</sup> )						
	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

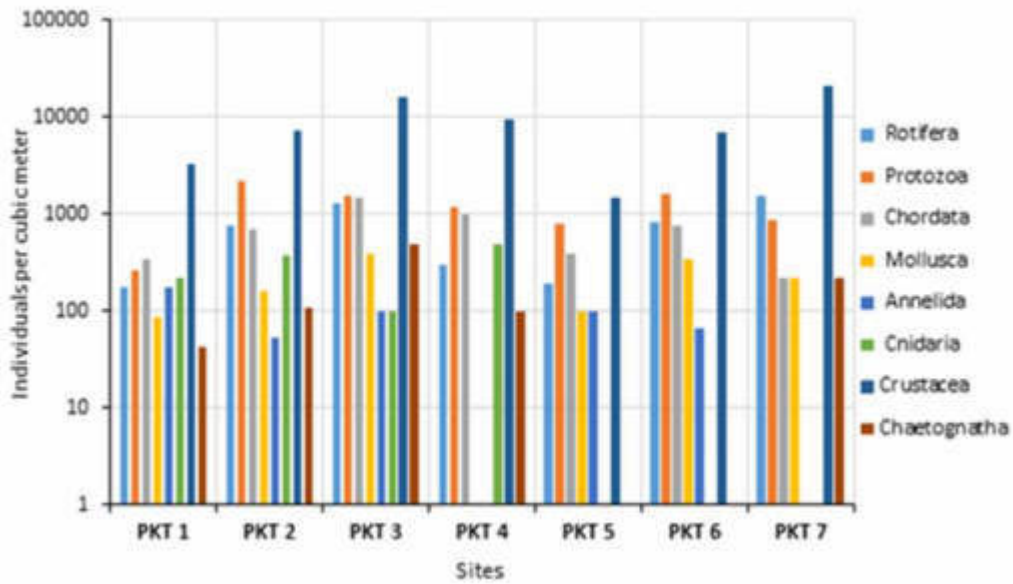


Figure 27: Abundance of common phylum of zooplankton from sites PKT 1 to PKT 7.



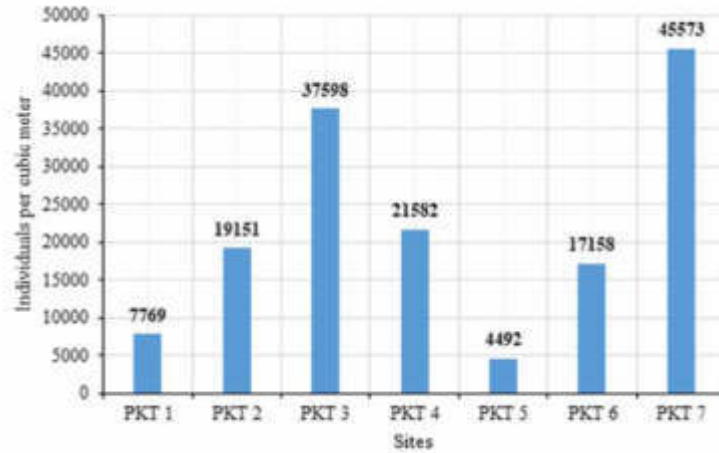


Figure 28: Total abundance of zooplankton from sites PKT 1 to PKT 7.

#### 5.14.1.4.1.2 Copepods

The dominating group of copepods observed in the sites were calanoids. The highest abundance of copepods were observed at site 7 and the lowest abundance of copepods at site 5. The table and figure below outlines the variation in copepod abundance between the sites.

Table 5: Abundance of copepods from sites PKT 1 to PKT 7.

Order	Abundance at Sites (Individuals/m <sup>3</sup> )						
	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

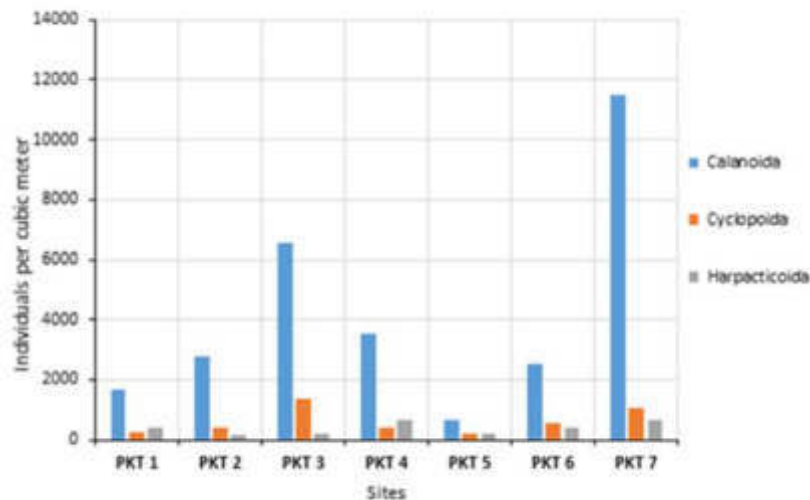


Figure 29: Abundance of copepods from sites PKT 1 to PKT 7.

#### 5.14.1.4.2 Phytoplankton

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 were observed from site 5. The Figures below show the variation in phytoplankton abundance between the sites.

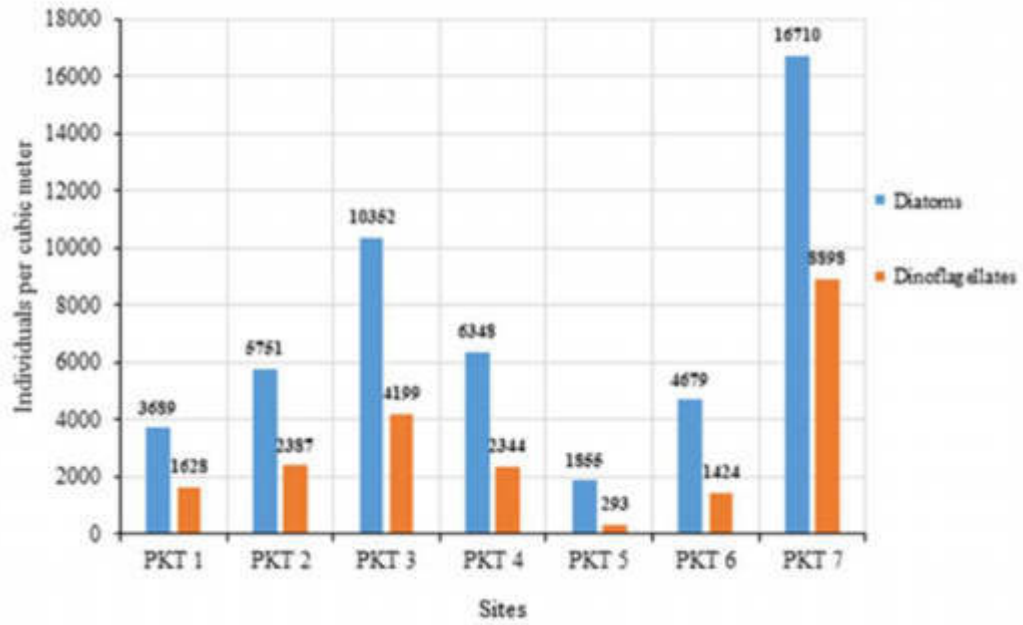


Figure 30: Abundance of diatoms and dinoflagellates from sites PKT 1 to PKT 7.

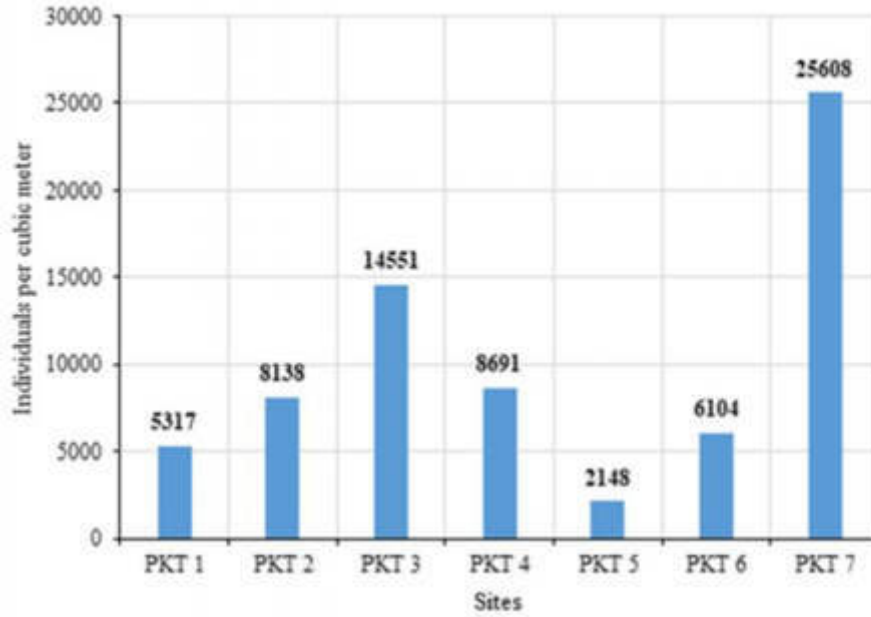


Figure 31: Total abundance of phytoplankton from sites PKT 1 to PKT 7.

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## 6 Conclusion

The coral reef of Thilafushi has been under a lot of stress over the past two decades from the various industrial activities and developments that have occurred on this once barren reef. Over the years, the coral reef has undergone significant direct and indirect impacts resulting from the evolution of this artificial island that has been reclaimed initially from waste and later expanded in a more ecologically sound manner.

Surveys were undertaken in April 2018 and September 2019 to assess the coral reef and its health. The initial surveys were carried out in April 2018 which indicates that the highest coral cover was prevalent at a depth of 10 meters in site M2. This site is adjacent to the current waste dumping area. Therefore based on this results, there is the possibility that one can conclude that the leachate from land fill is not having a significant negative impacts on the reef at site M2 in terms of coral cover. On the overall, the reef around Thilafushi does not indicate a very healthy reef with average coral cover below 20% in most of the surveyed sites (based on the surveys done in April 2018).

A new set of surveys were conducted in three sites, M8, M9, M10, on 1<sup>st</sup> September 2019. This detail marine survey was carried out along a 500 m coastal stretch of house reef on southern site of Thilafushi between M9 and M10. The results indicate that very few (or none at all) marine species are found at a depth of less than 10 m along this stretch. The survey also revealed further that no significant marine life such as live corals, fishes or other pelagic organisms was found at greater depths from 10 m to 30 m along this stretch of house reef. The marine survey carried out in September 2019 found that the reef profiles at M8, M9 and M10 are very identical and at any of these sites, an outfall could be laid. Geographically, these three sites does not pose major challenges when it comes to laying an outfall pipe. There were no sensitive corals nor benthic cover recorded in any of these sites nor are any odd slope formations there.

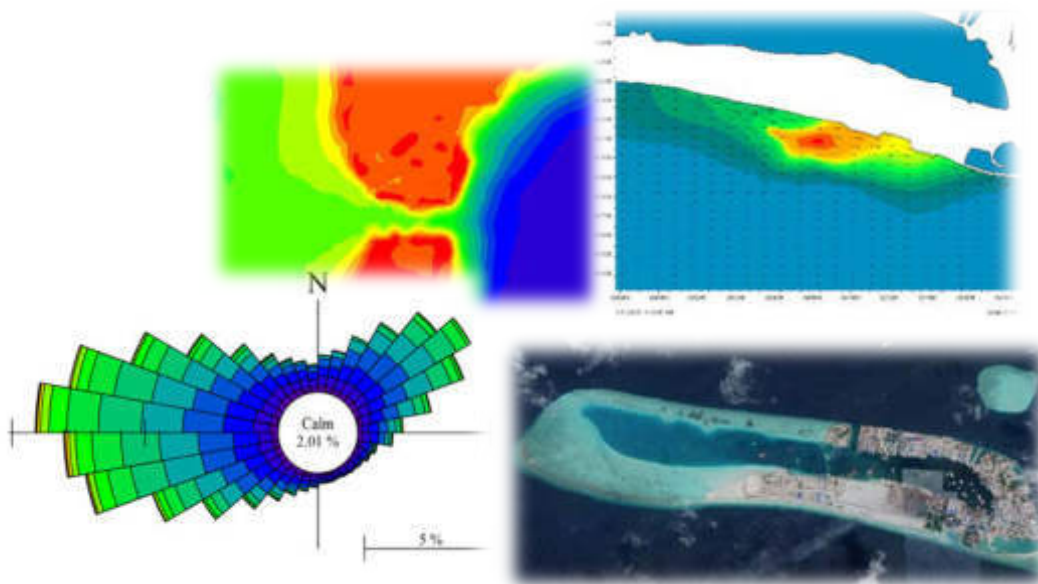
The reef slope at surveyed sites M8, M9 and M10 is characterized by a wall with the majority of the benthic composition being mainly rubble and silt. Along these sites, from a depth of approximately 20 meters and below, there is no live coral cover and the fish life is virtually none existent at the time of the survey on 1<sup>st</sup> September 2019. The southern side of Thilafushi is also exposed to a lot of sedimentation during south-west monsoon, which causes dispersion of sediments along a large area of the reef. This is the reason why the percentage of silt along M8, M9 and M10 were so high during the surveys undertaken in September 2019.

During the surveys in April 2018, one sea turtle was recorded. Sea turtles are very commonly observed throughout the Maldives due to their protected state. Their numbers have grown significantly since they were declared as a protected species in the 1980's. Since then, turtles are observed in a lot of reefs throughout the Maldives. Thilafushi being an artificial island does not possess the right coastal ecology for turtles to lay their eggs and no reports of turtle nests nor eggs have been reported to have been spotted from Thilafushi beaches. Hence, this single observation of a turtle can be confidently declared as an occasional occurrence.



**Water Solutions Pvt. Ltd.**

# **Effluent Dispersion Modelling at Thilafushi Island, Maldives**



**Model Rerun**

**Final Report**

**July 2020**



**Lanka Hydraulic Institute Ltd**

<b>Client</b> Water Solutions Pvt. Ltd		<b>Client's Representative</b> Mr. Ahmed Jameel			
<b>Project</b> Effluent Dispersion Modelling at Thilafushi Island, Maldives – Model Rerun		<b>Project No.</b> 2009			
<b>Authors</b> Eng. Lakshan Fernando Eng. (Ms) Nalika Engiliyage Eng. (Ms) Ganga Caldera		<b>Date</b> July 2020			
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## **1 INTRODUCTION**

Water Solutions Pvt Ltd (WS) is currently assisting Ministry of Environment and Energy (MEE) to undertake an Environmental Impact Assessment (EIA) for Waste Management Project at Thilafushi Island, Maldives. As part of the project, an incinerator is proposed to burn waste material and seawater through an intake will be used to cool condenser. After cooling process, the hot seawater will be re-discharged through outfalls into the sea. As part of the EIA work, the dispersion behaviour of the discharged hot water need to assessed.

Lanka Hydraulic Institute Ltd (LHI) engaged with Water Solutions Pvt Ltd to simulate the effluent dispersion of heat plumes through numerical modelling. The first set of models was simulated in 2018 and the final report was submitted in October 2018. Later, Water Solutions Pvt Ltd requested Lanka Hydraulic Institute Ltd to rerun the model for different outfall orientation and discharge. Hence this report presents the model results for the newly proposed system.

This report includes six chapters. Background of the project and basic methodology used in the study are given in Chapter 1. The details of collected wind data and analysis of it are given in Chapter 2. Wave transformation method and model usage for wave generation are discussed in detail in Chapter 3. In order to assess the water circulation, a set of hydrodynamic models was performed; those methods and results are discussed under Chapter 4. As the main part of study, thermal dispersion modelling system and discussion of its results are presented in Chapter 5. Finally the conclusions are given in Chapter 6.

### **1.1 Background**

The Thilafushi Island is located in North Male Atoll, Maldives, and around 7km westwards to Male City (Figure 1.1). Presently, the island is used as the main waste dumping site in the country capital Male and its adjacent inhabited islands and the airport at Hulhule. The Government of the Maldives has identified solid waste disposal as a priority problem and decided to implement a solid waste management plan to minimize the environmental problem.

As a part of the project, an incinerator has been proposed to burn the waste. The cooling system of incinerator will run using sea water as coolant. The dispersion of hot water in marine environment is required to assess with respect to the coastal process of region.

This island is subjected to two monsoon period namely South-West and North-East; South West monsoon is considered as from May to November while North East as from December to April. Energy of swell waves approach from southern Indian Ocean may reduce due to diffraction and other interaction of other atoll reefs, and mainly sea waves are affected to the island. Sea currents are developed around the island reef mainly wind, wave and tidal effect.



**Figure 1.1: Location of Thilafushi Island**

## **1.2 Objective of the Study**

The discharge of effluent in the coastal area is a sensitive issue in the context of environmental conservation and therefore dispersion of the effluent requires proper assessment to ensure that nearshore coastal environment will not be subjected to pollution and health risk due to discharged effluent. For this purpose it is extremely essential to ensure that effluent constituent is diluted to acceptable levels within the receiving water in the immediate vicinity of discharge point. Secondly, the advection dispersion of the effluent should be favourable to the environment for every monsoon period.

The objective of this modelling task is to simulate the dynamic behaviour of hot water discharged through the outfall, and to assess the impacts on the surrounding areas of the outfalls, near-shore areas and beaches.

## **1.3 Basic Methodology of Study**

Since the hot water dispersion is to be assessed for different monsoons and tidal conditions, at the first stage, wave conditions and tidal conditions require to be developed at site location. In

order to develop wave conditions for different monsoon periods at site location, long period wind data was used in a Wind-Wave Transformation Model (MIKE 21 SW). In order to find out current conditions, a Hydrodynamic Model (MIKE 21 HD) was utilised with giving wind/wave condition and tidal variation as input parameters. After that thermal dispersion model, CORMIX was used to find out initial dilution in near field and its results were further applied to the Hydrodynamic Model couple with thermal dispersion tool to assess the dilution in 2D plain.

Main activities of study are given below.

1. Obtain and analyze of UK Met Office (UKMO) wind data at site location.
2. Develop model bathymetries using Admiralty Chart Maps and measured data
3. Find out wave condition near the site using Wind-Wave Transformation Model (MIKE 21 SW)
4. Simulate a regional Hydrodynamic Model using known tidal boundaries in order to find out hydrodynamic conditions at local model boundaries.
5. Simulate local Hydrodynamic Model with applying wind, wave and tidal condition and find out current condition at site for different monsoons.
6. Apply current conditions obtained from Hydrodynamic Model in CORMIX model and find out initial dilution in near field.
7. Simulate again Hydrodynamic Model couple with thermal dispersion tool and applying CORMIX model results to assess the dilution in 2D plain.

## 2 WIND DATA AND WAVE GENERATION

The wind data was obtained based on the hind-cast data from Numerical Weather Prediction Atmospheric Global model of the UK Met Office (UKMO). The available nearest suitable data point (3.984 N, 73.477 E) which located in the South Male Atoll was selected with considering fetch length and open sea area which would be adopted in the wind wave model (Figure 2.1). Real time observational data from satellite wind radar, ship and buoy data were (and are) assimilated into the atmospheric model. This process strives to give the best possible rendition of the 'surface' wind field at analysis or run time, in order to give an optimum forecast. In effect, the atmospheric wind fields represent a hybrid of numerical and real data. It is the analysis time steps of these models of whatever resolution which go to make up the archive on which hind-casts are based.

Wind speed and wind direction for 30 years during January 1986 to June 2016 were utilized for the study. The data set contents 89,112 no of records with the interval of 3 hours. Analyses were carried out to assess the distribution of wind parameters and given in the Figure 2.2 and the Table 2.1.



Figure 2.1: Wind Data Extracted Location

### 2.1 Analysis of UKMO Wind Data

Analysis of raw data before apply it in the model is an essential part in wind - wave transformation numerical modelling process to gain an idea about the wind climates of the region. Therefore analyses for UKMO data were carried out based on wind speed and direction.

Figure 2.2 illustrates clearly wind distribution pattern in 360° angle. The length of slices represents the percentage of occurrence while the colour code for the wind speeds. Furthermore, Table 2.1 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 reached from South- East quadrant is negligible.

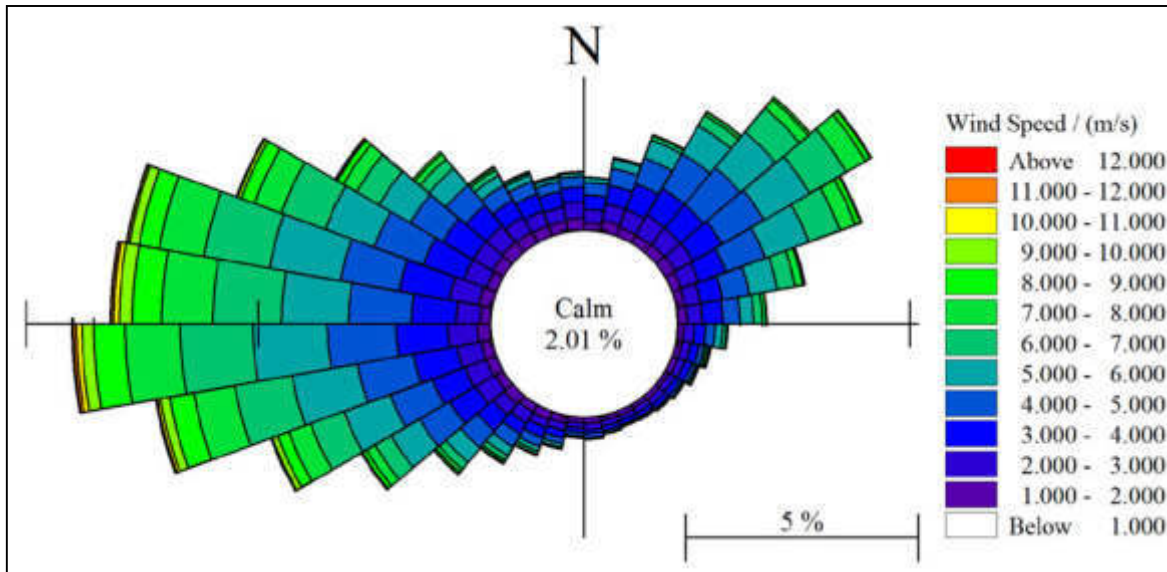


Figure 2.2: Annual Distribution of Wind

**Table 2.1: Directional Distribution of Wind Statistics (Percentage Occurrence for Wind Speed vs Wind Direction)**

Dir (Deg N) Speed (m/s)	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	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	0.06	0.05	0.06	0.07	0.05	0.04	0.09	0.03	0.03	0.05	0.04	0.06	0.05	0.04	0.05	0.08	0.03	0.06	0.07	0.06	0.06	0.06	0.07	0.06	0.11	0.03	0.08	0.07	0.08	0.06	0.07	0.06	0.06	0.03	2.07	
1 - 2	0.17	0.24	0.20	0.21	0.24	0.26	0.21	0.19	0.20	0.14	0.14	0.14	0.10	0.12	0.10	0.10	0.11	0.12	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	0.29	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	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	0.31	0.40	0.57	0.67	0.67	0.72	0.69	0.49	0.42	0.24	0.19	0.16	0.13	0.10	0.09	0.09	0.09	0.08	0.08	0.16	0.22	0.27	0.44	0.65	0.73	0.96	1.10	0.95	1.13	0.92	0.77	0.58	0.41	0.38	0.35	0.26	16.39	
4 - 5	0.26	0.38	0.58	0.86	1.03	1.06	0.90	0.61	0.37	0.20	0.10	0.08	0.07	0.03	0.04	0.04	0.05	0.09	0.08	0.13	0.20	0.31	0.48	0.75	0.97	1.26	1.48	1.36	1.31	1.11	0.82	0.55	0.38	0.29	0.21	0.19	18.62	
5 - 6	0.10	0.19	0.42	0.68	0.99	1.13	1.00	0.59	0.30	0.16	0.06	0.05	0.03	0.03	0.03	0.01	0.04	0.05	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	0.02	0.04	0.09	0.26	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	0.03	0.04	0.06	0.11	0.20	0.40	0.76	1.24	1.56	1.49	1.43	0.98	0.57	0.25	0.12	0.07	0.03	0.02	12.89	
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	0.02	0.02	0.02	0.06	0.09	0.21	0.50	0.90	1.16	1.07	0.98	0.62	0.33	0.15	0.05	0.03	0.00	0.01	7.78	
8 - 9		0.00	0.03	0.02	0.05	0.12	0.11	0.04	0.01	0.01	0.02	0.00							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				0.02	0.04	0.05	0.03	0.00	0.00	0.00	0.00										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						0.00	0.01															0.01	0.00	0.01	0.03	0.08	0.13	0.12	0.08	0.02	0.02	0.00					0.47	
11 - 12																									0.01	0.02	0.06	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																											0.01	0.01										0.02
14 - 15																																						0.00
15 - 16																												0.00										0.00
<b>Total</b>	<b>1.18</b>	<b>1.70</b>	<b>2.42</b>	<b>3.33</b>	<b>4.44</b>	<b>5.22</b>	<b>4.42</b>	<b>2.86</b>	<b>2.00</b>	<b>1.12</b>	<b>0.81</b>	<b>0.69</b>	<b>0.54</b>	<b>0.51</b>	<b>0.44</b>	<b>0.41</b>	<b>0.47</b>	<b>0.58</b>	<b>0.51</b>	<b>0.81</b>	<b>1.08</b>	<b>1.53</b>	<b>2.28</b>	<b>3.60</b>	<b>5.26</b>	<b>7.42</b>	<b>9.13</b>	<b>8.22</b>	<b>8.09</b>	<b>6.03</b>	<b>4.27</b>	<b>2.89</b>	<b>1.95</b>	<b>1.56</b>	<b>1.28</b>	<b>1.06</b>	<b>100</b>	

### **3 WAVE CLIMATE MODELLING**

#### **3.1 Introduction**

Wave climate condition is one of main input parameter for the hydrodynamic model. Therefore it is required to develop wave climate conditions for different monsoons in order to set up the hydrodynamic model. The wave data is not available for the desired location on the sea fit for usage. Most of the time wave data measured point is far away from the project location and it has to be transformed to a desired location by a model. In this case, MIKE 21 numerical wave model was used for wind wave generation and transformation process. The objectives of the wave climate modelling of this scheme is establishing nearshore wave climate at the site.

#### **3.2 Model Used – MIKE 21 SW Model System**

MIKE 21 SW includes a new generation spectral wind-wave model based on unstructured mesh. The model simulates the growth, decay and transformation of wind-generated waves and swells in offshore and coastal areas. It includes two different formulations, namely, directional decoupled parametric formulation and fully spectral formulation. The directional decoupled parametric formulation is based on a parameterization of the wave action conservation equation. The parameterization is made in the frequency domain by introducing the zeroth and first moment of the wave action spectrum as dependent variables. The fully spectral formulation is based on the wave action conservation equation, where the directional-frequency wave action spectrum is the dependent variable.

The basic conservation equations are formulated in either Cartesian co-ordinates for small-scale applications or Polar Spherical co-ordinates for large-scale applications.

MIKE 21 SW includes the following physical phenomena:

- Wave growth by action of wind
- Non-linear wave-wave interaction
- Dissipation due to white capping
- Dissipation due to bottom friction
- Dissipation due to depth induced wave breaking
- Refraction and shoaling due to depth variation
- Wave-current interaction
- Effect of time varying water depth and flooding and drying

The discretization of the governing equation in geographical and spectral space is performed using cell-centered finite volume method. In the geographical domain, an unstructured mesh

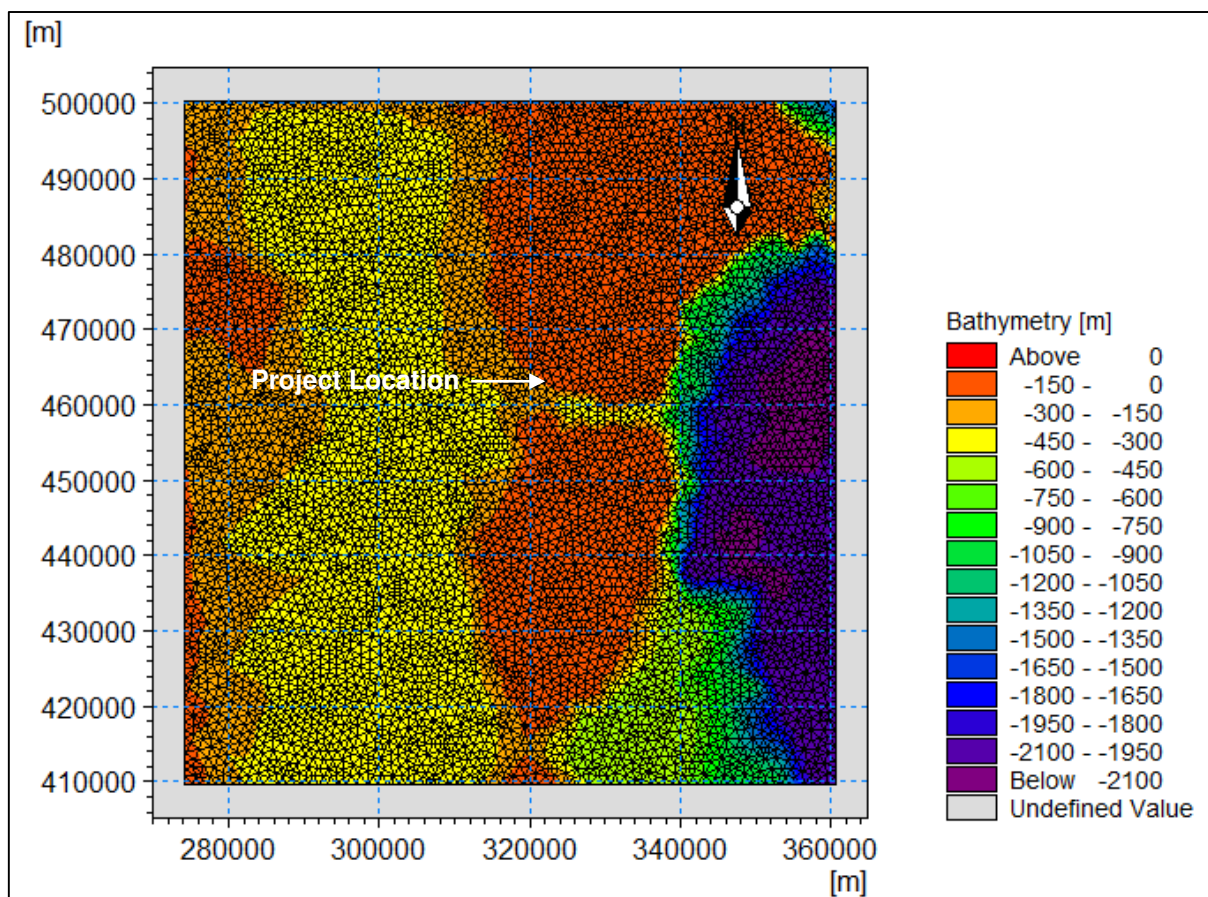


technique is used. The time integration is performed using a fractional step approach where a multi-sequence explicit method is applied for the propagation of wave action.

### 3.3 Model Setup

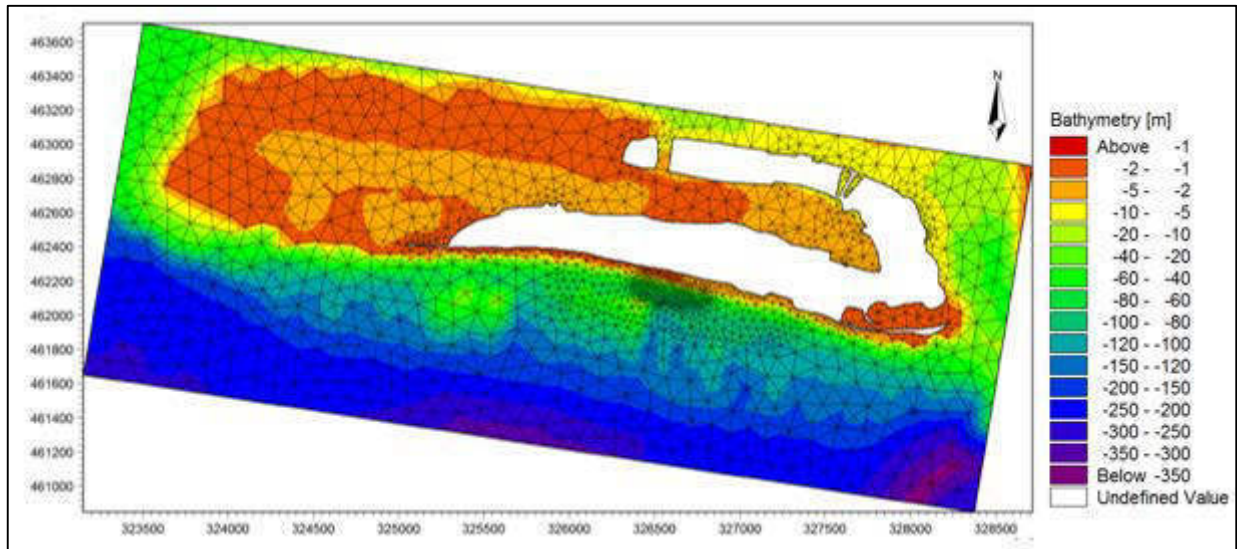
MIKE 21 SW model was used to generate waves and transfer them to the proposed site location base on UKMO wind data. All data set obtained from UKMO; i.e. 3 hour interval data from 1986 to 2016 were transferred to the site location.

The model was established by digitizing from the Admiralty charts No. 1013 & 3323, and near shore bathymetry data which were provided by WS. The preparation of model bathymetry was completed using flexible mesh as a requirement of SW model with reference to the Mean Sea Level. Figure 3.1 shows the regional model bathymetry of MIKE 21 SW model.



**Figure 3.1: Wave Model Bathymetry - Regional**

Additionally, a local model was also incorporated to improve the performance and accuracy of results. Then deep sea wind generated waves were transferred to 300m depth by regional model and then analysed wave data were further transferred to the site location by local model. The selected local model which the offshore boundary laid on around 300m depth is shown in Figure 3.2.



**Figure 3.2: Wave Model Bathymetry - Local**

### 3.4 Model Results

The wave analysis details of results obtained from the regional model at 300m depth are given below. The extracted results were analysed considering different seasons such as annual, South-West and North-East monsoon periods. South West monsoon was considered as from May to November while North East as from December to April. Tables 3.1 to 3.6 indicate the percentage of occurrence of waves, and their average peak wave period corresponding to the wave height and direction while Figures 3.3 to 3.5 graphically illustrate the wave height distribution patten in 360° angle.

**Table 3.1: Annual Directional Distribution of Wave Height at 300m Depth (Percentage of Occurrence)**

Dir (Deg.N) Hs (m)	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	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 -- 0.2	0.71	0.88	0.99	1.17	1.36	1.30	1.30	1.05	0.80	0.67	0.47	0.41	0.32	0.33	0.28	0.26	0.25	0.28	0.29	0.36	0.43	0.53	0.62	0.78	0.89	1.01	1.10	1.31	1.20	1.14	1.11	0.98	0.83	0.81	0.73	0.69	27.64		
0.2 -- 0.4	0.19	0.32	0.49	0.99	1.73	2.78	3.30	2.53	1.47	0.76	0.43	0.27	0.23	0.17	0.15	0.13	0.14	0.13	0.15	0.18	0.25	0.37	0.58	1.03	1.52	2.41	2.93	2.76	2.04	1.27	0.72	0.46	0.28	0.19	0.16	0.16	33.67		
0.4 -- 0.6		0.00	0.01	0.02	0.09	0.44	1.06	0.90	0.41	0.18	0.11	0.07	0.03	0.02	0.01	0.01	0.01	0.02	0.02	0.05	0.12	0.22	0.59	1.59	3.40	4.53	4.29	2.76	1.31	0.41	0.14	0.05	0.01	0.01			22.88		
0.6 -- 0.8			0.00	0.00	0.01	0.01	0.03	0.03	0.01	0.00	0.01	0.00	0.00	0.00	0.00			0.00	0.00	0.00	0.01	0.05	0.15	0.52	2.17	3.58	2.84	1.15	0.30	0.04	0.00	0.00	0.00	0.00			10.95		
0.8 -- 1			0.00	0.00	0.00		0.00	0.00	0.00	0.00			0.00		0.00	0.00						0.00	0.03	0.13	0.81	1.56	0.97	0.19	0.03	0.00		0.00		0.00				3.75	
1 -- 1.2			0.00	0.00	0.00	0.00										0.00			0.00				0.00	0.01	0.18	0.42	0.19	0.03	0.00		0.00		0.00					0.85	
1.2 -- 1.4		0.00	0.00		0.00	0.00										0.00	0.00	0.00								0.02	0.11	0.04						0.00	0.00			0.17	
1.4 -- 1.6					0.00			0.00	0.00																	0.00	0.01	0.00			0.00	0.00	0.00	0.00					0.03
1.6 -- 1.8				0.00		0.00	0.00		0.00						0.00												0.00	0.00	0.00		0.00	0.00		0.00					0.01
1.8 -- 2					0.00			0.00													0.00		0.00															0.01	
2 -- 2.2					0.00	0.00		0.00	0.00										0.00	0.00											0.00			0.00				0.01	
Above 2.2		0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00				0.00						0.00	0.00						0.00			0.00					0.02	
Total	0.90	1.20	1.49	2.19	3.19	4.53	5.69	4.52	2.68	1.61	1.02	0.74	0.58	0.52	0.44	0.39	0.41	0.43	0.46	0.59	0.82	1.15	1.97	4.06	8.98	13.64	12.36	8.20	4.87	2.85	1.97	1.49	1.12	1.02	0.90	0.85	100.00		

**Table 3.2: Annual Directional Distribution of Peak Wave Period at 300m Depth**

Dir (Deg.N) Hs (m)	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	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	Average	
0 -- 0.2	1.8	1.9	1.9	1.9	2.0	2.0	2.0	2.0	1.9	2.0	1.9	1.8	1.9	1.9	1.8	1.8	2.1	1.9	1.9	1.8	1.7	1.7	1.8	1.8	1.8	1.8	1.9	1.9	1.9	1.8	1.8	1.8	1.8	1.8	1.7	1.7	1.9	
0.2 -- 0.4	2.3	2.5	2.5	2.5	2.5	2.6	2.7	2.7	2.7	2.7	2.7	2.8	2.8	2.8	2.8	3.0	3.1	3.2	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.9	2.8	2.7	2.6	2.5	2.4	2.4	2.4	2.8	
0.4 -- 0.6		9.1	7.8	7.0	3.2	3.0	3.1	3.1	3.1	3.2	3.4	3.5	3.3	4.3	7.6	8.5	4.8	8.8	3.6	3.6	3.7	3.8	3.8	3.8	3.8	3.7	3.7	3.6	3.5	3.3	3.4	3.2	3.6	4.9			3.6	
0.6 -- 0.8			11.6	10.9	12.4	8.7	7.3	5.3	6.4	5.2	3.5	6.5	13.3	11.5	13.4			19.9	4.0	9.7	4.2	4.2	4.3	4.3	4.2	4.2	4.1	4.0	3.9	3.7	8.9	14.7	13.5	12.9			4.2	
0.8 -- 1			13.0	14.1	14.7		10.7	12.2	11.0	12.7			11.8	19.4	7.9	7.0							4.7	5.3	4.6	4.6	4.5	4.4	4.3	4.2	4.1		14.2		12.4			4.5
1 -- 1.2			12.3	10.9	15.9	12.2										12.1		12.3					5.0	5.0	4.9	4.8	4.7	4.6	10.9		13.0		16.3				5.1	
1.2 -- 1.4		13.5	12.7		16.6	13.8										13.1	9.8	14.4								5.2	5.1	5.0					14.4	14.0				6.0
1.4 -- 1.6					16.7			14.1	12.8																	5.5	5.3	5.2			11.8	14.3	18.8	18.0				9.2
1.6 -- 1.8				13.0		14.2	11.2		14.5						21.2											5.4	5.4	11.6		13.6	16.0		15.8				13.4	
1.8 -- 2					15.6			13.0													12.7																	14.8
2 -- 2.2					12.8	13.4		14.7	16.9										10.9	12.2												19.8		14.2				15.3
Above 2.2		17.7	15.1		10.1	12.8	16.4	12.8	15.6	19.6		16.8	13.1				20.9				16.4			15.3	15.4						16.2		15.3				16.3	
Average	1.9	2.1	2.3	2.2	2.4	2.5	2.6	2.6	2.6	2.5	2.4	2.3	2.4	2.3	2.5	2.4	2.5	2.5	2.3	2.3	2.4	2.6	3.0	3.3	3.7	3.7	3.5	3.2	2.9	2.5	2.3	2.1	2.0	2.0	1.9	1.8	3.0	

**Table 3.3: Directional Distribution of Wave Height for South-West Monsoon at 300m Depth (Percentage of Occurrence)**

Dir (Deg.N) Hs (m)	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	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 -- 0.2	0.09	0.09	0.08	0.06	0.07	0.03	0.04	0.05	0.07	0.09	0.08	0.08	0.15	0.21	0.24	0.20	0.25	0.31	0.38	0.49	0.60	0.74	0.84	1.13	1.18	1.17	1.19	1.32	1.04	0.79	0.68	0.45	0.30	0.21	0.19	0.10	15.00
0.2 -- 0.4	0.00		0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.08	0.13	0.15	0.21	0.22	0.27	0.35	0.45	0.65	1.10	1.88	2.55	3.87	4.13	3.52	2.08	1.11	0.57	0.27	0.13	0.04	0.03	0.02	23.96
0.4 -- 0.6			0.01	0.00	0.00		0.01	0.00		0.00	0.00			0.01	0.01	0.01	0.02	0.03	0.05	0.10	0.23	0.37	1.07	3.00	6.42	8.04	7.35	4.46	2.04	0.66	0.24	0.06	0.00	0.00			34.20
0.6 -- 0.8			0.01	0.01	0.01	0.01								0.00	0.00				0.00	0.00	0.02	0.08	0.31	1.03	4.22	6.25	4.86	1.94	0.57	0.09	0.01					19.41	
0.8 -- 1				0.00	0.00	0.00	0.01						0.00			0.00						0.00	0.04	0.22	1.24	2.47	1.63	0.33	0.07	0.01						6.03	
1 -- 1.2			0.01	0.00	0.00	0.00												0.00					0.00	0.02	0.19	0.49	0.33	0.05	0.01				0.00			1.10	
1.2 -- 1.4			0.00		0.00											0.00		0.01								0.01	0.11	0.07									0.21
1.4 -- 1.6											0.01															0.01	0.02	0.01				0.00	0.00				0.05
1.6 -- 1.8				0.00			0.00		0.00																		0.00	0.00	0.00								0.02
1.8 -- 2					0.01			0.00																													0.01
2 -- 2.2						0.00			0.00										0.00	0.00																	0.01
Above 2.2			0.00		0.00	0.00			0.00														0.00														0.01
<b>Total</b>	0.09	0.09	0.12	0.08	0.10	0.05	0.07	0.07	0.09	0.11	0.10	0.10	0.18	0.30	0.37	0.37	0.49	0.58	0.70	0.95	1.30	1.85	3.36	7.28	15.82	22.44	19.56	11.61	5.80	2.65	1.49	0.79	0.44	0.25	0.22	0.12	100.00

**Table 3.4: Directional Distribution of Peak Wave Period for South-West Monsoon at 300m Depth**

Dir (Deg.N) Hs (m)	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	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	Average	
0 -- 0.2	1.4	2.5	4.8	2.1	2.4	2.4	1.3	1.4	2.7	1.6	1.8	1.7	2.1	1.9	1.9	1.8	1.8	1.9	1.8	1.8	1.8	1.8	1.8	1.8	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.8	1.8	1.7	2.0	1.6	1.6	1.9
0.2 -- 0.4	2.2		5.3	4.1	6.1	8.6	3.7	10.3	11.5	7.9	2.5	3.7	2.7	2.7	2.8	3.0	2.9	3.1	3.1	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.9	2.9	2.8	2.7	2.5	2.4	2.4	2.4	2.4	3.0	
0.4 -- 0.6			11.7	9.3	10.1		12.2	7.9		7.9	15.7	8.1		6.8	3.3	5.9	3.8	3.5	3.5	3.7	3.8	3.8	3.8	3.8	3.8	3.8	3.7	3.7	3.6	3.5	3.4	3.2	3.1	3.1	13.0		3.7	
0.6 -- 0.8			11.5	9.0	9.9		12.7							11.5	17.2				4.0	4.2	4.2	4.2	4.3	4.2	4.2	4.2	4.1	4.0	3.9	3.7	3.6						4.2	
0.8 -- 1				14.1	16.1		10.7	12.2								7.9							4.6	4.7	4.6	4.6	4.5	4.4	4.3	4.2	4.1							4.5
1 -- 1.2			12.3	10.3	13.1	13.0													12.3				4.9	5.0	4.9	4.8	4.7	4.6	10.9					18.7			5.1	
1.2 -- 1.4			12.7		16.6											13.1		13.5								5.2	5.1	5.0										5.9
1.4 -- 1.6											14.3															5.5	5.3	5.2				11.8	13.6					8.6
1.6 -- 1.8				13.0			11.2		14.5																		5.4	5.4	11.6									11.1
1.8 -- 2					15.6			13.0																														14.7
2 -- 2.2						13.4			13.1										10.9	12.2																		12.6
Above 2.2			15.8		10.1	12.8			20.0														15.3															11.5
<b>Average</b>	1.5	2.5	6.8	4.0	6.2	7.1	6.0	4.4	5.8	2.6	3.5	2.0	2.4	2.3	2.3	2.6	2.4	2.5	2.5	2.5	2.6	2.7	3.1	3.3	3.7	3.7	3.6	3.3	3.0	2.7	2.4	2.1	2.0	2.2	1.7	1.7	3.4	

**Table 3.5: Directional Distribution of Wave Height for North East Monsoon at 300m Depth (Percentage of Occurrence)**

Dir (Deg.N) Hs (m)	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	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 -- 0.2	1.31	1.73	2.15	2.52	2.85	2.81	2.76	2.01	1.42	1.01	0.65	0.53	0.31	0.28	0.18	0.12	0.16	0.08	0.07	0.07	0.15	0.12	0.07	0.13	0.16	0.20	0.27	0.31	0.33	0.48	0.70	0.87	0.85	0.98	1.04	1.18	30.86	
0.2 -- 0.4	0.62	0.98	1.59	3.31	5.87	9.57	11.03	7.95	4.07	1.84	0.87	0.60	0.33	0.22	0.12	0.07	0.04		0.02	0.01	0.02	0.03	0.02	0.07	0.11	0.20	0.31	0.49	0.55	0.51	0.45	0.53	0.43	0.42	0.42	0.46	54.14	
0.4 -- 0.6		0.01	0.01	0.07	0.34	1.67	4.06	3.32	1.42	0.62	0.33	0.20	0.05	0.01	0.03	0.01			0.00		0.01	0.02	0.00	0.04	0.20	0.21	0.30	0.17	0.13	0.10	0.07	0.03	0.02	0.01		0.01	13.49	
0.6 -- 0.8					0.01	0.01	0.10	0.11	0.01	0.01	0.02	0.00	0.00									0.01	0.00		0.11	0.33	0.18	0.03	0.00		0.00		0.00				0.95	
0.8 -- 1																							0.02	0.02	0.16	0.18	0.02							0.00			0.41	
1 -- 1.2				0.00											0.00											0.01	0.06	0.01			0.00						0.10	
1.2 -- 1.4		0.00																								0.00											0.01	
1.4 -- 1.6																																	0.00	0.00				0.01
1.6 -- 1.8															0.00																0.00	0.00					0.01	
1.8 -- 2																																			0.00		0.00	
2 -- 2.2																																					0.00	
Above 2.2								0.00	0.00	0.00							0.00																					0.02
Total	1.94	2.73	3.75	5.89	9.08	14.06	17.95	13.40	6.93	3.48	1.87	1.33	0.69	0.52	0.34	0.20	0.20	0.08	0.10	0.09	0.19	0.17	0.13	0.26	0.79	1.13	1.08	1.00	1.02	1.09	1.23	1.44	1.31	1.43	1.45	1.64	100.00	

**Table 3.6: Directional Distribution of Peak Wave Period for North East Monsoon at 300m Depth**

Dir (Deg.N) Hs (m)	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	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	Average	
0 -- 0.2	1.8	1.9	1.9	1.9	2.0	2.0	2.0	2.0	1.9	2.1	1.8	1.8	1.8	1.8	2.2	1.8	2.4	2.1	2.8	1.9	2.0	1.5	1.9	1.9	1.6	1.8	1.7	1.8	1.9	1.9	1.9	1.8	1.7	1.8	1.8	1.8	1.8	1.9
0.2 -- 0.4	2.3	2.4	2.4	2.4	2.5	2.6	2.7	2.7	2.7	2.7	2.7	2.7	2.9	2.8	2.8	2.9	3.1		2.5	2.6	2.9	2.8	3.1	2.8	3.0	2.9	3.0	2.9	2.9	2.8	2.7	2.6	2.5	2.4	2.4	2.3	2.6	
0.4 -- 0.6		6.5	5.0	2.9	3.0	3.0	3.0	3.1	3.1	3.1	3.2	3.2	3.3	3.2	7.4	7.2			7.6		3.8	3.9	3.7	3.7	3.8	3.7	3.6	3.5	3.4	3.3	3.7	3.1	3.0	2.9		2.8	3.1	
0.6 -- 0.8					3.2	3.3	3.4	3.6	3.4	8.7	3.5	3.6	14.2									4.3	4.5		4.3	4.2	4.1	3.9	3.8		10.0		13.5				4.1	
0.8 -- 1																							6.9	4.8	4.6	4.5	4.4								12.4		4.8	
1 -- 1.2				14.5												12.1															13.0						6.1	
1.2 -- 1.4		13.5																																			9.3	
1.4 -- 1.6																																		18.8	18.0		18.4	
1.6 -- 1.8															21.2																13.6	13.3					16.0	
1.8 -- 2																																			14.2		14.2	
2 -- 2.2																																					17.5	
2.2 -- 2.4								12.8	11.1	19.6							20.9																					17.5
Average	2.0	2.1	2.2	2.2	2.4	2.5	2.6	2.7	2.6	2.7	2.5	2.5	2.5	2.2	3.1	2.8	3.0	2.1	3.0	2.0	2.2	2.1	3.2	2.7	3.6	3.5	3.1	2.7	2.6	2.4	2.4	2.2	2.1	2.1	1.9	1.9	2.5	

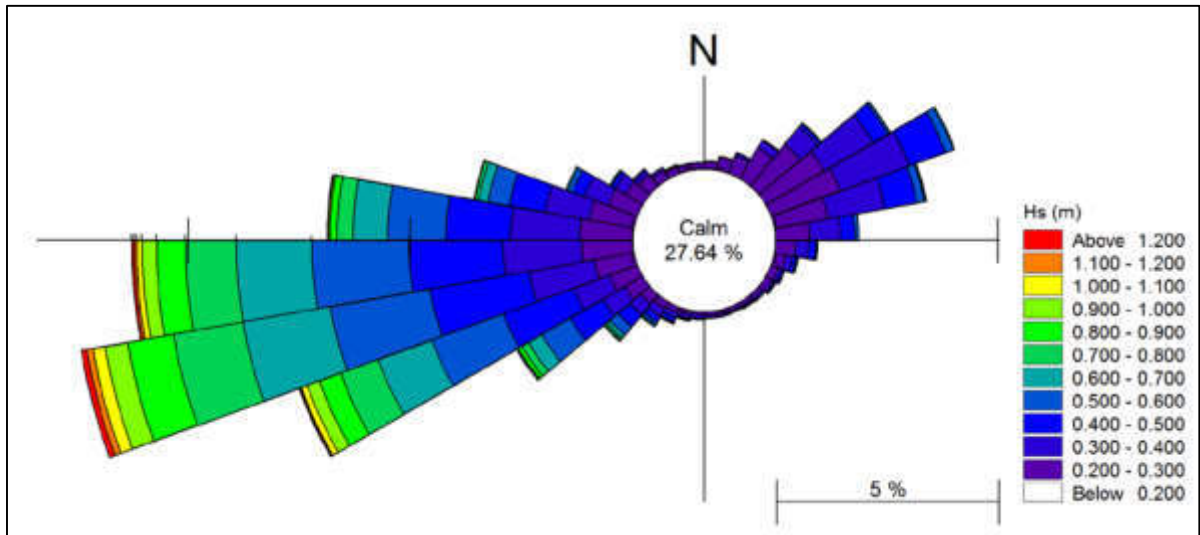


Figure 3.3: Annual Wave Height Distribution at 300m Depth

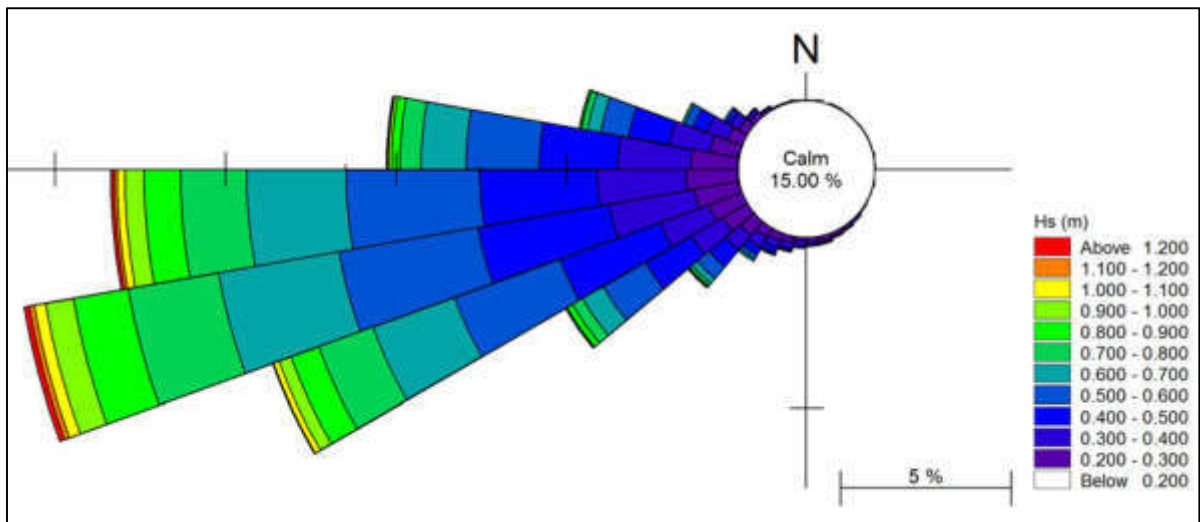


Figure 3.4: Wave Height Distribution for South-West Monsoon at 300m Depth

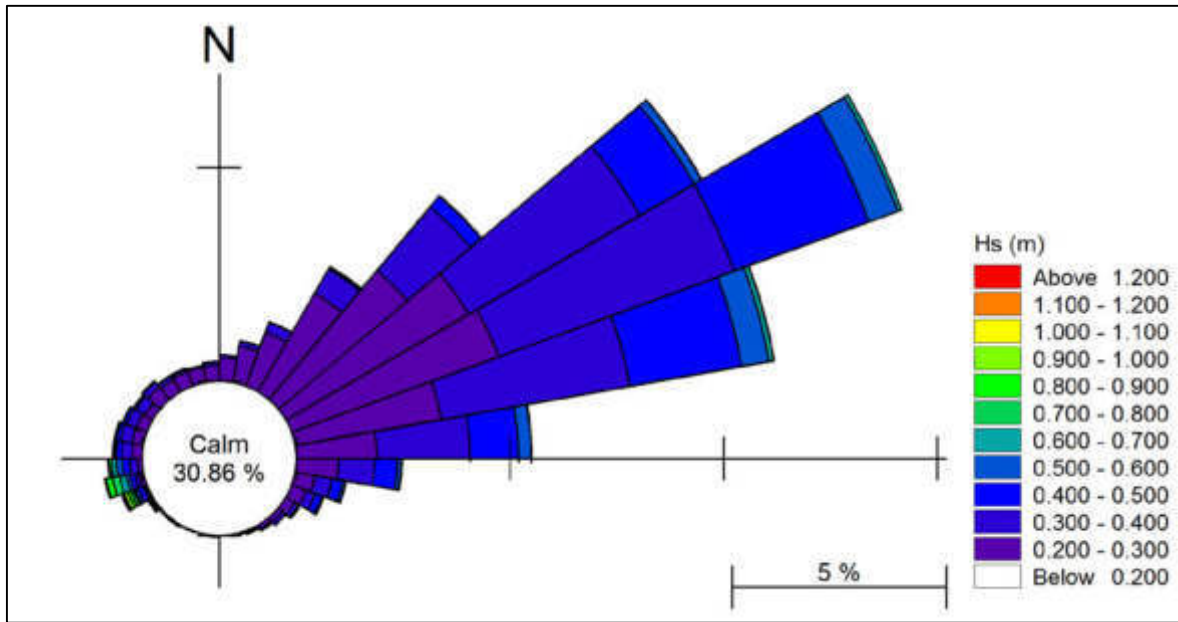


Figure 3.5: Wave Height Distribution for North-East Monsoon at 300m Depth

## **4 HYDRODYNAMIC MODELLING**

In order to compute water circulation with effect of tidal flow, wave and wind in and around the study area, a hydrodynamic model required to be carried out. Hence, the numerical model, MIKE 21 HD was used in this process.

### **4.1 MIKE 21 Hydrodynamic Model System**

MIKE 21 HD (Flexible Mesh) model developed by Danish Hydraulic Institute was used for the simulation. It is a modelling system for 2D free-surface flows and applicable to the simulation of hydraulic and environmental phenomena in lakes, rivers, estuaries, bays, coastal areas and seas in response to a variety of forcing functions including tide, wind, wave and river flow. The HD module allows you to specify a variety of hydrographic boundary conditions, initial conditions, bed resistance and wind forcing. It also allows you to include different types of sources and sinks as well as a number of different structures. It provides the hydrodynamic basis for the computations performed in the environmental hydraulics and sediment transport modules.

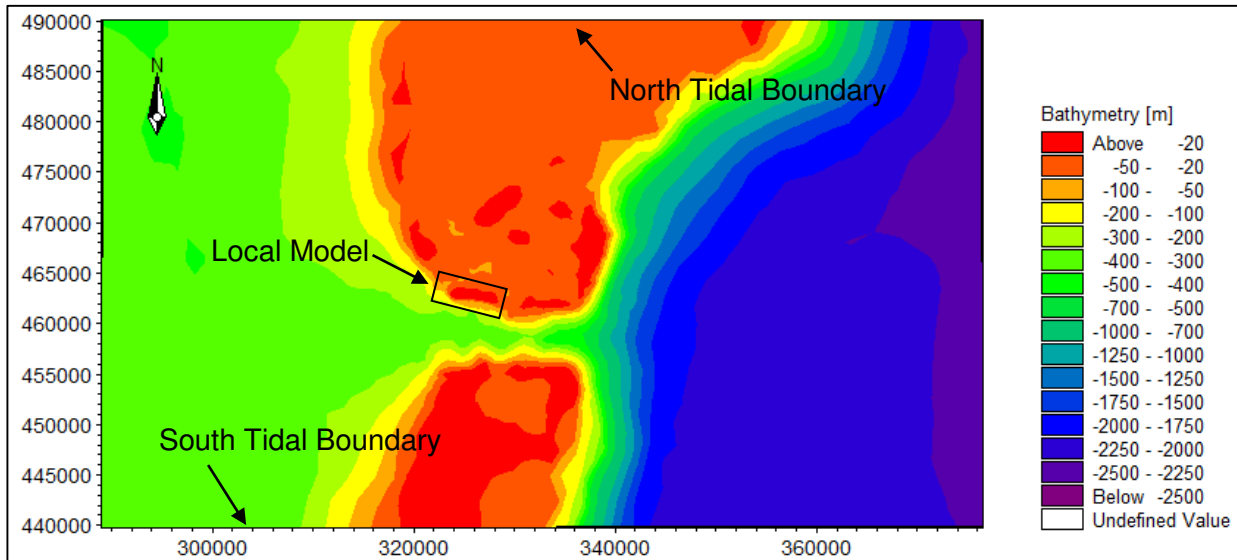
### **4.2 MIKE 21 HD Model Set Up**

#### *4.2.1 Model Bathymetry*

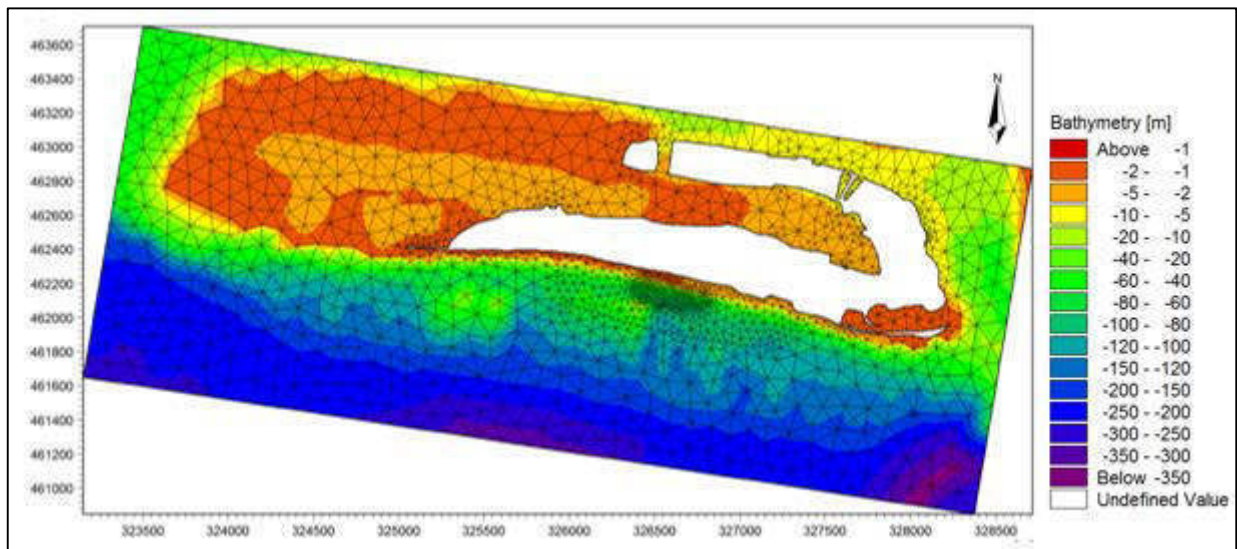
Same as the wave model, Admiralty charts and bathymetry data provided by the client were used for the development of model bathymetry. Since tidal variation would be applied as main boundary condition for the regional model, availability of tidal data was considered when setting up the model. Tidal boundaries were developed using MIKE 21 Toolbox Tide developer considering 25km away from Thilafushi in North and South directions, and 45km in West and East direction. Therefore the regional model covers the model area of 50km in north-south way and 90km east-west way. Figure 4.1 illustrates the bathymetry of regional model and position of the local model on it. Local model was selected considering the bathymetry, and kept offshore boundary at 300m depth.

Triangular flexible mesh was generated by MIKE 21 Bathymetry Creator Tool while considering finer mesh size for more concern area. The UTM 43 coordinate system was used for (x, y) coordinates and Mean Sea Level (MSL) was used as the elevation datum. The local bathymetry with mesh is given in Figure 4.2.





**Figure 4.1: Bathymetry for Regional Hydrodynamic Model**



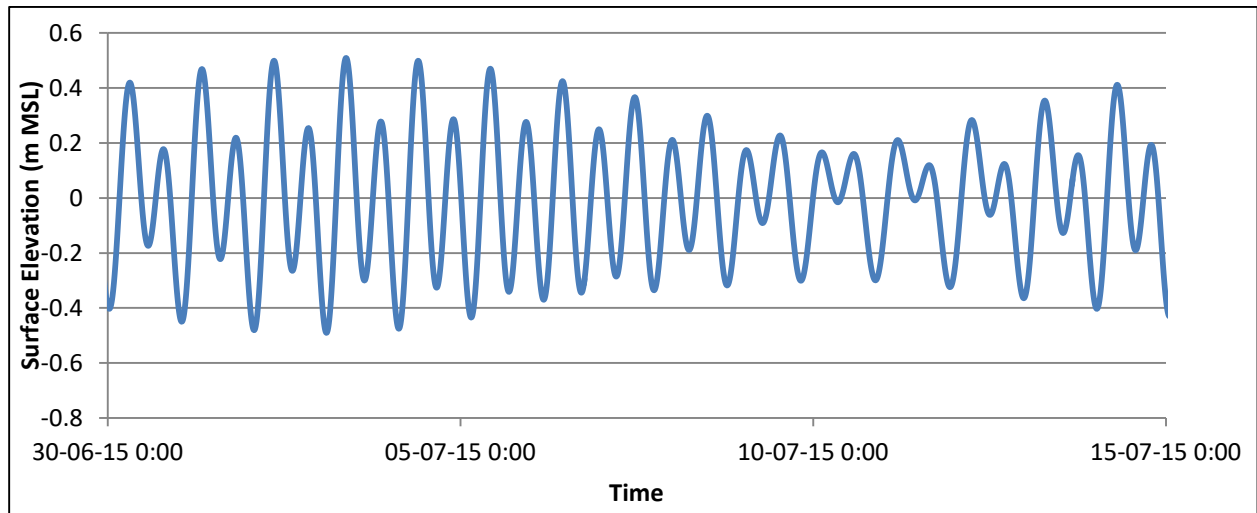
**Figure 4.2: Bathymetry for Local Hydrodynamic Model**

#### 4.2.2 Simulation Period

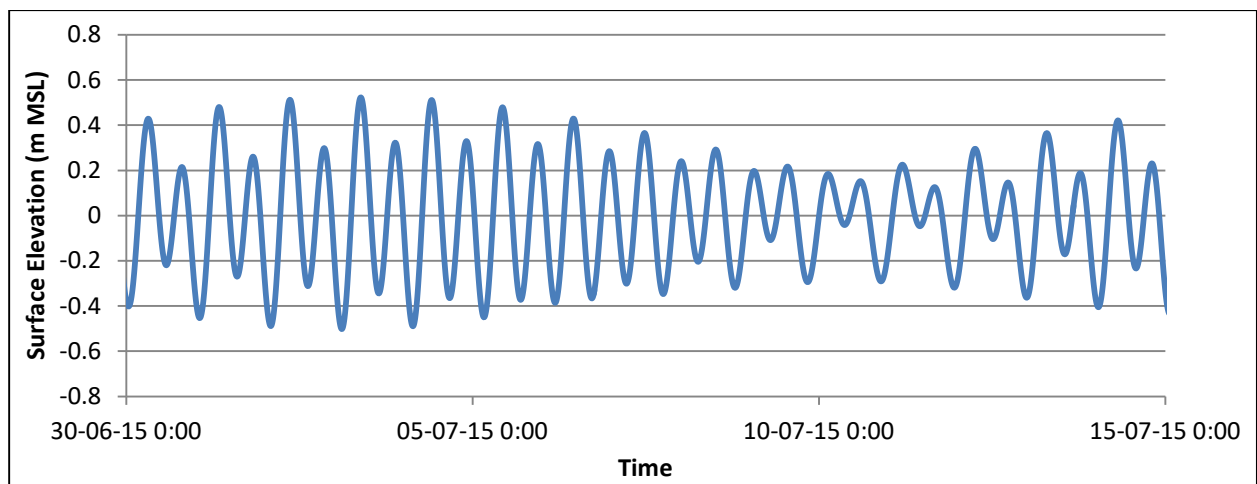
The regional model was run for one month period for each South-West and North-East monsoon and the local model was run for three days for each monsoon which covering spring and neap tide. The regional model was run with the time step of 3s and the local model with 1s.

#### 4.2.3 Boundary Conditions

The tide levels of the boundaries are used as boundary conditions for regional model. Time series of water levels were predicted using MIKE 21 Toolbox Tide developer for north and south tidal boundaries as indicated in Figure 4.1. Representative predicted tidal plots in north and south boundaries for few days in South-West Monsoon are shown in Figures 4.3 and 4.4.



**Figure 4.3: Predicted Tide in North Boundary**



**Figure 4.4: Predicted Tide in South Boundary**

Water levels and discharges extracted from regional model at the boundaries of the local model were used as boundary conditions for the local model.

#### 4.2.4 Wave and Wind Conditions

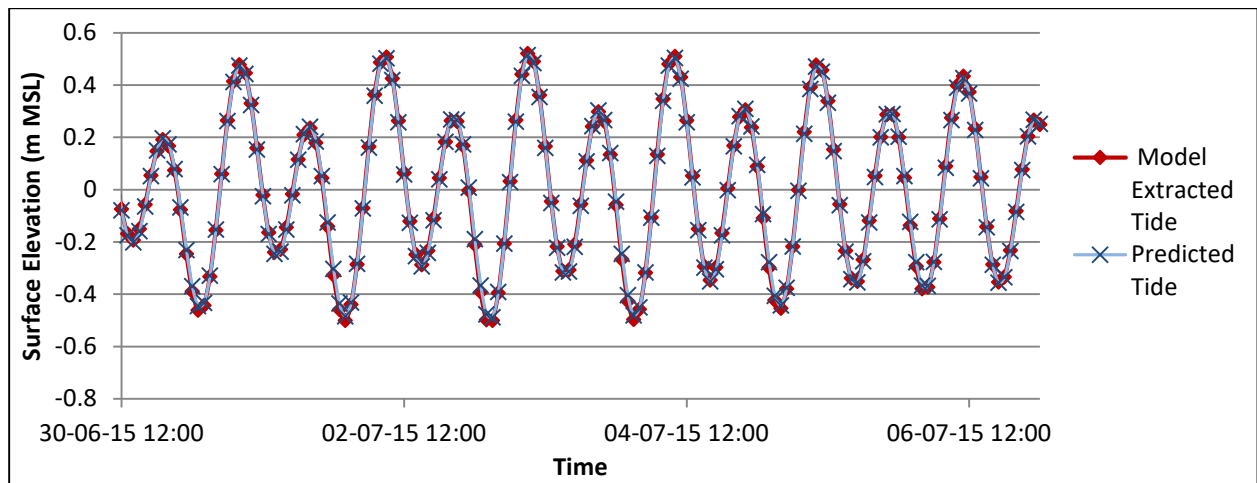
Local model was run for average wave/wind condition for both monsoons. The average condition was selected considering 50% of occurrence line of wave height of the wave data extracted at 300m depth from wave transformation model (MIKE 21 SW). In this process, most dominant directional bands were selected for the calculations (as coloured in Table 3.3 to 3.6). Same as wave, 50% of occurrence line of wind speed of UKMO wind data was selected to obtain corresponding wind speed. The selected wave and wind conditions are given in following table and both wind and wave conditions were applied at the same time in the model for each monsoon.

Monsoon	Wave Condition			Wind Condition	
	Hs (m)	Tp (s)	Direction (deg)	Speed (m/s)	Direction (deg)
SW	0.49	3.6	260	5.75	270
NE	0.26	2.4	60	5.02	55

**Table 4.1: Applied Wave/Wind Conditions for the Local Hydrodynamic Model**

### 4.3 MIKE 21 HD Model Calibration

Calibration was done for predicted tide levels at Male considering the variation of surface elevations. Figure 4.5 shows the water level comparison between model values and predicted tide at male. The bed roughness was used as the calibration parameter and Manning’s Number of 32 was set as the suitable values for the calibration.



**Figure 4.5: Calibration with Predicted Tide at Male**

### 4.4 MIKE 21 HD Results

The main objective of the HD modelling is to observe the flow pattern in the site area and find out the effective current flow for thermal dispersion at outfall. Hence current speeds and directions were extracted at the outfall location (Figure 4.6) for both monsoon periods and spring and neap tidal conditions. The average current speed and direction for different conditions are given in Table 4.2.

According to the results, it can be observed that the wave condition is not significantly affected for the current at outfall location; it is basically tide dominant. The direction of current varies almost 180 degree with ebb and flood conditions, but Table 4.2 gives direction values only considering westward current flow condition.

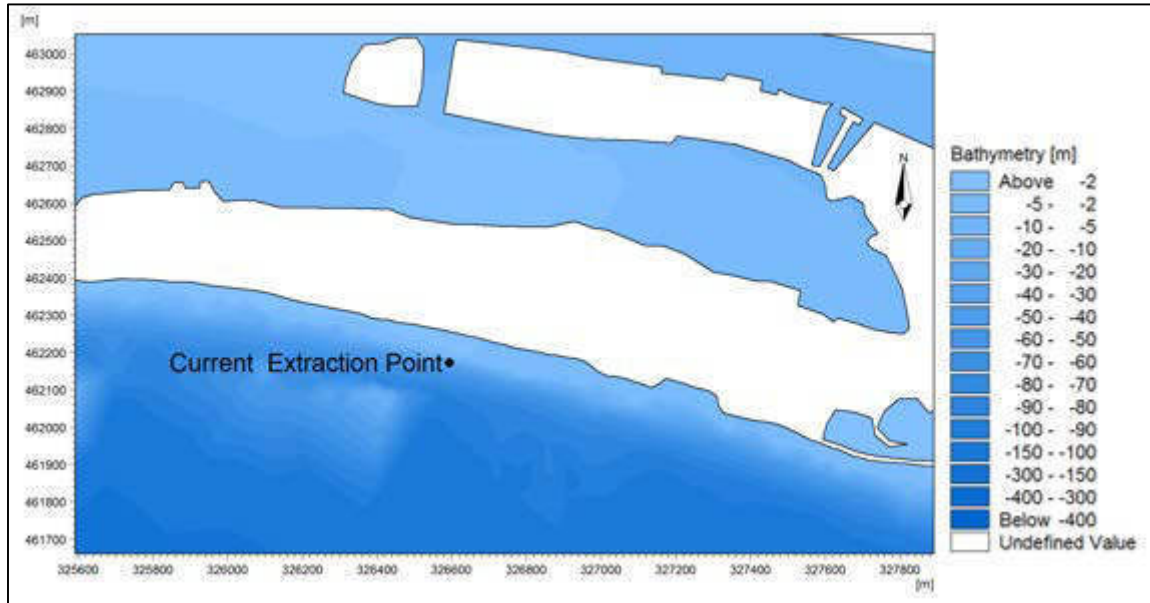


Figure 4.6: Current Extracted Points

Table 4.2: Average Current Condition at Extracted Point

Monsoon	Tidal Condition	Current Speed (m/s)	Direction (deg)
SW	Neap Tide	0.10	277
	Spring Tide	0.22	280
NE	Neap Tide	0.10	280
	Spring Tide	0.20	271

## 5 THERMAL DISPERSION MODELLING

### 5.1 Introduction

The proposed incinerator will use sea water as the coolant and discharge hot 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 such temperature will have significant impact to the aquatic organisms and to the local biological and biogeochemistry of the ocean. Impacts of high water temperature discharge are such as:

- Coral bleaching
- Reduction of dissolved oxygen level
- Stimulation of phytoplankton and benthic algal growth
- Alteration in ecosystem which affects the mortality and reproduction
- Alteration of thermal structure of the ocean, current patterns, surface wave patterns

In this modelling process, initial dilution is estimated using a near field model (CORMIX). Thereafter using its results 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.

### 5.2 Simulation Scenarios

Three single port outfalls, each consists of 1.1 m diameter pipe in which discharges effluent having 3 K excess temperature relative to the ambient temperature at 2 m/s flow velocity were considered in simulations. These outfalls release the hot water plume at 30 m depth. These scenarios have been selected based on indicative model runs from the previous study taking all possible monsoonal and tidal conditions into account. Therefore all together four number of scenarios were simulated as given in the following table.

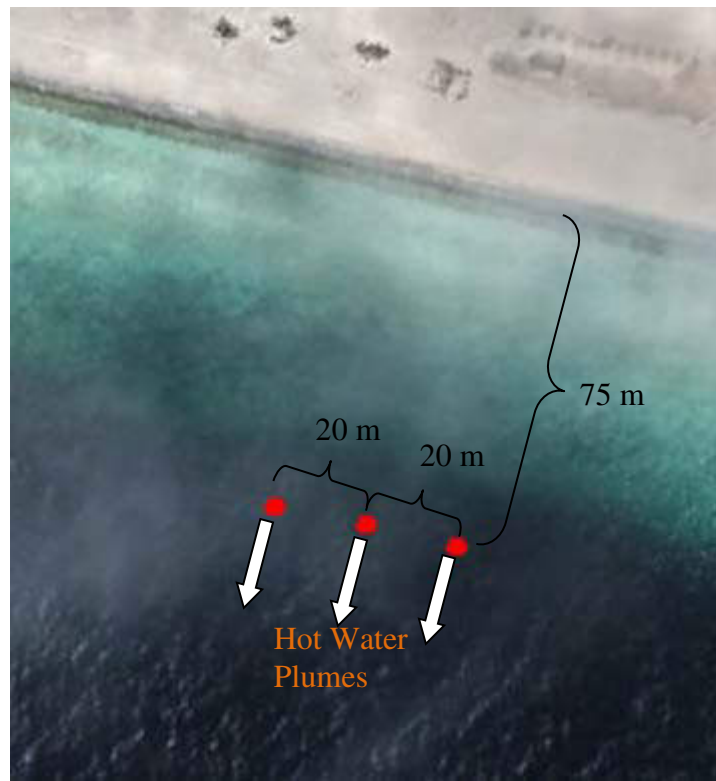
**Table 5.1: Simulation Scenarios**

Sc. ID	Monsoon	Tide	Current Condition	
			Speed (m/s)	Direction (Deg. N)
NE_S	North-East	Spring	0.2	271
NE_N		Neap	0.1	280
SW_S	South-West	Spring	0.22	280
SW_N		Neap	0.1	277

In addition, single outfall which releases total discharge of above mentioned three outfalls was also simulated in near field model to check the effect compared to three outfalls. Thus, this single outfall discharges 19,880 m<sup>3</sup>/h hot water plume through a 1.9 m diameter pipe at 2 m/s velocity.

### 5.3 Near Field Modelling

Three outfalls placed 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 the **Figure 5.1**.



**Figure 5.1: Locations of Outfalls**

The outfalls are set perpendicular to the shore in which the outlets are arranged to release the hot water jet parallel to the centre line of their ports at a depth of 30 m towards the deep sea. It releases horizontally close to the sea bottom. Since the density of the heated plume is less it acts as negatively buoyant discharges and tends to move upwards. The initial dispersion 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 reduced below a certain limit due to the dilution, the mixing ceases to be the dominant factor and the discharge transforms into what is generally known as a plume. After this, the discharge enters the far field. To examine the near field behaviour of the heated plume CORMIX mixing zone model is used.

#### 5.3.1 CORMIX Modelling System

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 behaviour and plume geometry (Doneker & Jirka 2007).

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).

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).

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.

### **5.3.2 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.

In general near field of an outfall is governed by the initial jet characteristics of the plume, current flow acting on the outfall location, and outfall geometry. In this case, horizontal single port discharge is considered in the modelling simulations. The density of effluent is  $1021.4\text{m}^3/\text{kg}$  according to its temperature  $31\text{ }^{\circ}\text{C}$  and the ambient density of the sea water is considered as  $1025\text{m}^3/\text{kg}$ . Ambient temperature level is assumed as  $28\text{ }^{\circ}\text{C}$ . Simulations were carried out for a list of scenarios given in Table 5.1.

Since all three outfalls have the same conditions in discharge effluent and all are single port outfalls, one outfall discharge was considered in near field modelling, but the combine effect of all three outfalls was interpreted using excess temperature isolines (refer Section 5.3.3). However, the resultant condition of all three discharges was applied in the far field model (HD model) through extracting the near field model results.

### 5.3.3 CORMIX Model Results

Visualization of the effluent discharged from the port and rising to the surface in a cross flow at near-field region is given in below 3D plots for all simulations. Both plan view and the elevation of the plume for these scenarios are given in Annex A. In addition, the graphs which show variation of excess temperature with downstream distance are also given in Annex A.

The apparent ‘discontinuity’ effects in the Excess temperature vs. Downstream distance graphs (refer Annex A) 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 visualisation 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.

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.

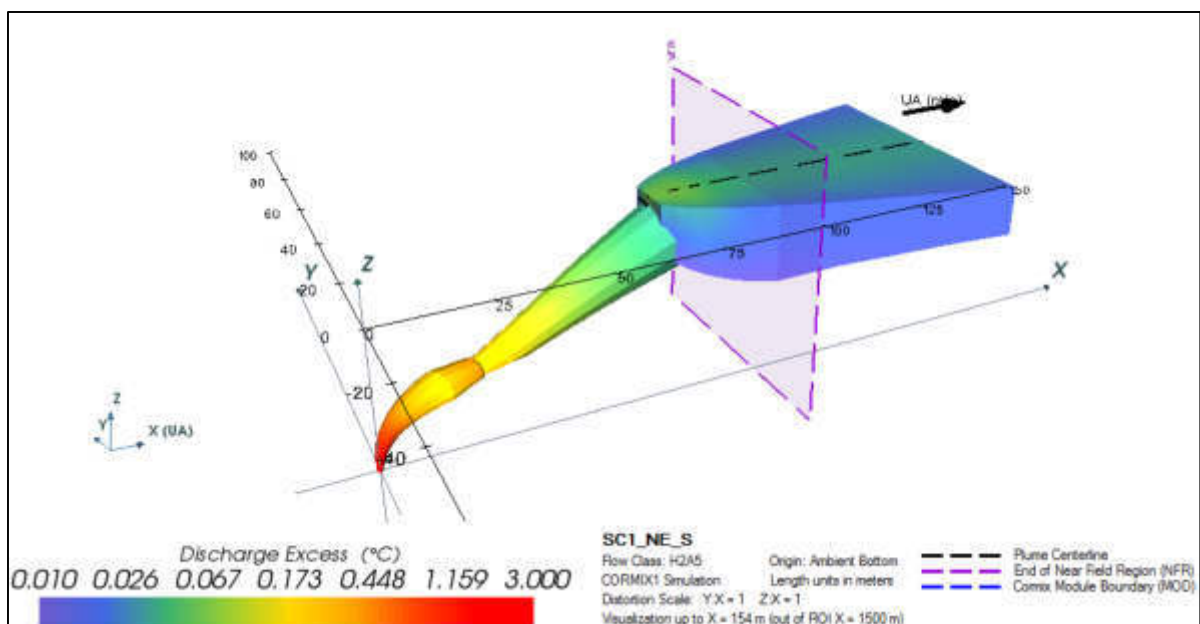


Figure 5.2: Effluent Discharged at Near-Field Region (NE Monsoon – Spring Tide)



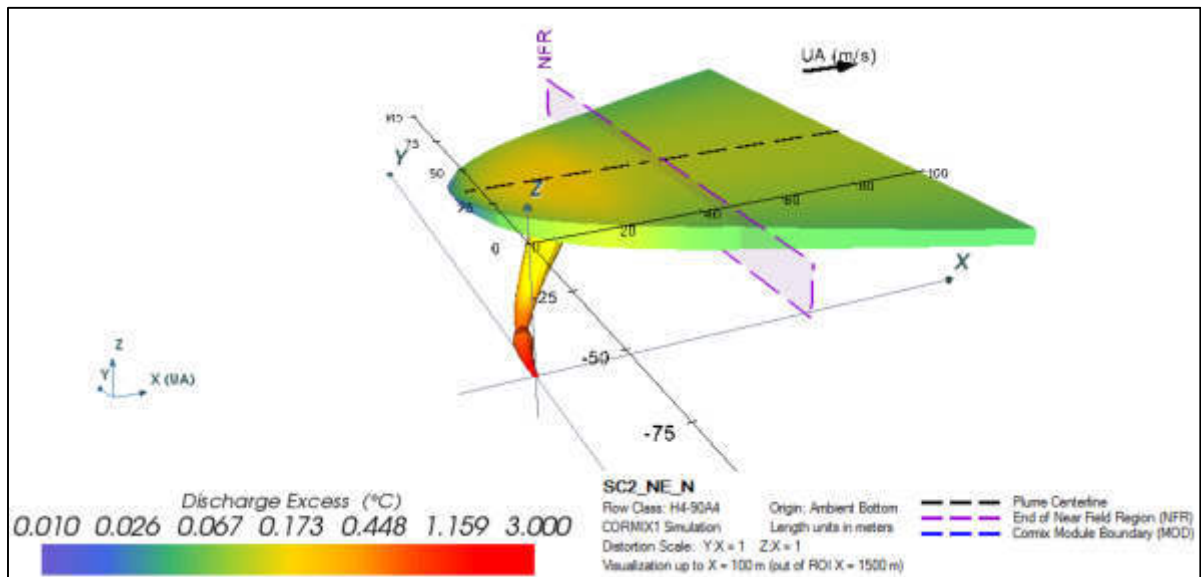


Figure 5.3: Effluent Discharged at Near-Field Region (NE Monsoon – Neap Tide)

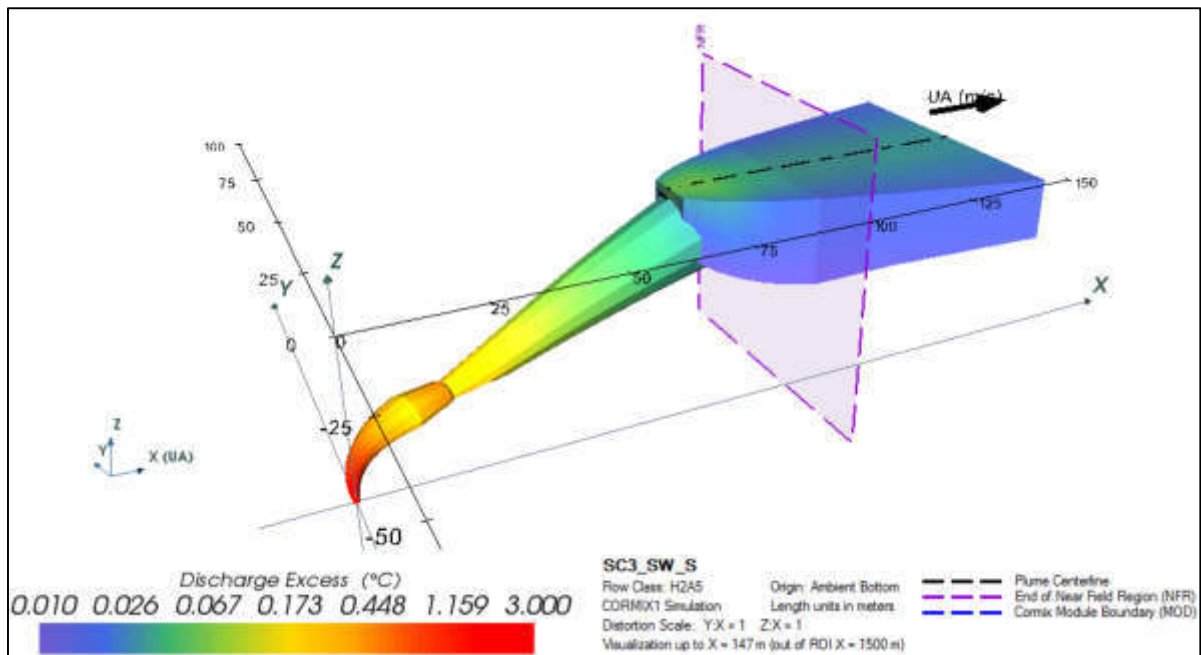
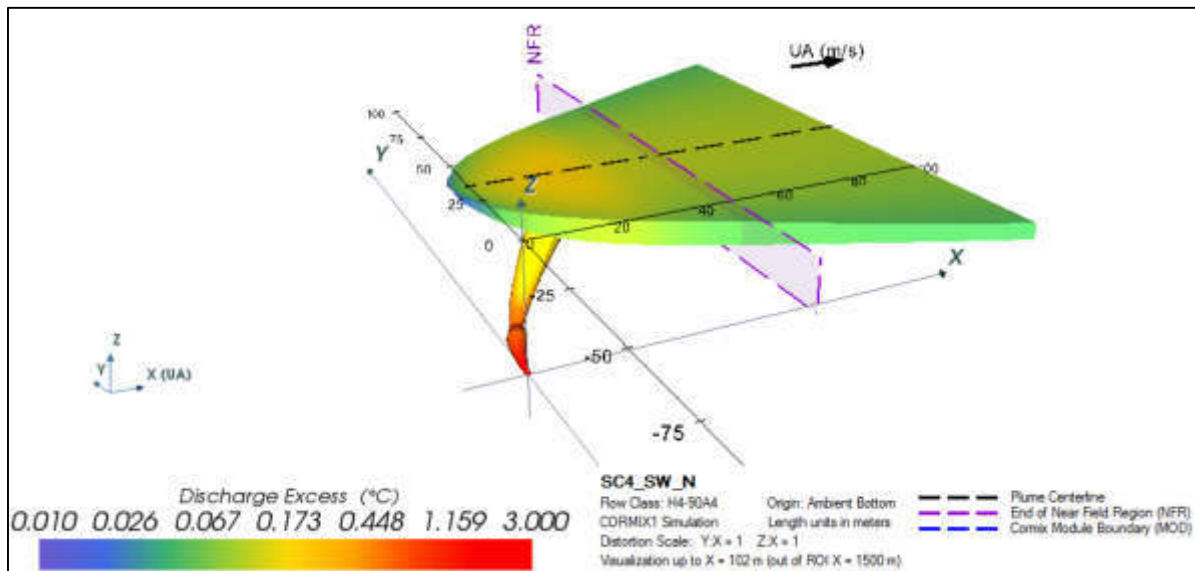


Figure 5.4: Effluent Discharged at Near-Field Region (SW Monsoon – Spring Tide)



**Figure 5.5: Effluent Discharged at Near-Field Region (SW Monsoon – Neap Tide)**

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.

**Table 5.2: Excess Temperatures at Near Field Boundary**

Sc. ID	Monsoon	Tide	Current Condition		Excess Temperature at Edge of Near Field (K)
			Speed (m/s)	Direction (Deg. N)	
NE_S	North-East	Spring	0.2	271	0.039
NE_N		Neap	0.1	280	0.114
SW_S	South-West	Spring	0.22	280	0.036
SW_N		Neap	0.1	277	0.112

### **Effect of Three Outfalls**

As mentioned above, the heat plume discharge of only one outfall was considered in the near field simulation, but to visualize the combine effect of heat dispersion from all the 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.

Figures 5.6 to 5.9 show the overall results of the vertical profile of heat plume dispersion in the near field region while Figures 5.10 to 5.13 show the same in the plan view. In this case, the results were interpreted using excess temperature isolines.

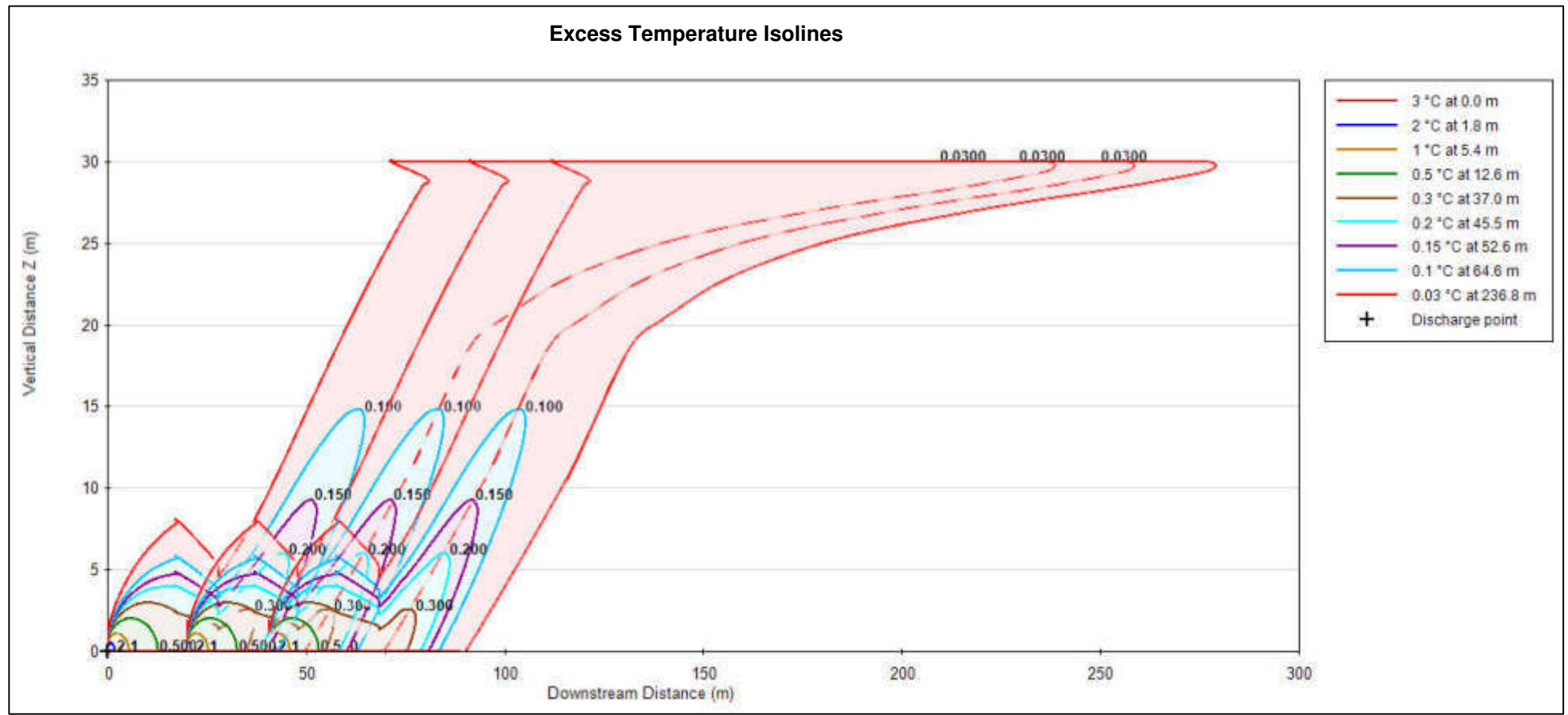


Figure 5.6: Interpreted Overall Results for Vertical Profile of Heat Plume for NE Monsoon – Spring Tide

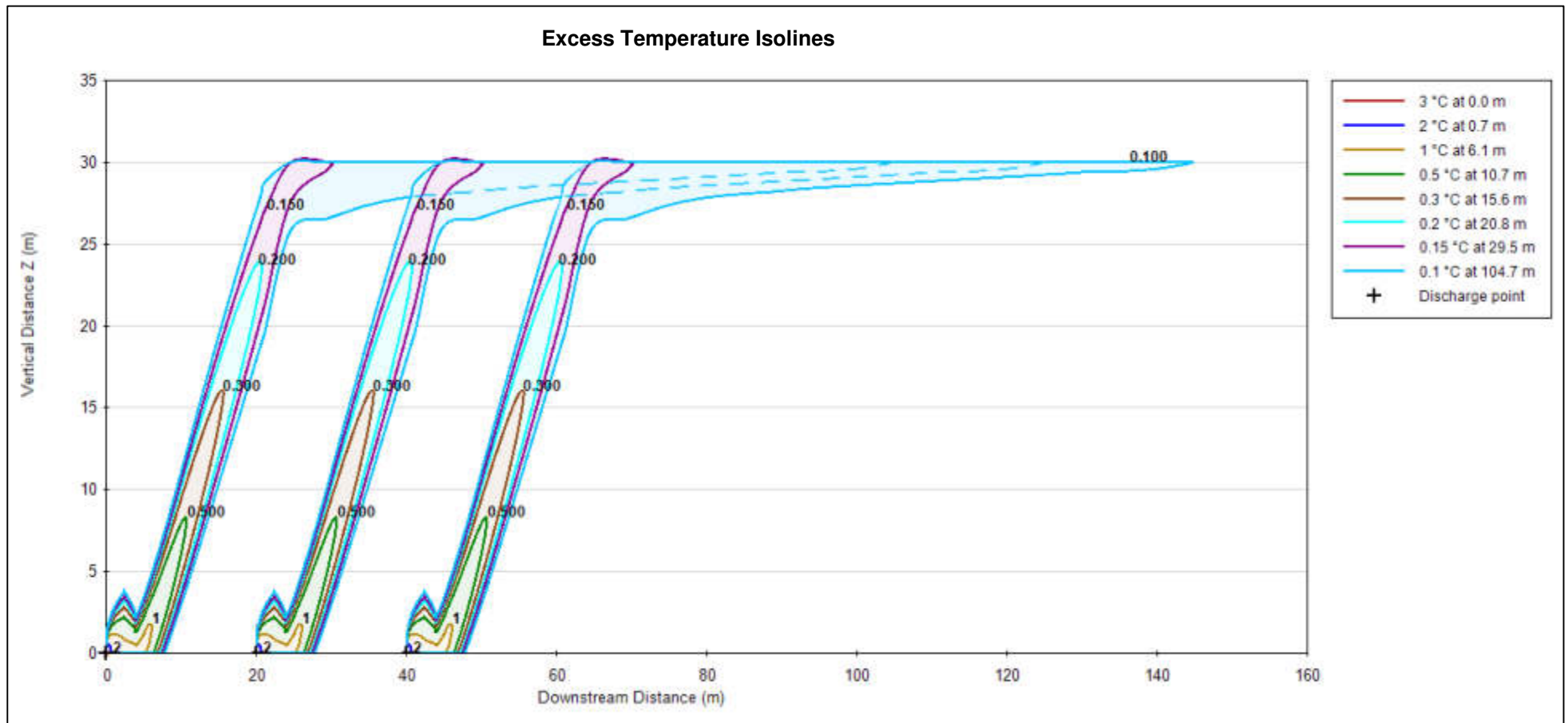


Figure 5.7: Interpreted Overall Results for Vertical Profile of Heat Plume for NE Monsoon – Neap Tide

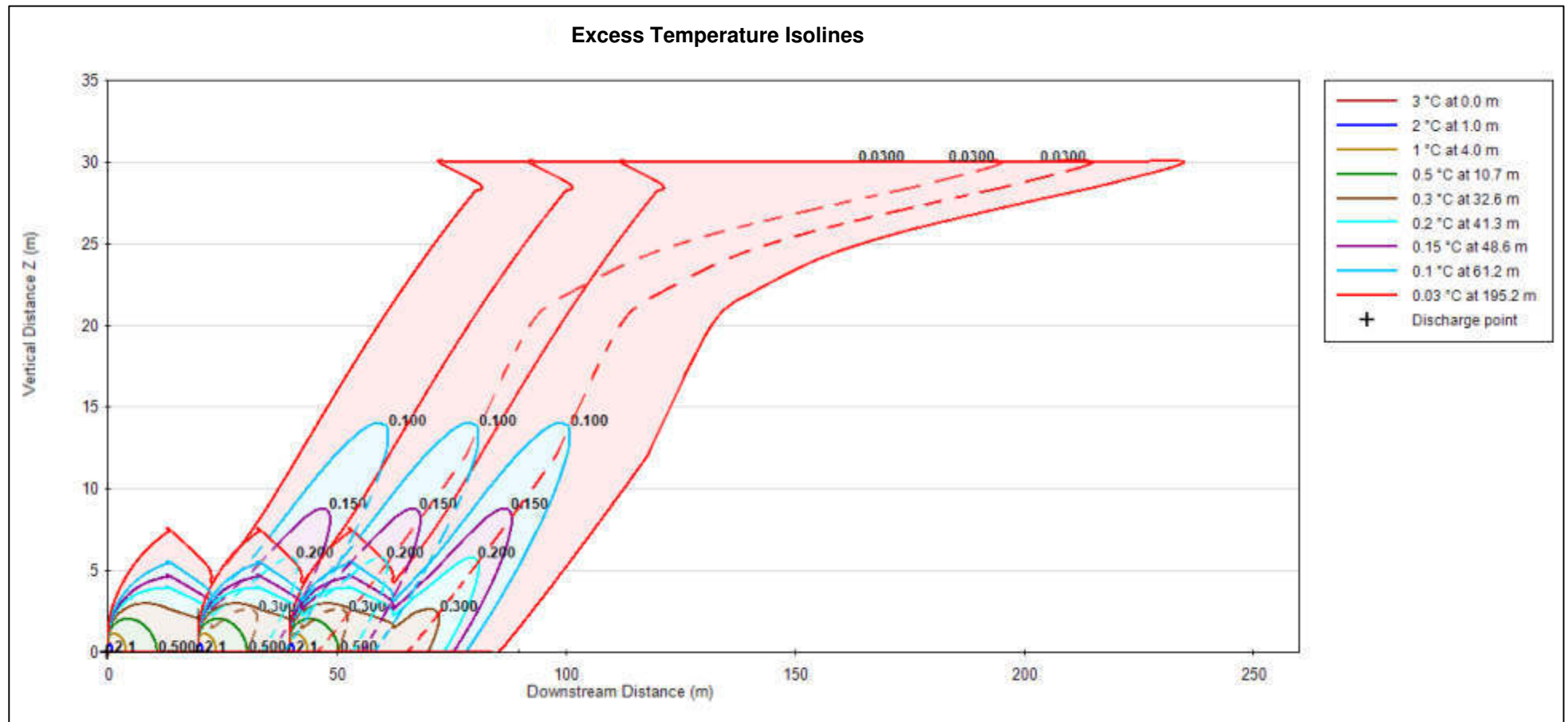


Figure 5.8: Interpreted Overall Results for Vertical Profile of Heat Plume for SW Monsoon – Spring Tide

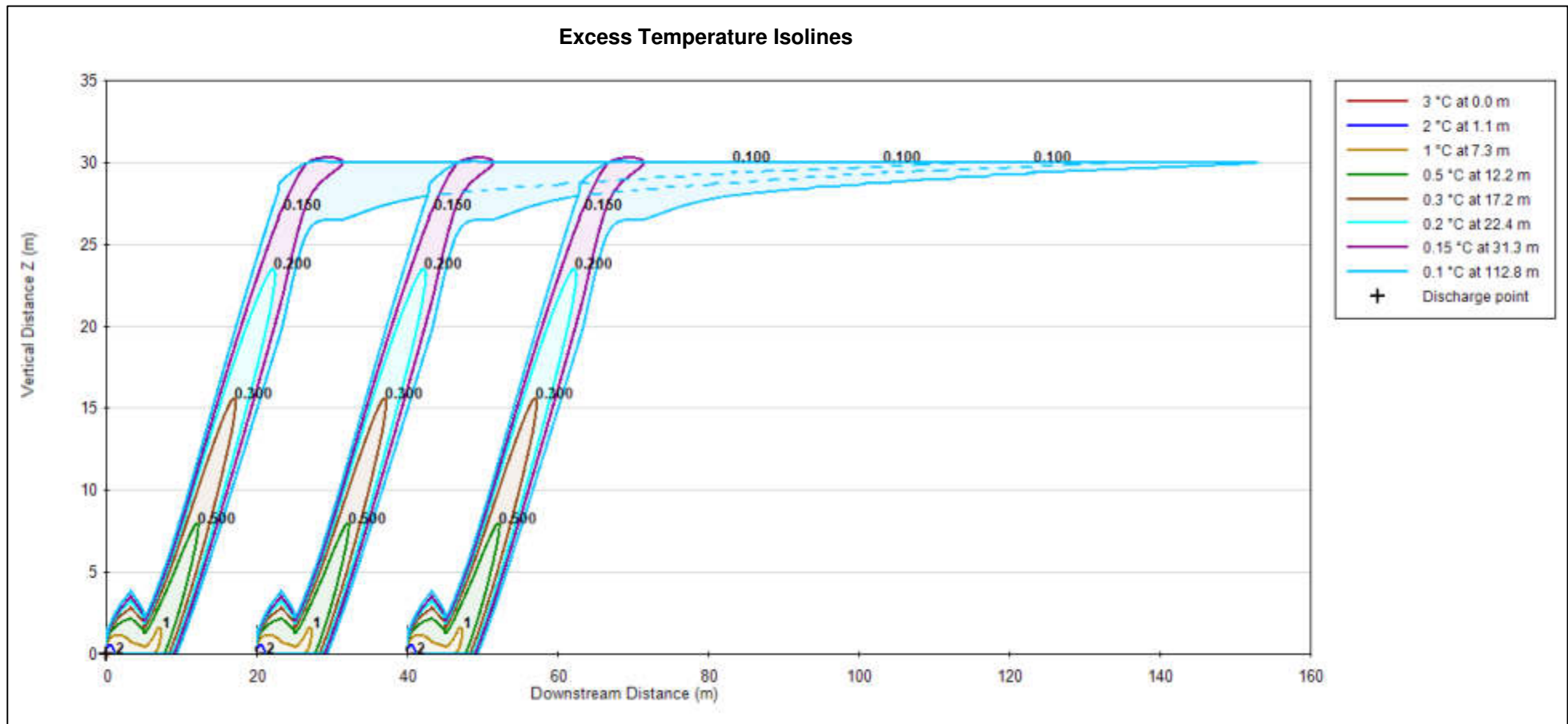


Figure 5.9: Interpreted Overall Results for Vertical Profile of Heat Plume for SW Monsoon – Neap Tide

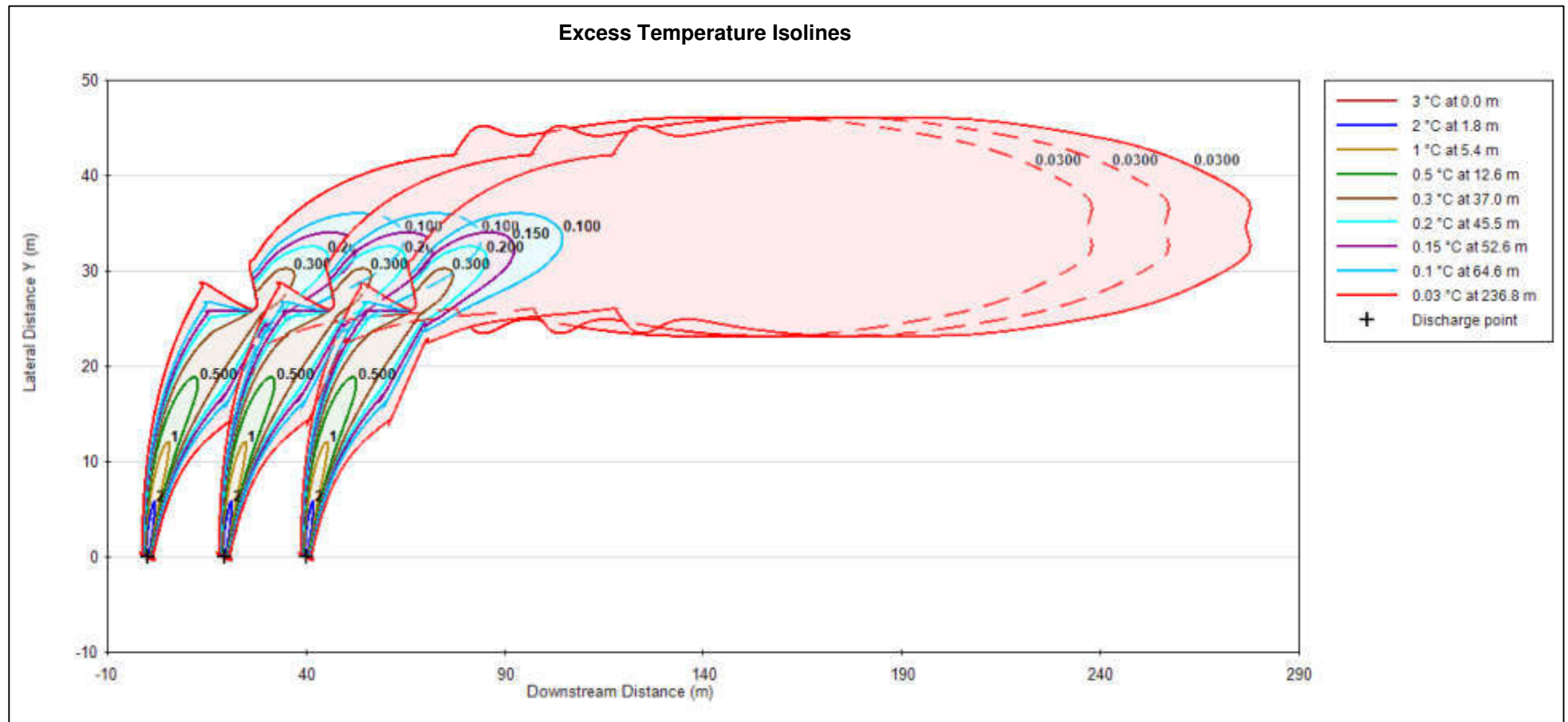


Figure 5.10: Interpreted Overall Results for Plan View of Heat Plume for NE Monsoon – Spring Tide

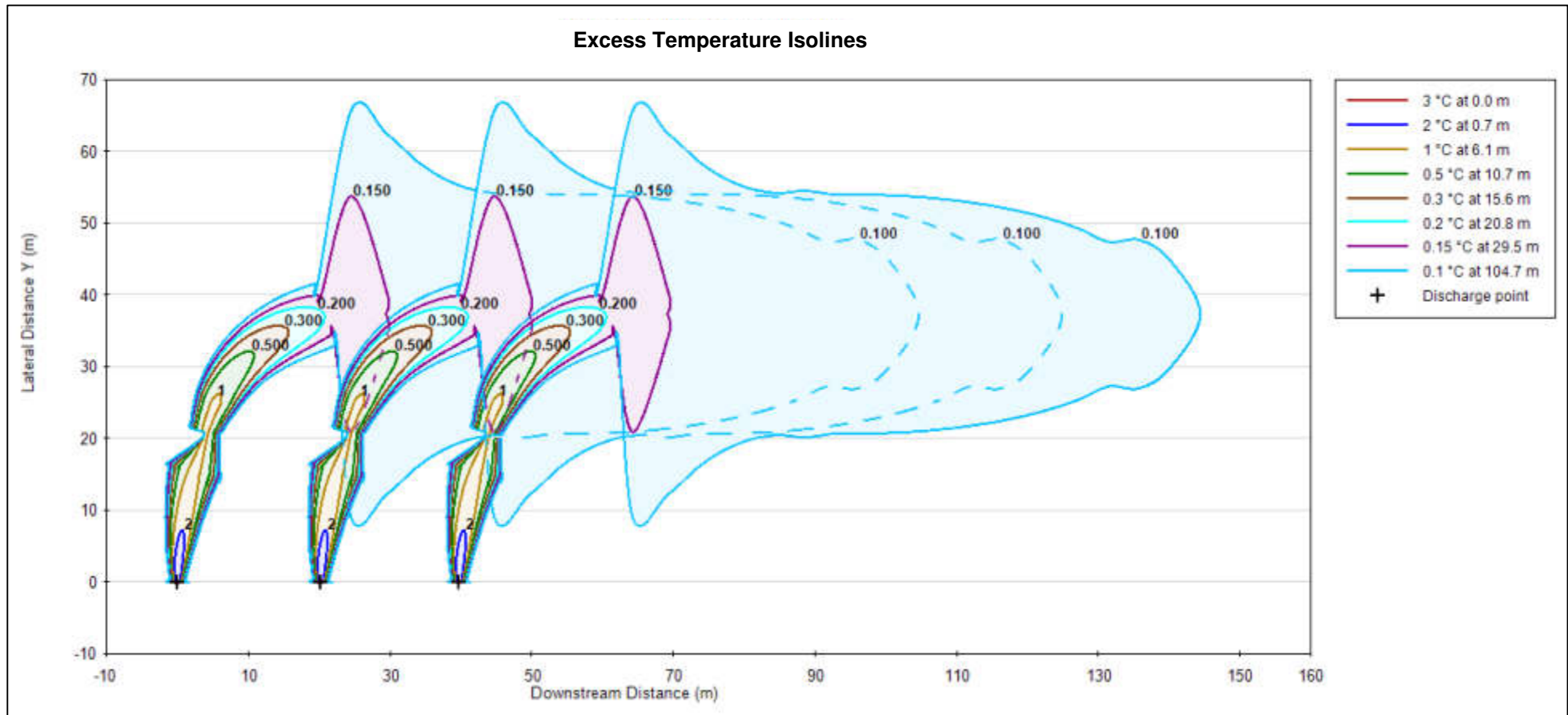


Figure 5.11: Interpreted Overall Results for Plan View of Heat Plume for NE Monsoon – Neap Tide



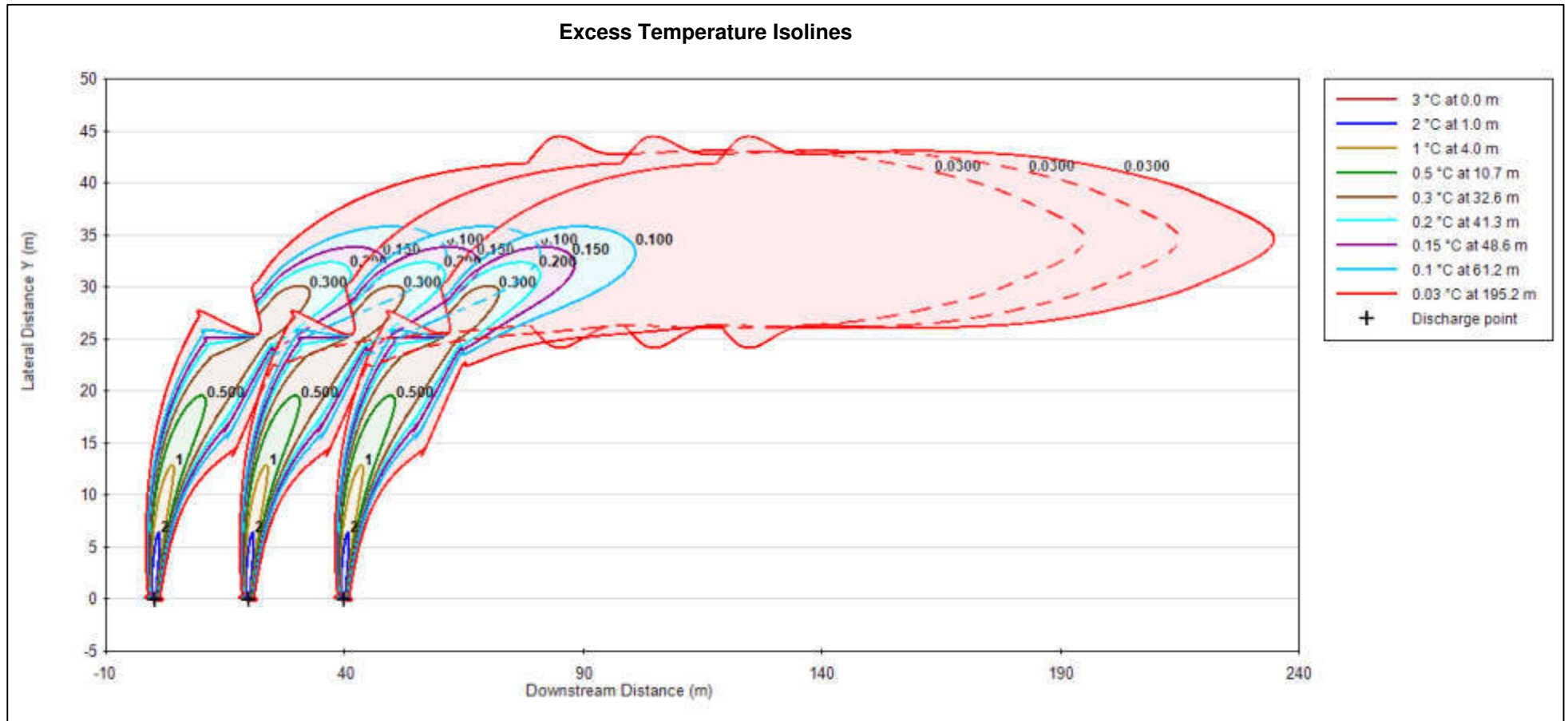


Figure 5.12: Interpreted Overall Results for Plan View of Heat Plume for SW Monsoon – Spring Tide

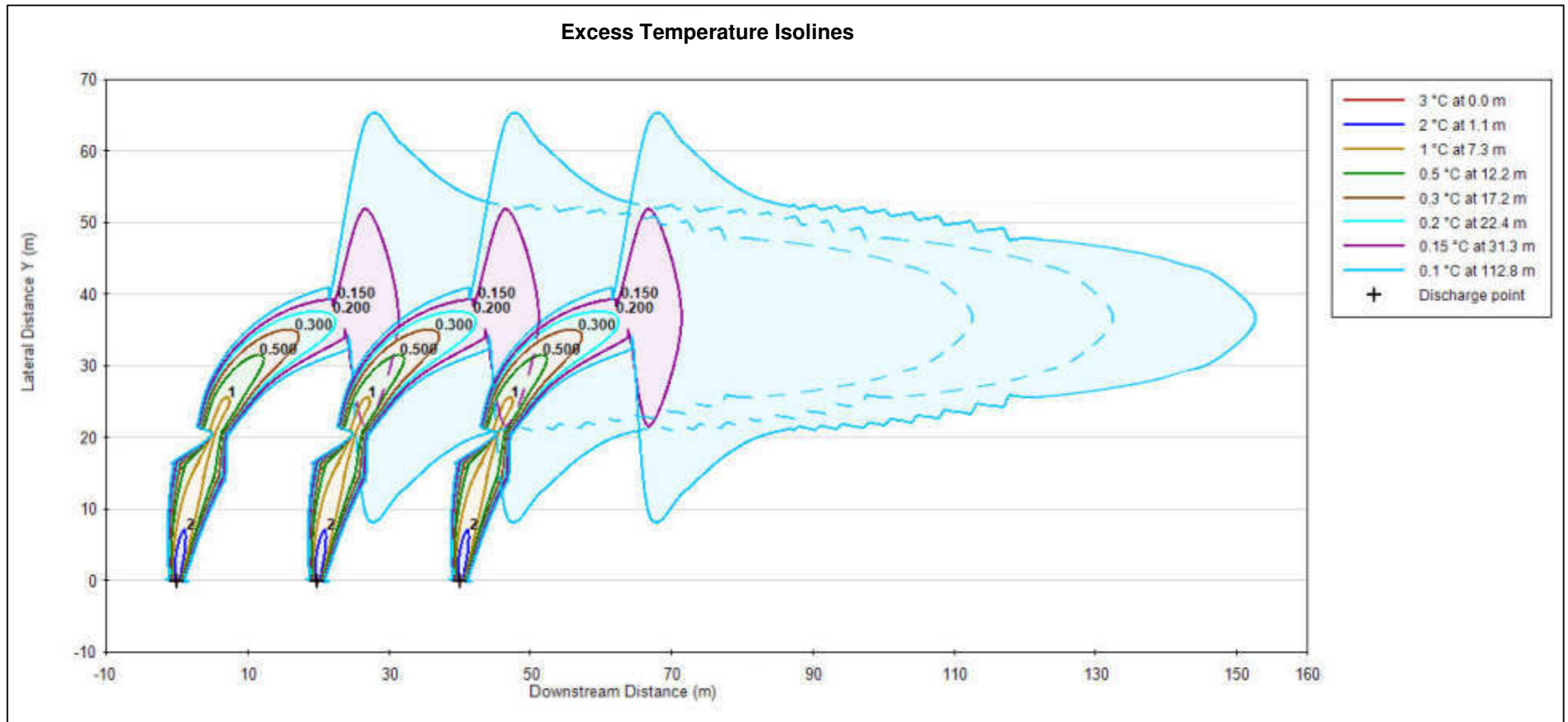
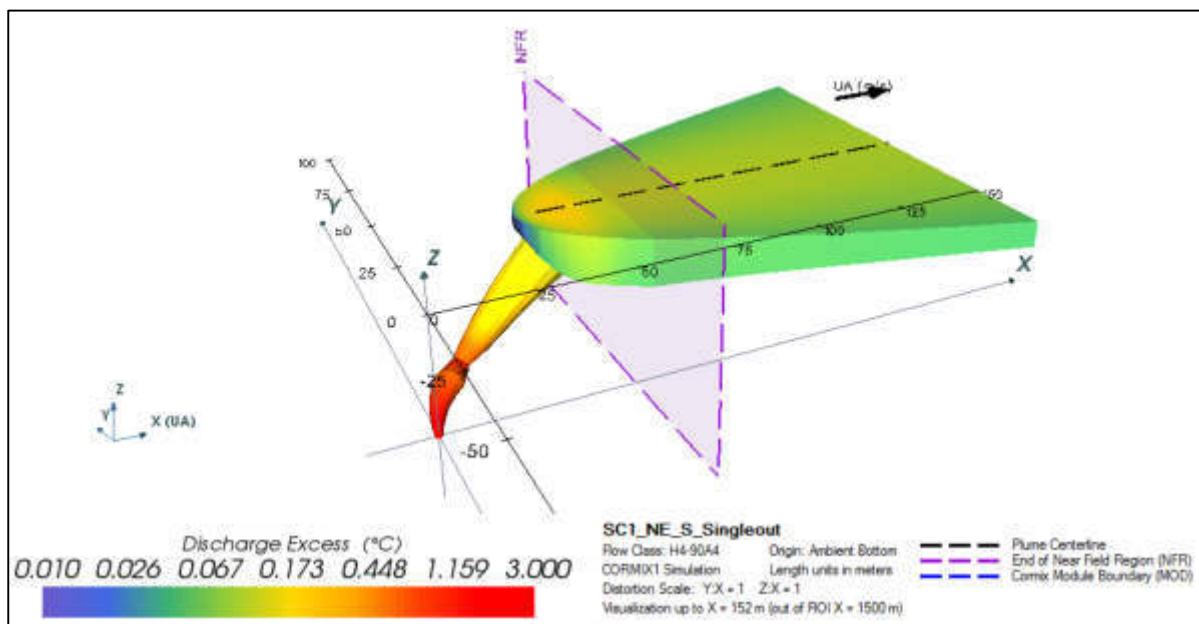


Figure 5.13: Interpreted Overall Results for Plan View of Heat Plume for SW Monsoon – Neap Tide

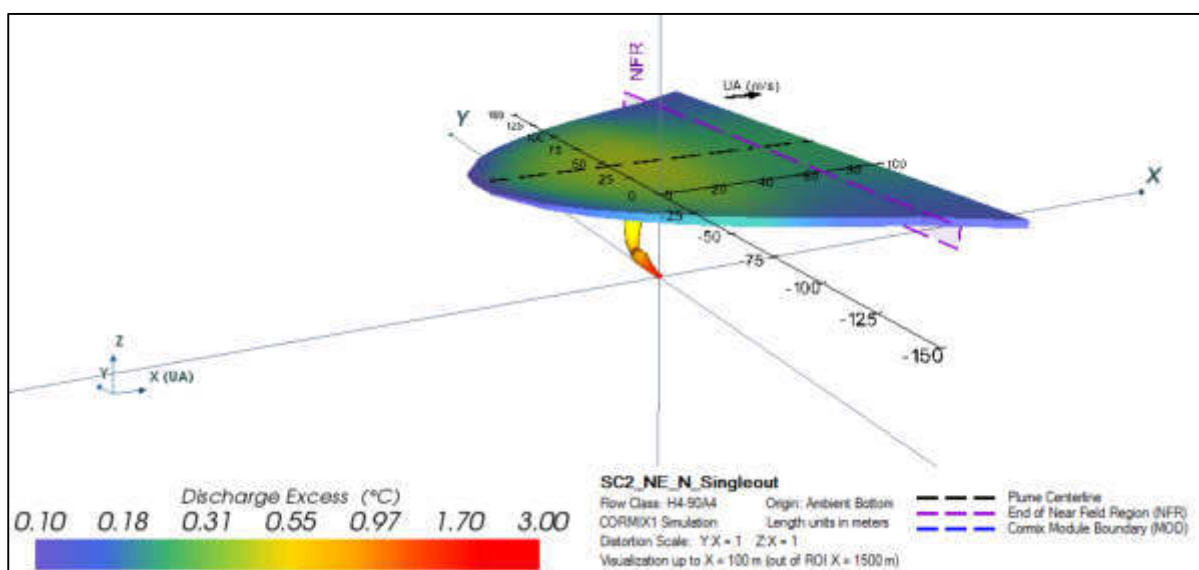
### One Outfall instead of Three Outfalls

What would be the result, if all three outfall flows are combined together and discharged through one single outfall? Although this is not the real case, this system was also simulated in the near field model to compare the effect relative to the three single outfalls.

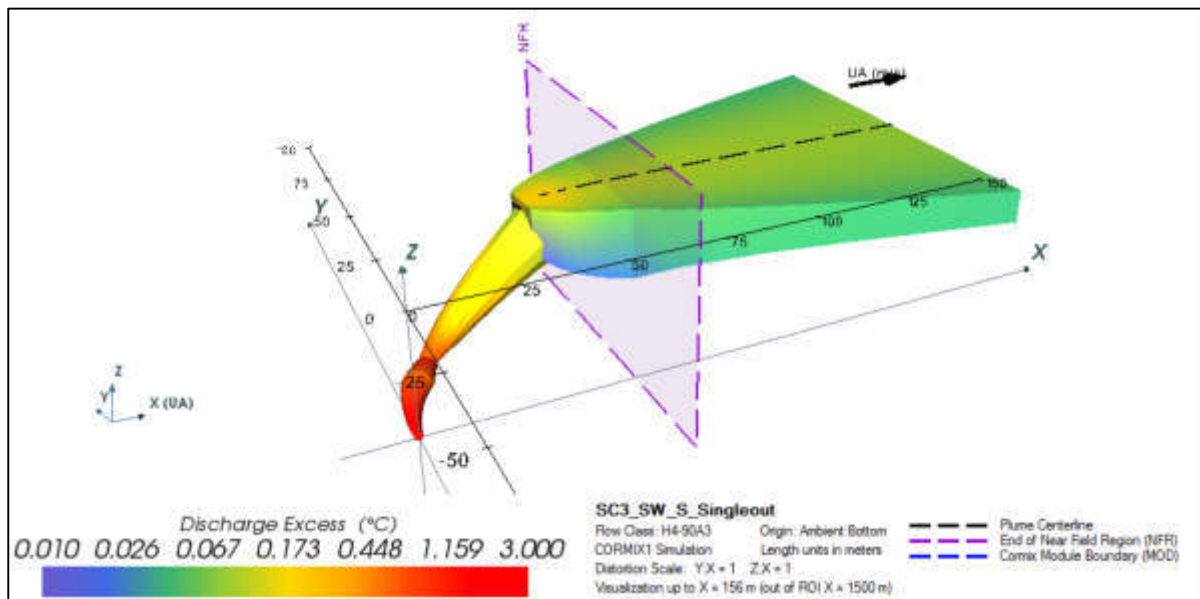
Same as the previous simulations, four scenarios, (i.e. two monsoon conditions and two tidal conditions) were also considered in this simulation. Accordingly, 3D views of heat plume dispersion for different scenarios are given in Figures 5.14 to 5.17 and plan views, elevations and graphs of excess temperature vs downstream distance are given in Annex B.



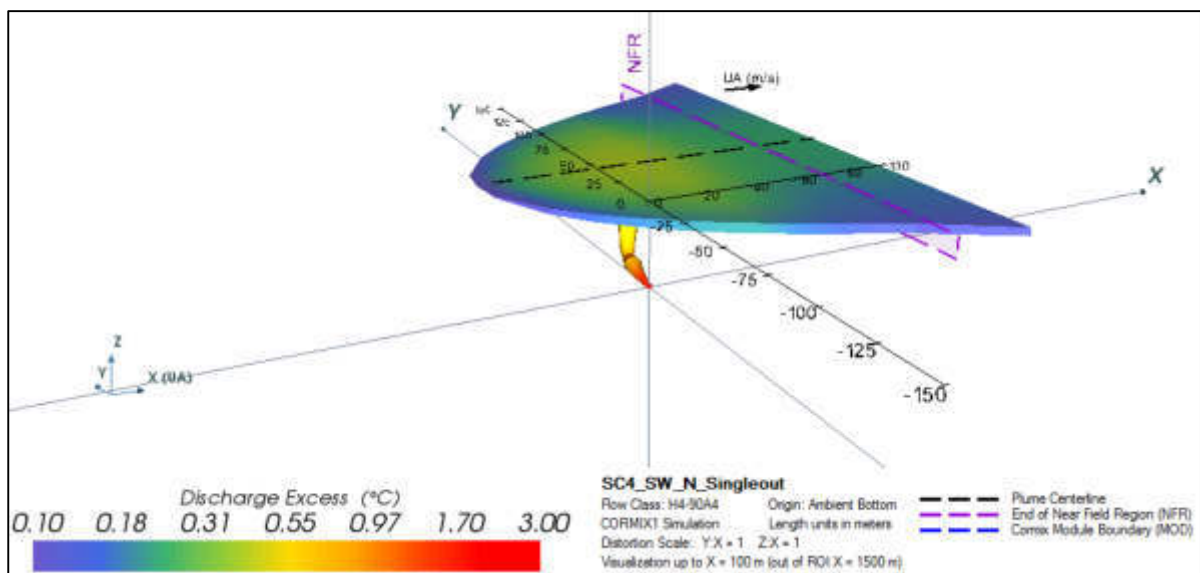
**Figure 5.14: Effluent Discharged at Near-Field Region for Combined Single Outfall (NE Monsoon – Spring Tide)**



**Figure 5.15: Effluent Discharged at Near-Field Region for Combined Single Outfall (NE Monsoon – Neap Tide)**



**Figure 5.16: Effluent Discharged at Near-Field Region for Combined Single Outfall (SW Monsoon – Spring Tide)**



**Figure 5.17: Effluent Discharged at Near-Field Region for Combined Single Outfall (SW Monsoon – Neap Tide)**

The excess temperatures at the boundary of the near field were extracted from the model results for every scenario of combined single outfall case and they are presented in the table below.

**Table 5.3: Excess Temperatures at Near Field Boundary for Combined Single Outfall**

Sc. ID	Monsoon	Tide	Current Condition		Excess Temperature at Edge of Near Field (K)
			Speed (m/s)	Direction (Deg. N)	
NE_S	North-East	Spring	0.2	271	0.118
NE_N		Neap	0.1	280	0.244
SW_S	South-West	Spring	0.22	280	0.107
SW_N		Neap	0.1	277	0.240

### 5.3.4 Discussion

According to the results of the above scenarios, the excess temperature of 3K is decreased significantly down to 1K within the first 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 (1K to 2K) 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.

The interpretations of isolines overlaying to represent three single 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 0.1 K. However temperature isolines overlap for less than 0.5 K for spring tide condition, 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 0.03 K.

The results in Table 5.3 show that an increment of excess temperature at near field boundary for the combined one outfall case compared to the three outfall system. High flow rate would be the reason for this temperature increase.

### 5.4 Far Field Modelling

As discussed earlier two models were used to assess the dispersion pattern of the heat plume, one for the near field and one for the far field. The use of the semi-empirical length scale model, CORMIX, for the near field is described in Section 5.3.

As the 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 treatment. Then in order to simulate the current phenomena, it is possible to use two-dimensional models. MIKE 21 Hydrodynamic Model combine with Thermal Dispersion Tool has been used for hydrodynamic and thermal dispersion simulation in far field region.

#### 5.4.1 Input Data

All input parameters used in local hydrodynamic model (as given in Chapter 4) 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 **Table 5.4**.

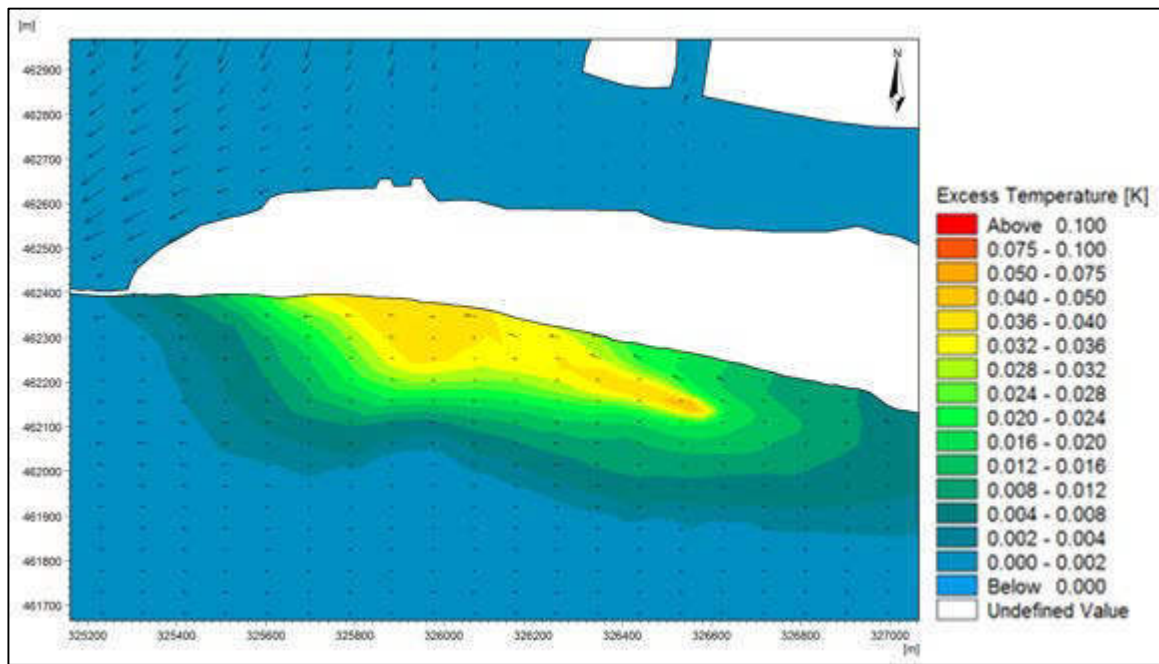
**Table 5.4: Input Excess Temperature for Far-Field Model**

Sc. ID	Monsoon	Tide	Current Condition		Input Excess Temperature for Far- Field Model (K)
			Speed (m/s)	Direction (Deg. N)	
NE_S	North-East	Spring	0.2	271	0.039
NE_N		Neap	0.1	280	0.114
SW_S	South-West	Spring	0.22	280	0.036
SW_N		Neap	0.1	277	0.112

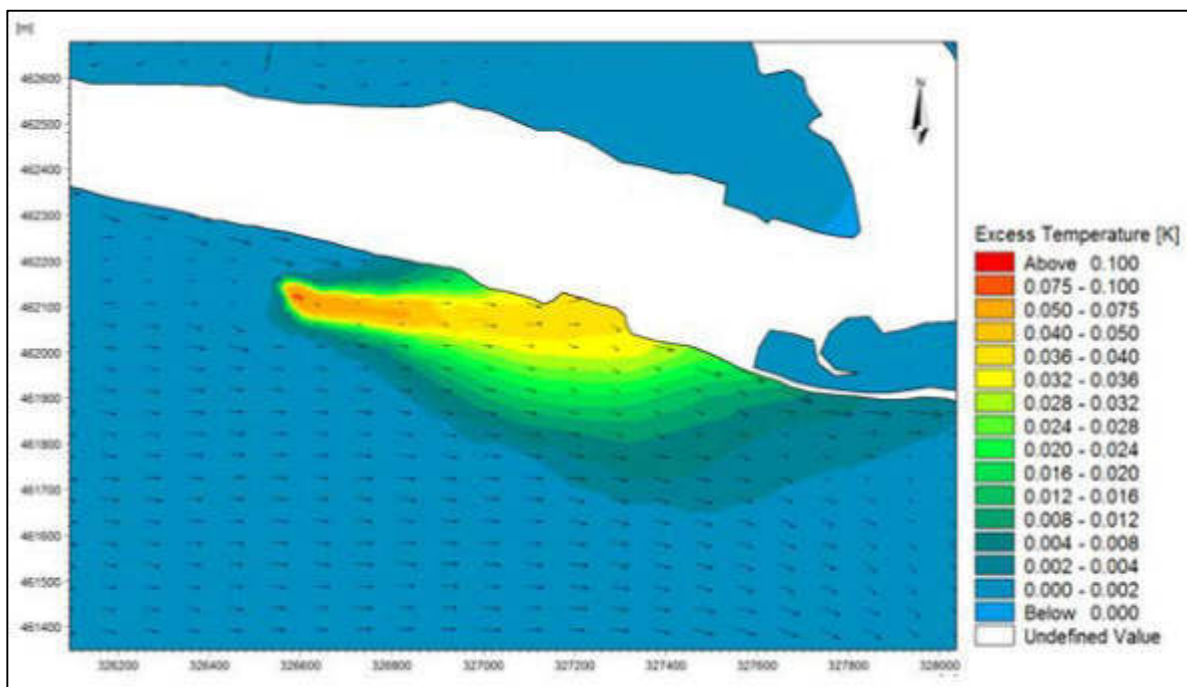
#### 5.4.2 Model Results and Discussion

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 Sc. 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 5.18 and 5.19 show the temperature variation in 2D plain for this high influence scenario when current directed westward and eastward respectively. According to the results, 0.03K excess temperature transfer around 1km range from the discharge point for both cases. However 0.03K 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 it will be a very low effect to the coastal environment. Thermal dispersion plots for all scenarios are given in Annex C.

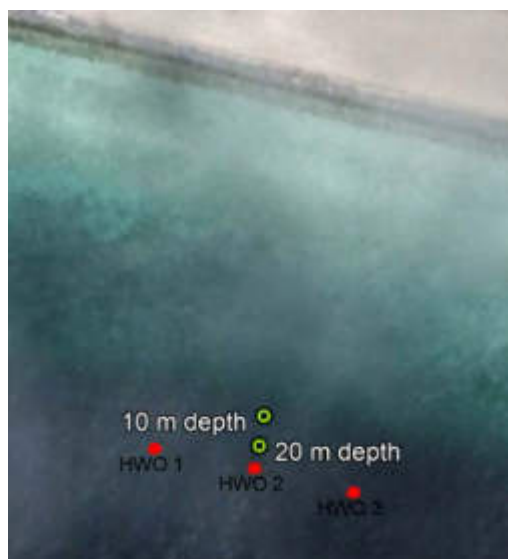


**Figure 5.18: Thermal Dispersion towards West at Scenario NE\_N**



**Figure 5.19: Thermal Dispersion towards East at Scenario NE\_N**

Temperatures at 10m and 20m depths next to the middle outfall (HWO2) location were extracted from far field model results. The locations and coordinates of the extracted points are given below.



**Table 5.5: Coordinates of Results Extracted**

**Locations**

Location	Coordinate	
	Lat	Long
10m Depth	4°10'47.56"N	73°26'15.58"E
20m Depth	4°10'47.37"N	73°26'15.55"E

**Figure 5.20: Excess Temperature Extracted**

**Locations**

The maximum temperatures obtained through extracted results for different scenarios are given in Table 5.6. Even though extracted points are very close to the middle outfall (both points are located around within 10m distance from HWO2), 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 to the seaward, but the extracted points are located at the other way, hence high temperatures would not transfer to the north side of outfalls. Therefore the direction of heat plume projections would be the reason for low maximum temperatures in the north side of the outfalls.

**Table 5.6: Maximum Excess Temperatures at Extracted Points**

Sc. ID	Monsoon	Tide	Maximum Excess Temperature (K)	
			10m Depth	20m Depth
NE_S	North-East	Spring	0.020	0.021
NE_N		Neap	0.036	0.038
SW_S	South-West	Spring	0.016	0.017
SW_N		Neap	0.065	0.073



## 6 SUMMARY AND CONCLUSION

- In order to find out thermal dispersion in coastal environment for outfall of hot water plume of a proposed incinerator at Thilafushi Island, a set of numerical model simulation was carried out for different monsoon and tidal conditions.
- Measured data as well as reliable predicted data were utilized as model inputs, and analysed them before applied to the model.
- 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 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.
- Two modelling system were used thermal dispersion modelling, namely CORMIX model for **near-field** dispersion and MIKE 21 HD coupled with thermal dispersion tool for **far-field** dispersion.
- According to the near-field model results,
  - Excess temperatures at the near field boundary for the neap tidal conditions (around 0.11 K) were higher than for the spring tidal conditions (0.03 K)
  - A high temperature reduction was observed within a few meters from the released point.
  - 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 K at near field boundary.
  - Higher excess temperatures (0.11 to 0.24 K) at the near field boundary were observed in the combined single outfall case compared to the three separate outfalls system. The high flow rate would be the reason for that result.
- Results obtained from near-field model were used as input parameter for far-field model.
- Far-field model results represent the temperature spreading in 2D plain for different scenarios.
- According to far-field model results,
  - Same as the near-field model, scenarios with the neap tidal condition show some influence compared to the spring tidal situations.
  - High spreading of heat is also observed in the neap tidal condition but however spread excess temperature values are small and it would not significantly impact coastal environment.
  - Maximum excess temperatures extracted shoreward to the outfall are not significantly high. 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 deep sea). Therefore the direction of heat plume projections would be the reason for low maximum temperatures in the north side of the outfalls.

# **ANNEX A**

## **Near Field Model Results**

### **Plan Views & Elevations of Heat Plume and Excess Temperature vs. Downstream Distance Graphs**

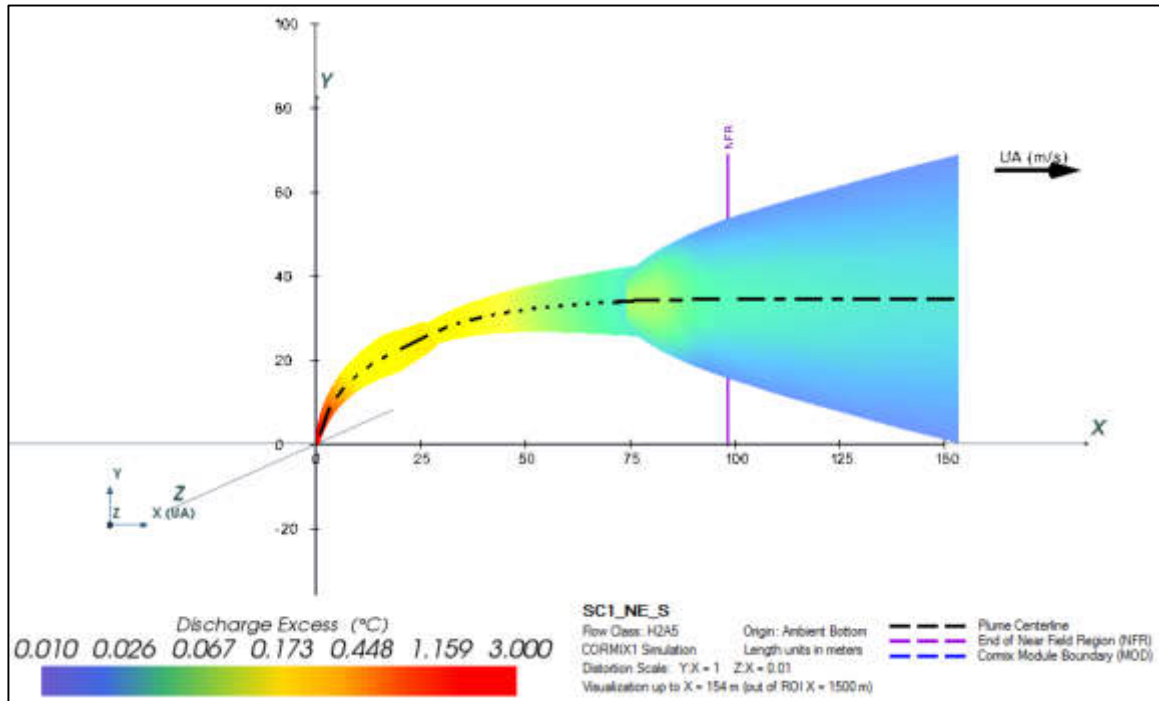


Figure A.1: Plan View - Effluent Discharged at Near-Field Region (NE Monsoon – Spring Tide)

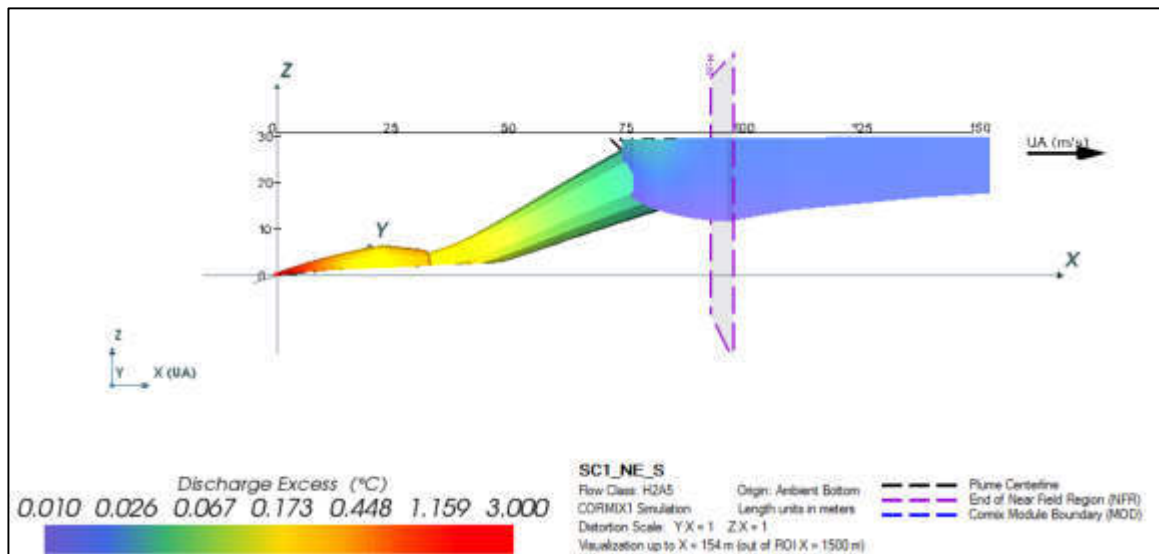


Figure A.2: Elevation - Effluent Discharged at Near-Field Region (NE Monsoon – Spring Tide)

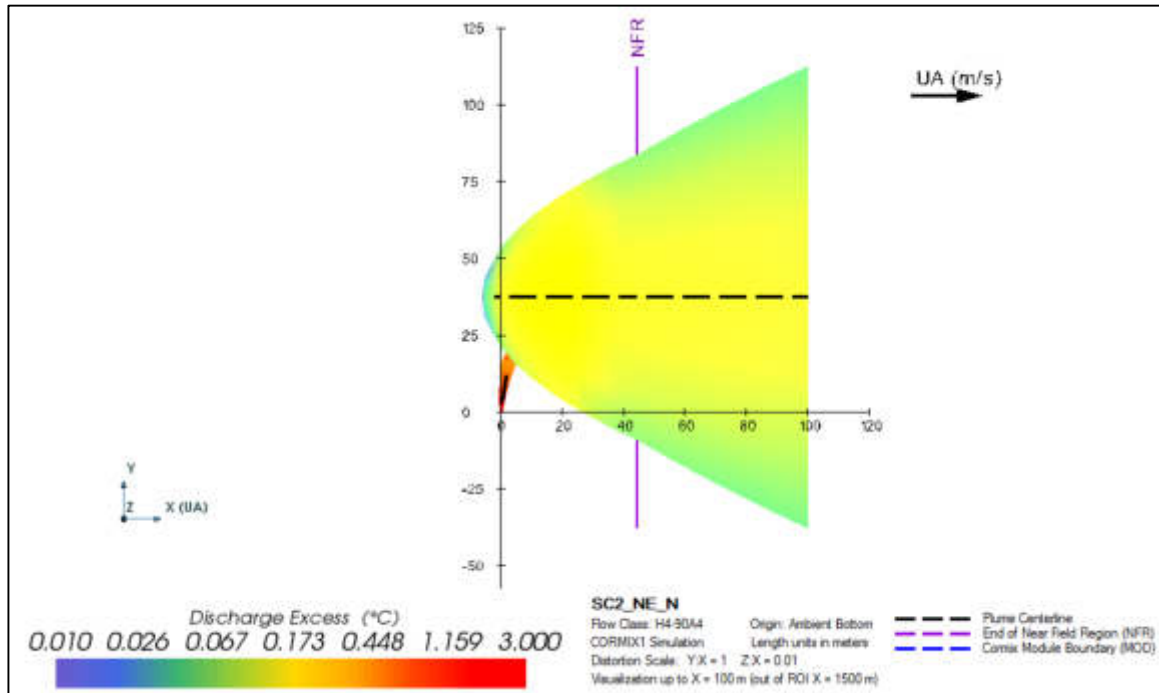


Figure A.3: Plan View - Effluent Discharged at Near-Field Region (NE Monsoon – Neap Tide)

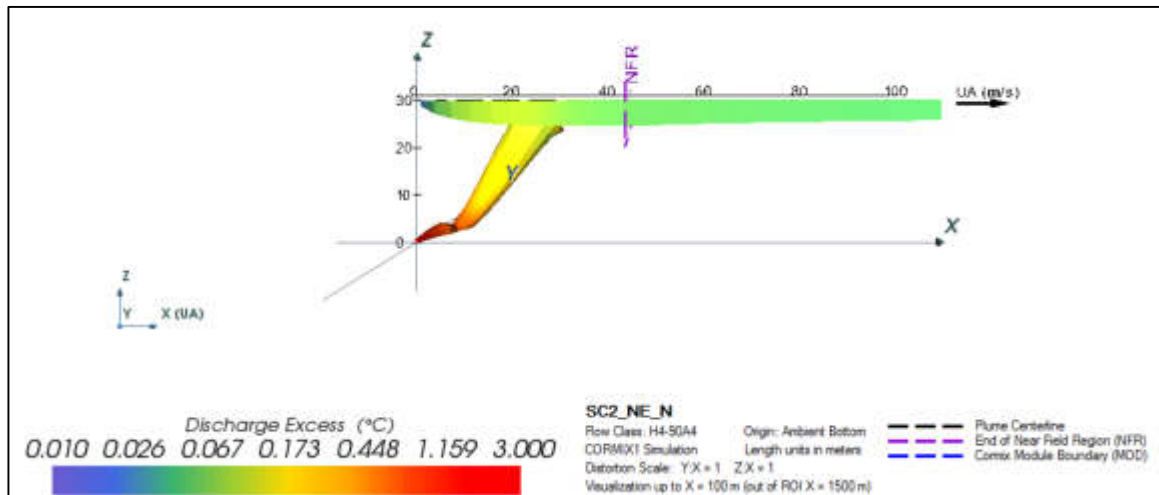


Figure A.4: Elevation - Effluent Discharged at Near-Field Region (NE Monsoon – Neap Tide)

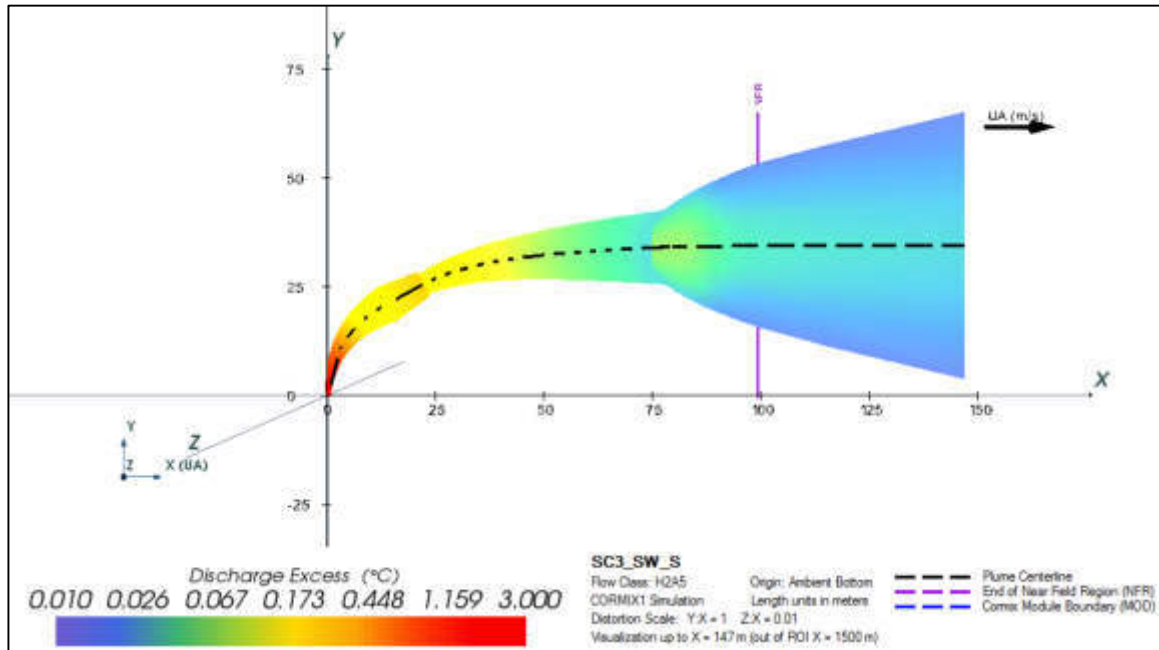


Figure A.5: Plan View - Effluent Discharged at Near-Field Region (SW Monsoon – Spring Tide)

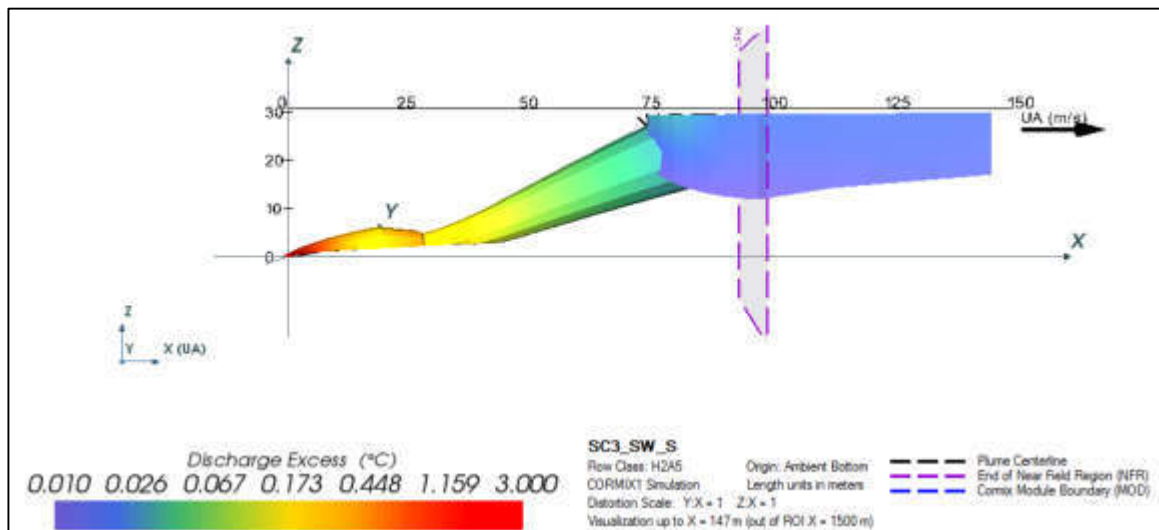


Figure A.6: Elevation - Effluent Discharged at Near-Field Region (SW Monsoon – Spring Tide)

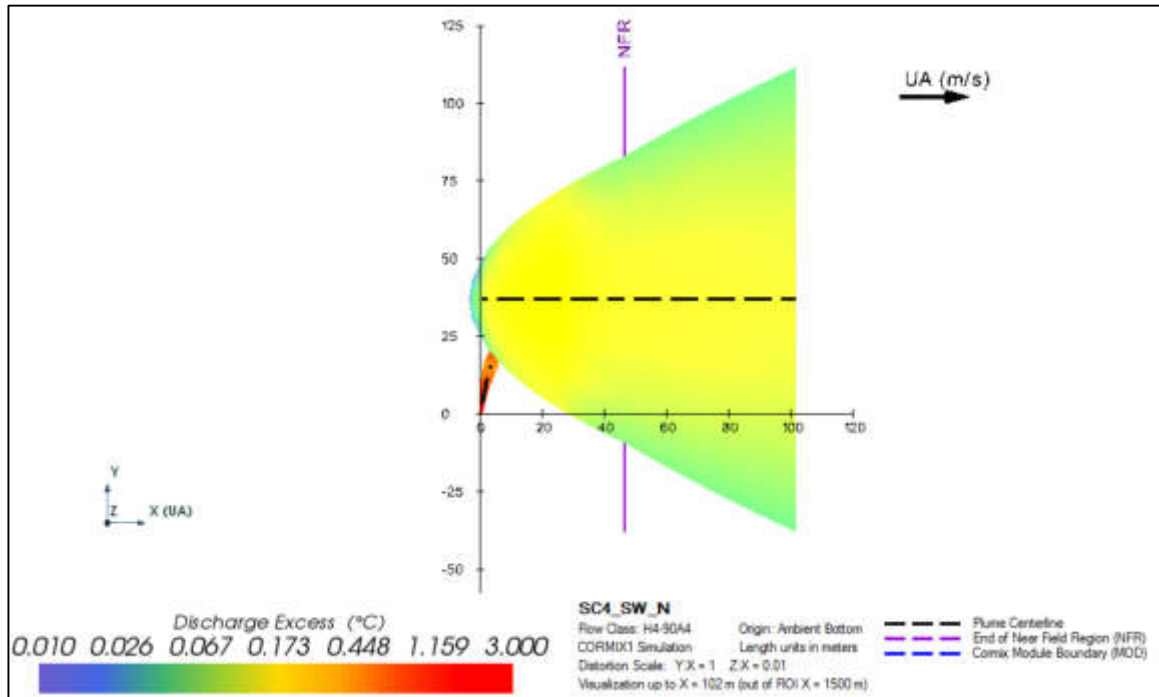


Figure A.7: Plan View - Effluent Discharged at Near-Field Region (SW Monsoon – Neap Tide)

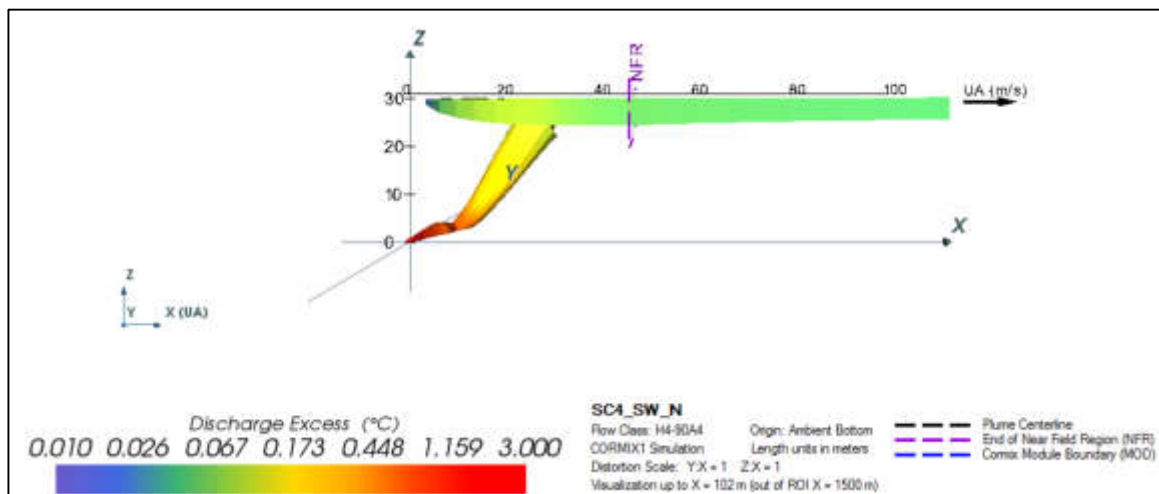
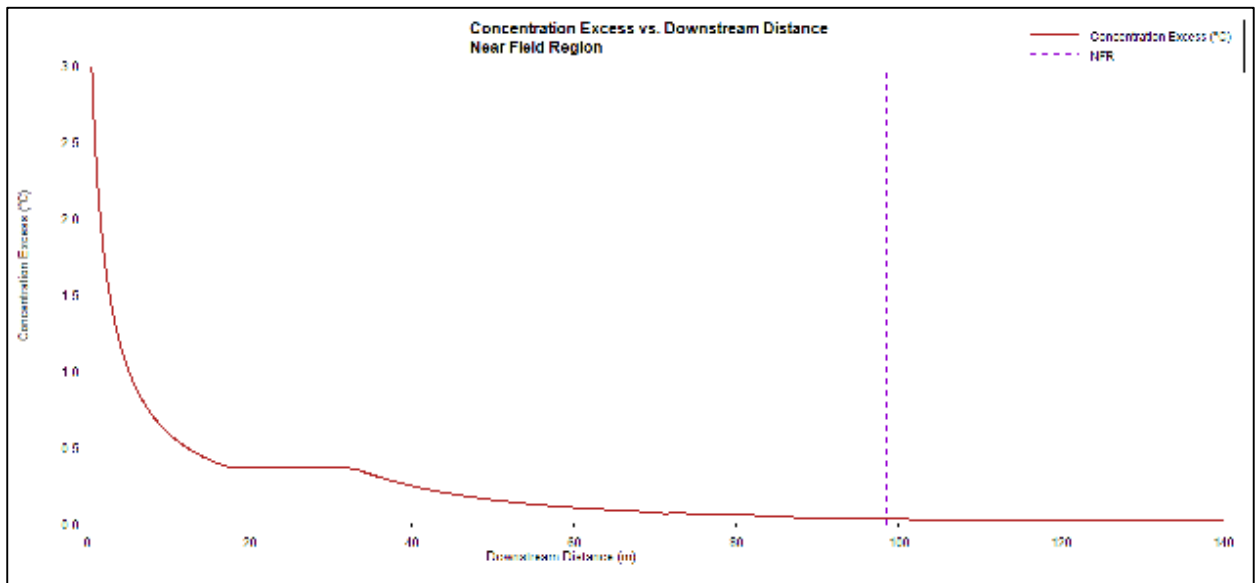
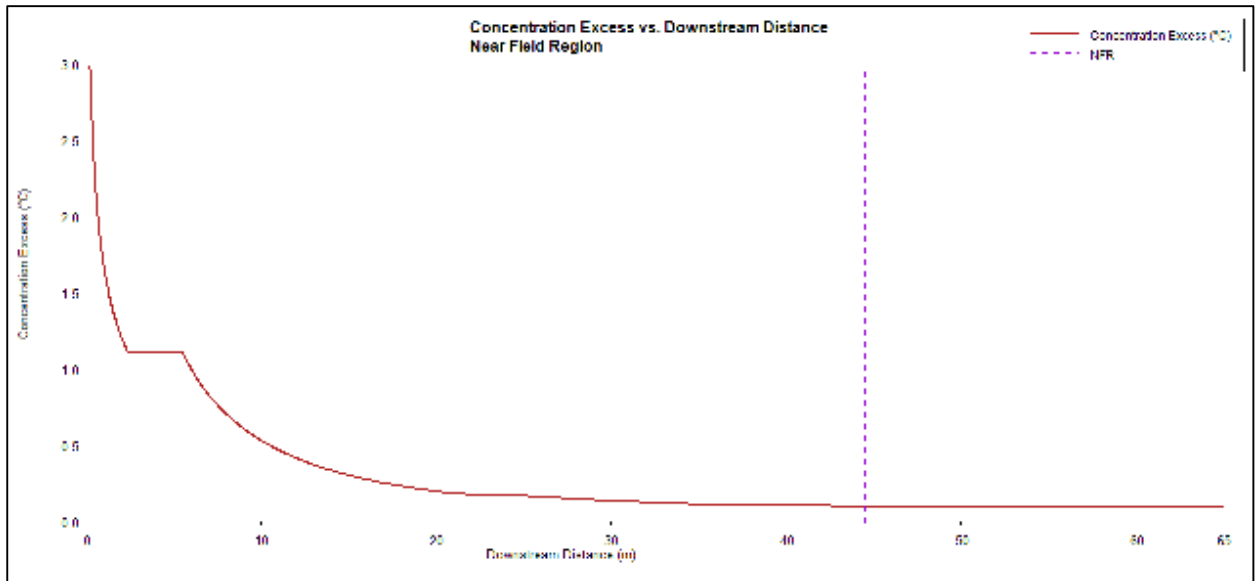


Figure A.8: Elevation - Effluent Discharged at Near-Field Region (SW Monsoon – Neap Tide)

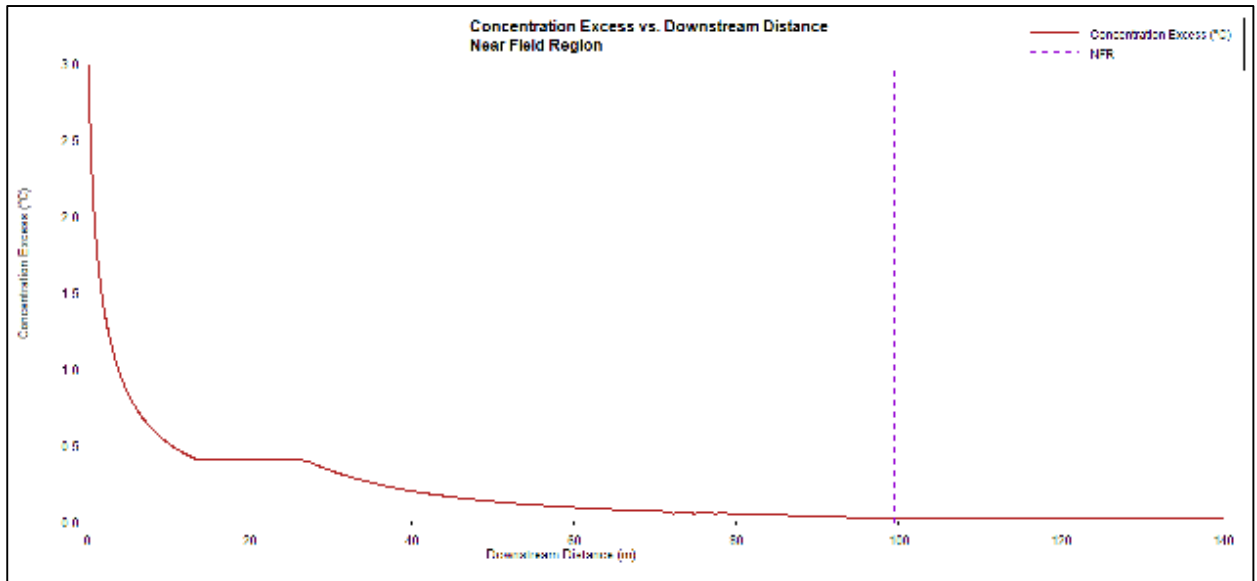


**Figure A.9: Excess Temperature vs Downstream Distance (NE Monsoon – Spring Tide)**

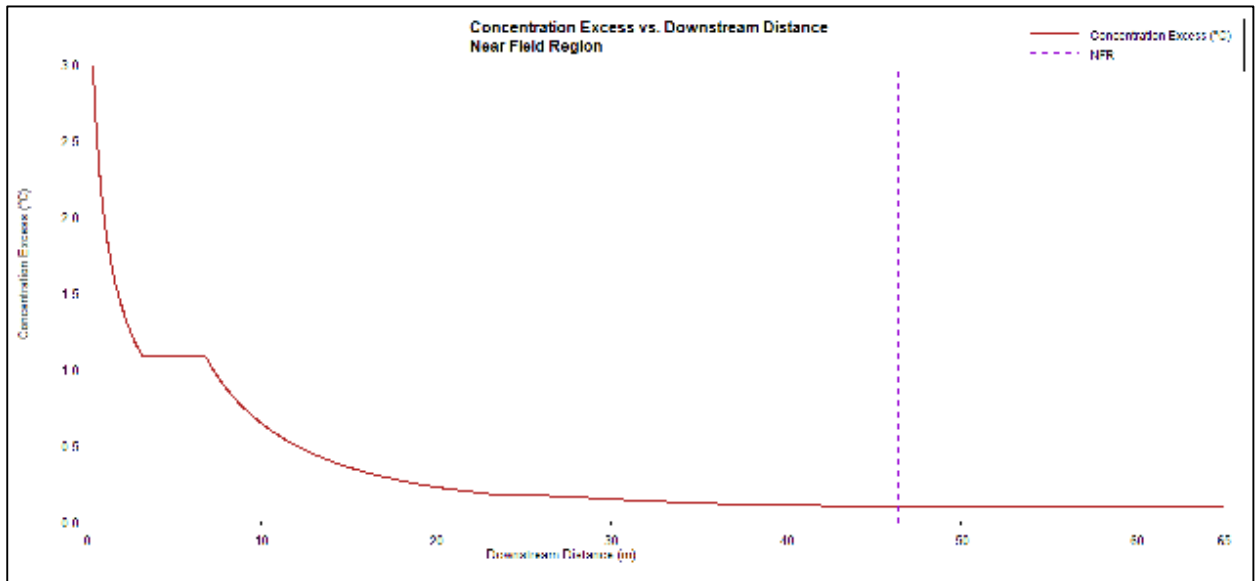


**Figure A.10: Excess Temperature vs Downstream Distance (NE Monsoon – Neap Tide)**





**Figure A.11: Excess Temperature vs Downstream Distance (SW Monsoon – Spring Tide)**



**Figure A.12: Excess Temperature vs Downstream Distance (SW Monsoon – Neap Tide)**

## **ANNEX B**

### **Near Field Model Results for Combined Single Outfall**

#### **Plan Views & Elevations of Heat Plume and Excess Temperature vs. Downstream Distance Graphs**

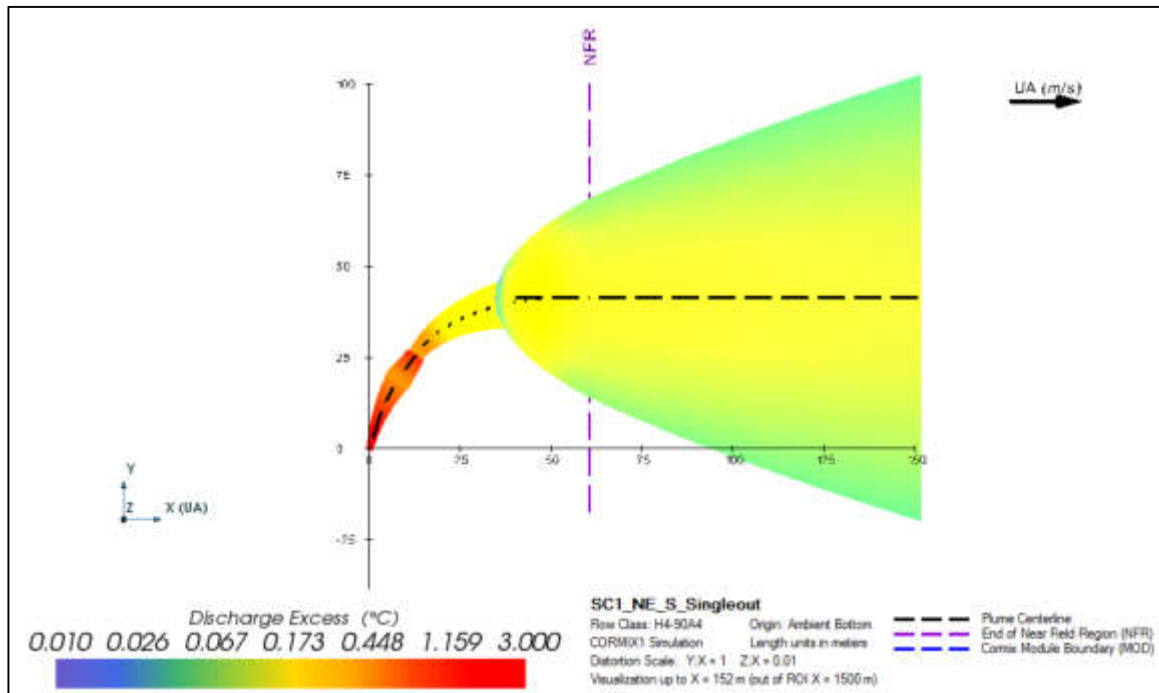


Figure B.1: Plan View - Effluent Discharged at Near-Field Region for Combine Single Outfall (NE Monsoon – Spring Tide)

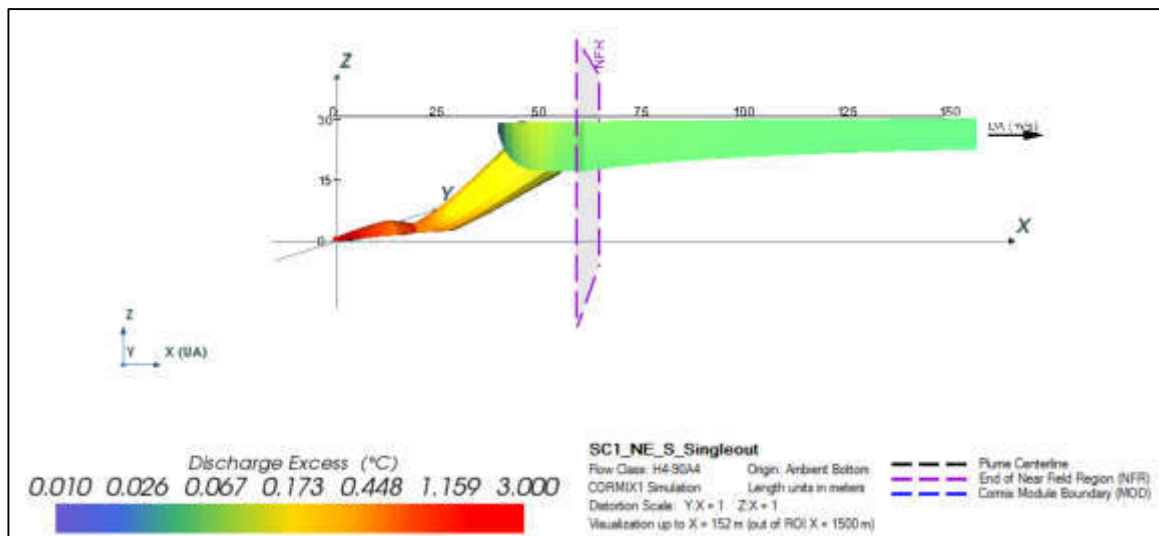
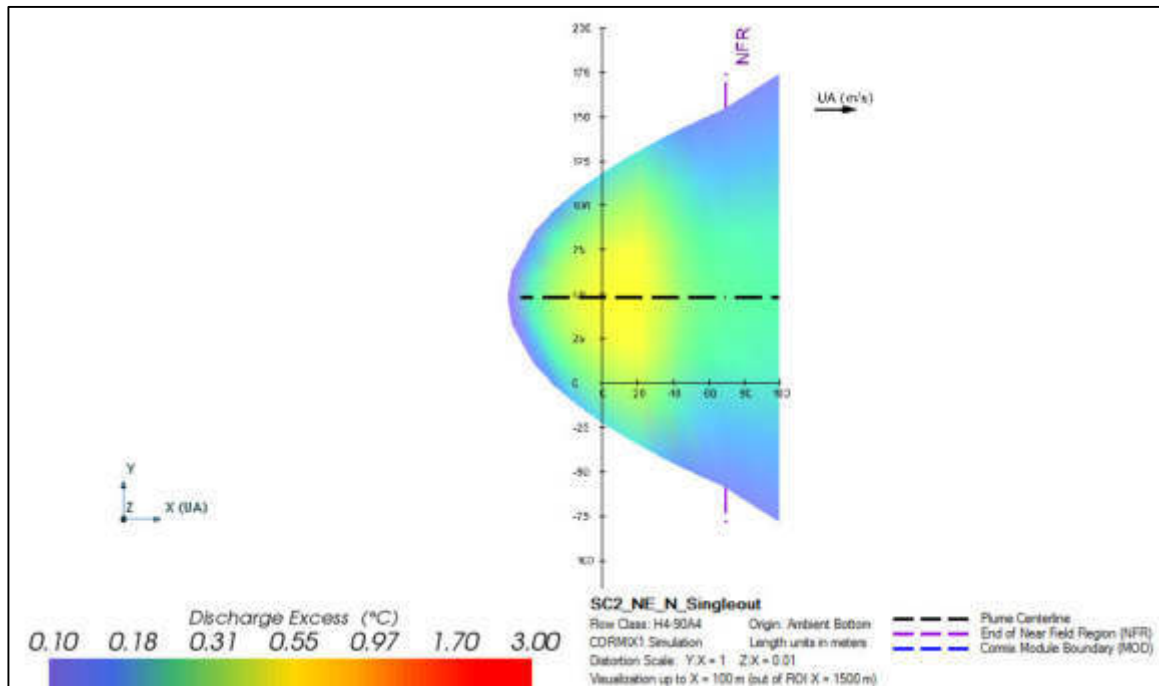
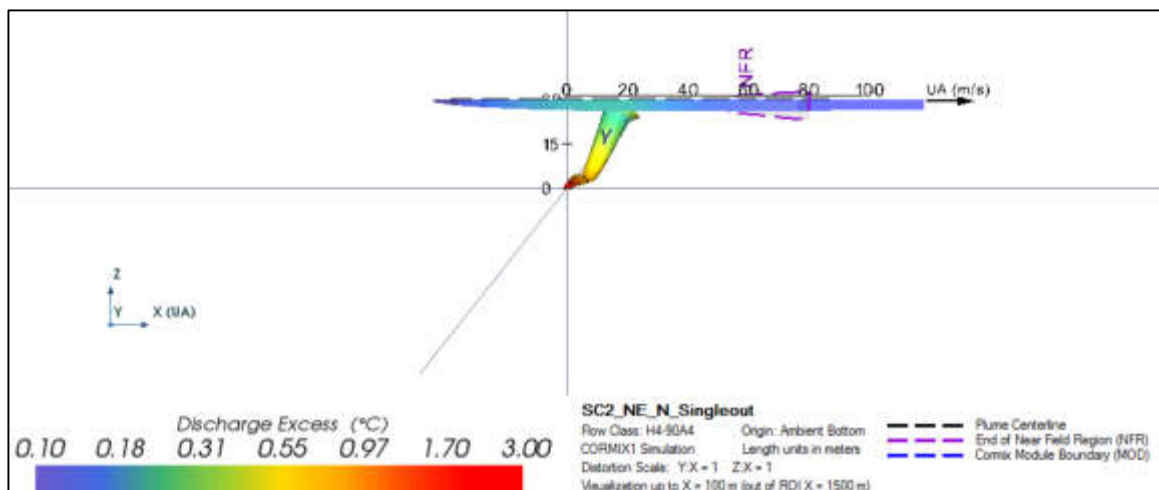


Figure B.2: Elevation - Effluent Discharged at Near-Field Region for Combine Single Outfall (NE Monsoon – Spring Tide)



**Figure B.3: Plan View - Effluent Discharged at Near-Field Region for Combine Single Outfall (NE Monsoon – Neap Tide)**



**Figure B.4: Elevation - Effluent Discharged at Near-Field Region for Combine Single Outfall (NE Monsoon – Neap Tide)**

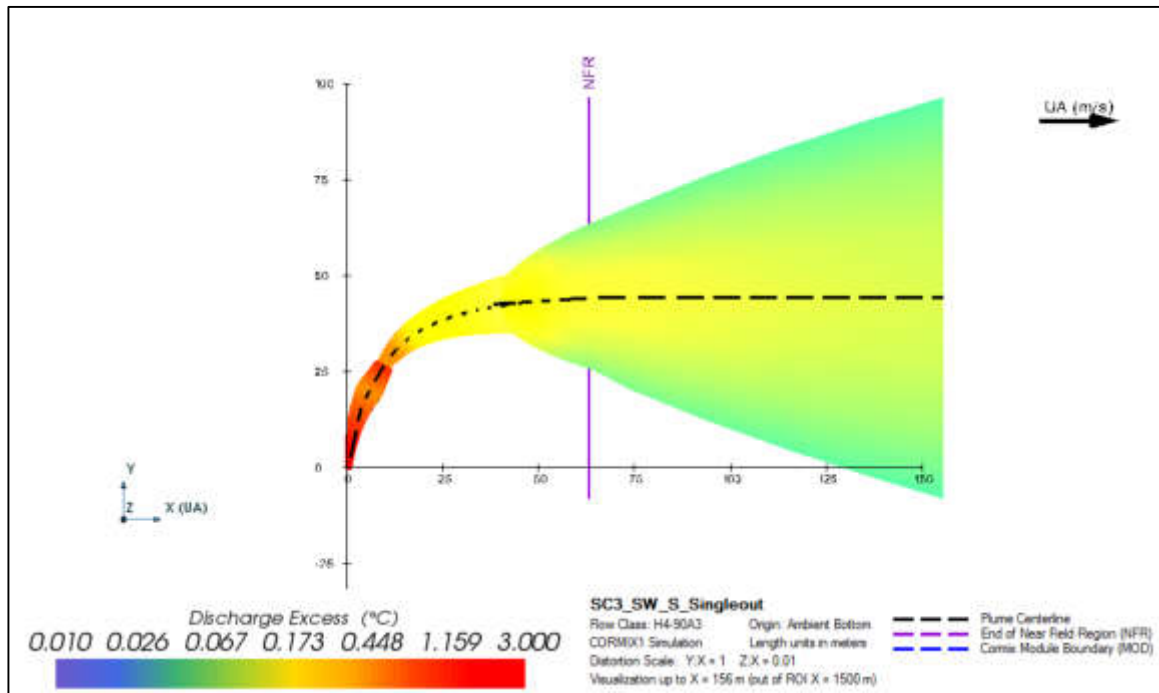


Figure B.5: Plan View - Effluent Discharged at Near-Field Region for Combine Single Outfall (SW Monsoon – Spring Tide)

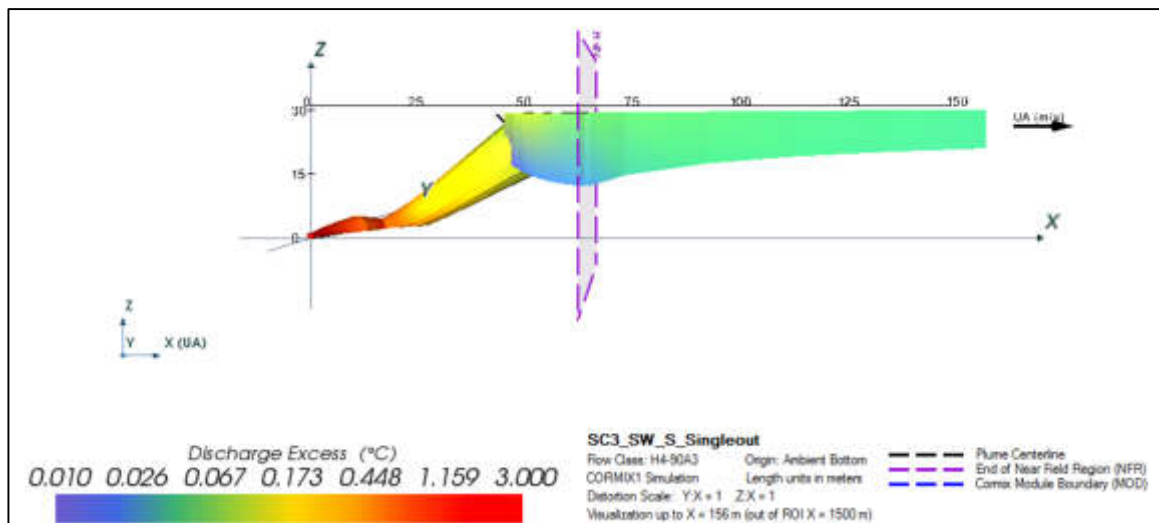
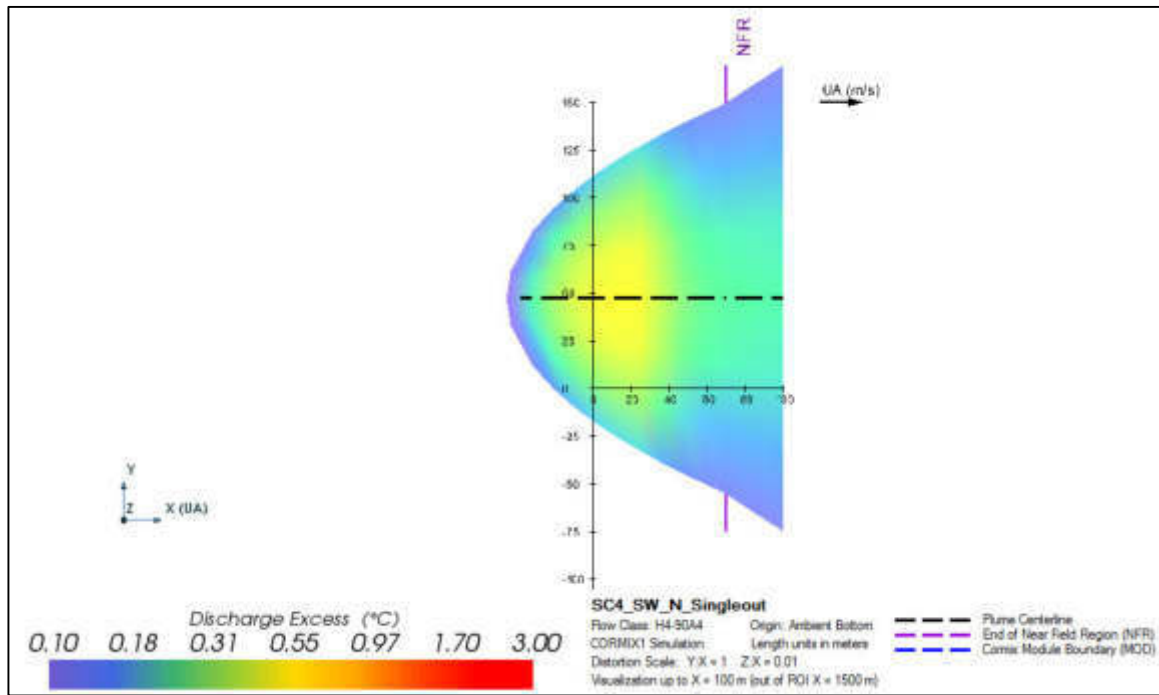
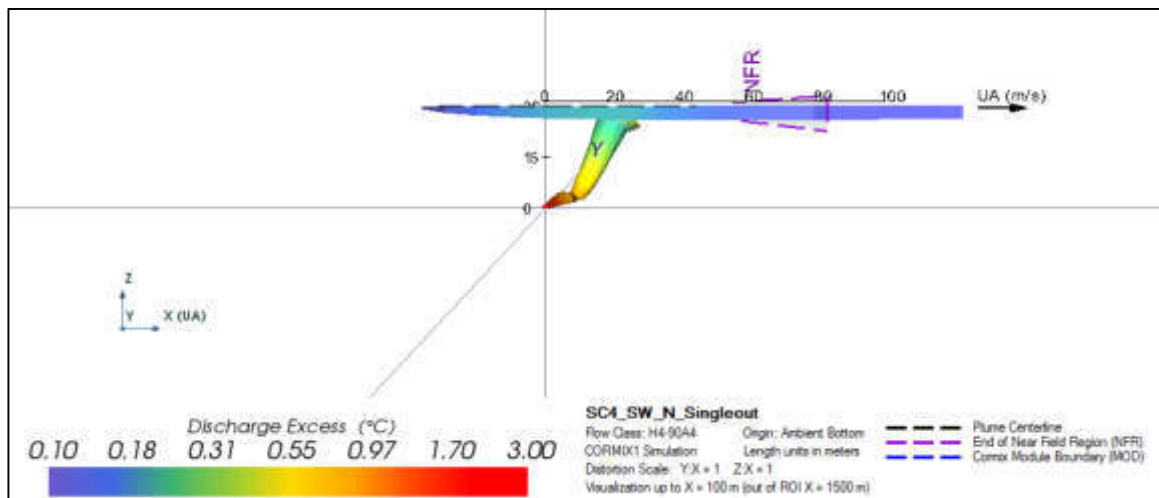


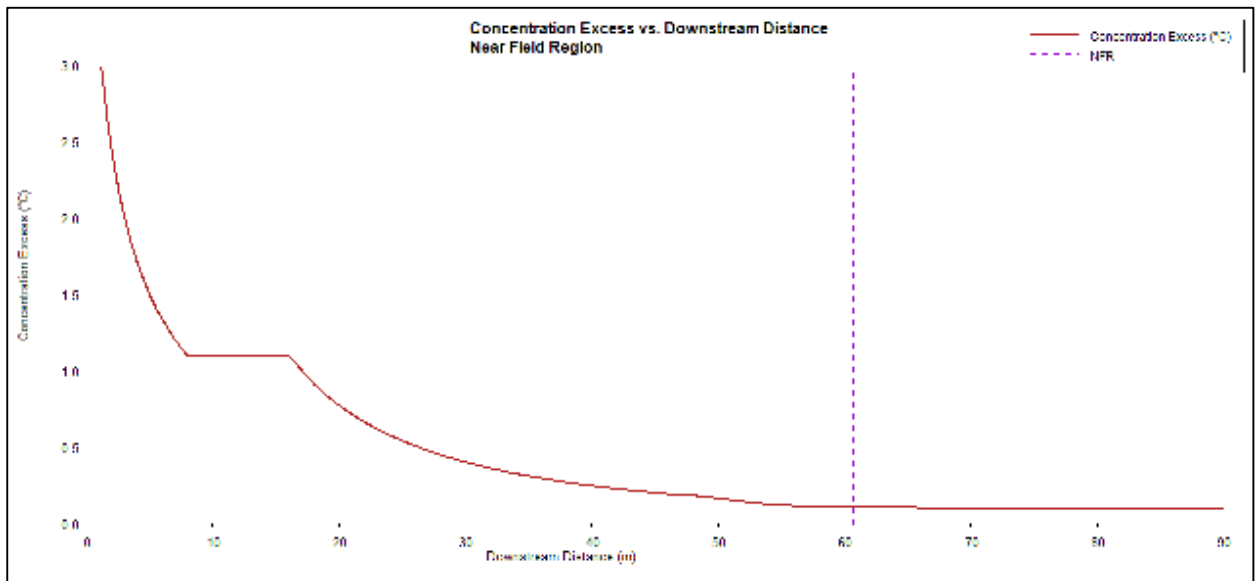
Figure B.6: Elevation - Effluent Discharged at Near-Field Region for Combine Single Outfall (SW Monsoon – Spring Tide)



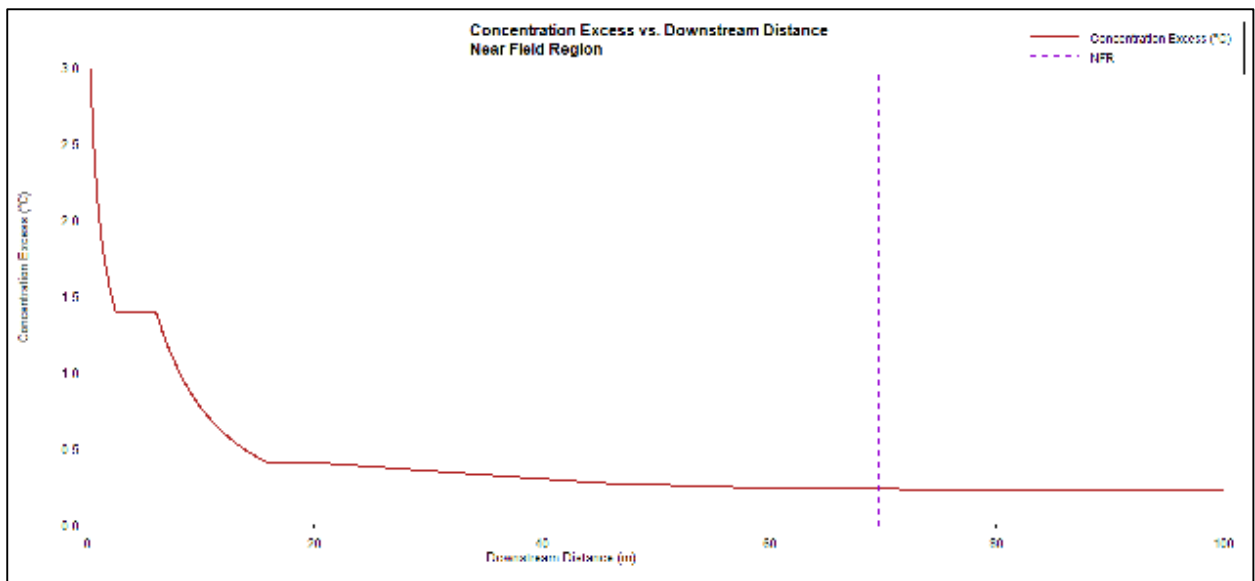
**Figure B.7: Plan View - Effluent Discharged at Near-Field Region for Combine Single Outfall (SW Monsoon – Neap Tide)**



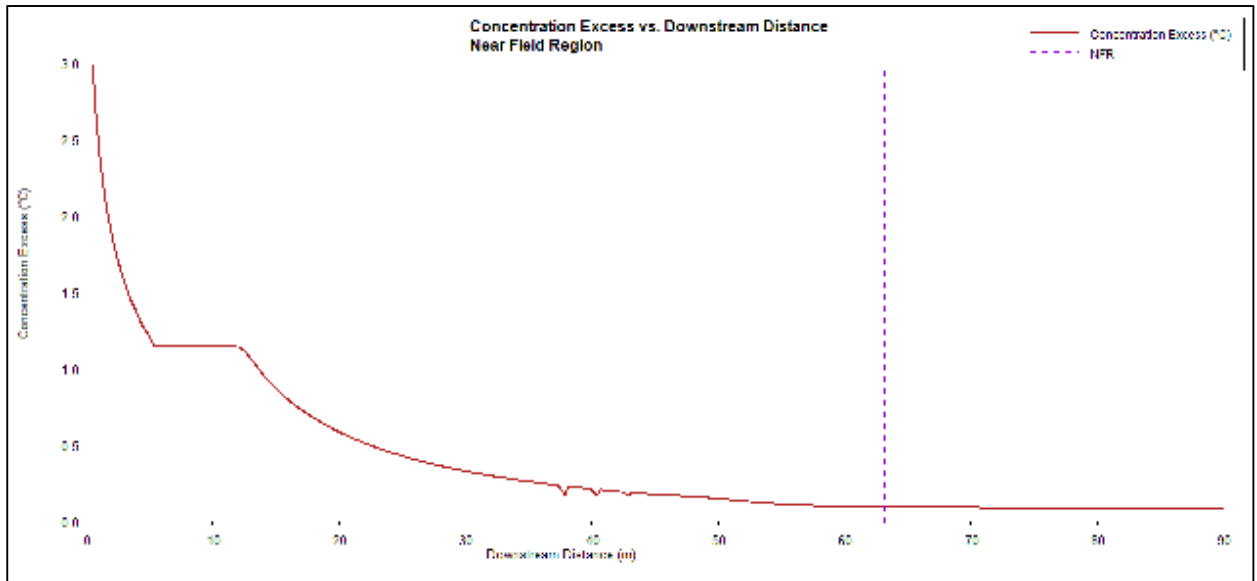
**Figure B.8: Elevation - Effluent Discharged at Near-Field Region for Combine Single Outfall (SW Monsoon – Neap Tide)**



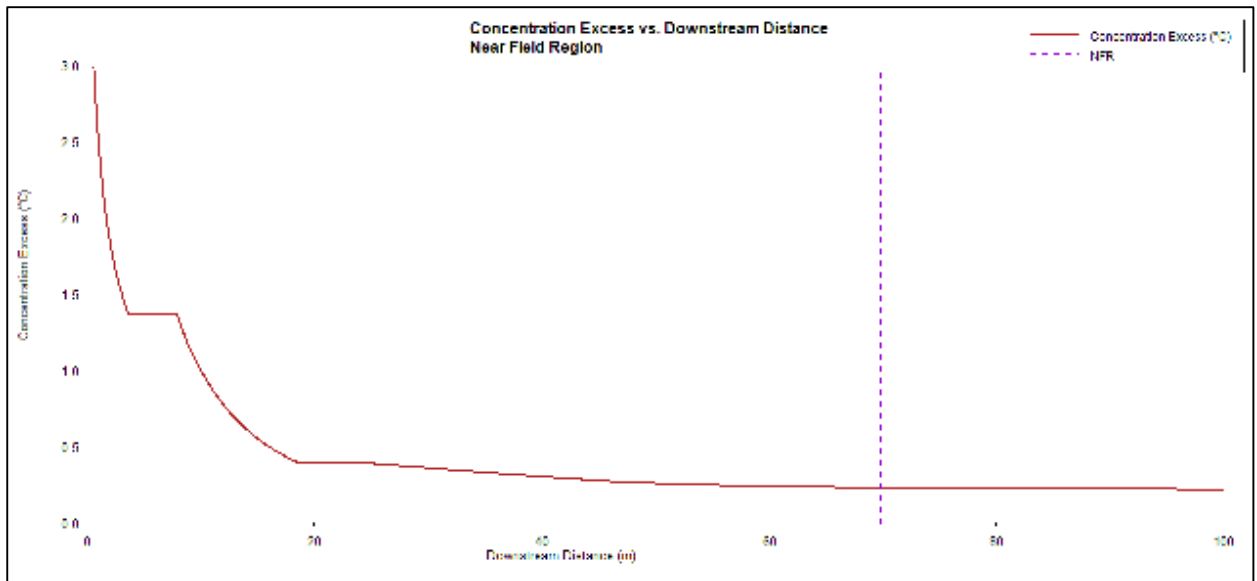
**Figure B.9: Excess Temperature vs Downstream Distance for Combine Single Outfall (NE Monsoon – Spring Tide)**



**Figure B.10: Excess Temperature vs Downstream Distance for Combine Single Outfall (NE Monsoon – Neap Tide)**



**Figure B.11: Excess Temperature vs Downstream Distance for Combine Single Outfall (SW Monsoon – Spring Tide)**



**Figure B.12: Excess Temperature vs Downstream Distance for Combine Single Outfall (SW Monsoon – Neap Tide)**



## **ANNEX C**

### **Heat Dispersion in Far Field (MIKE 21 HD)**

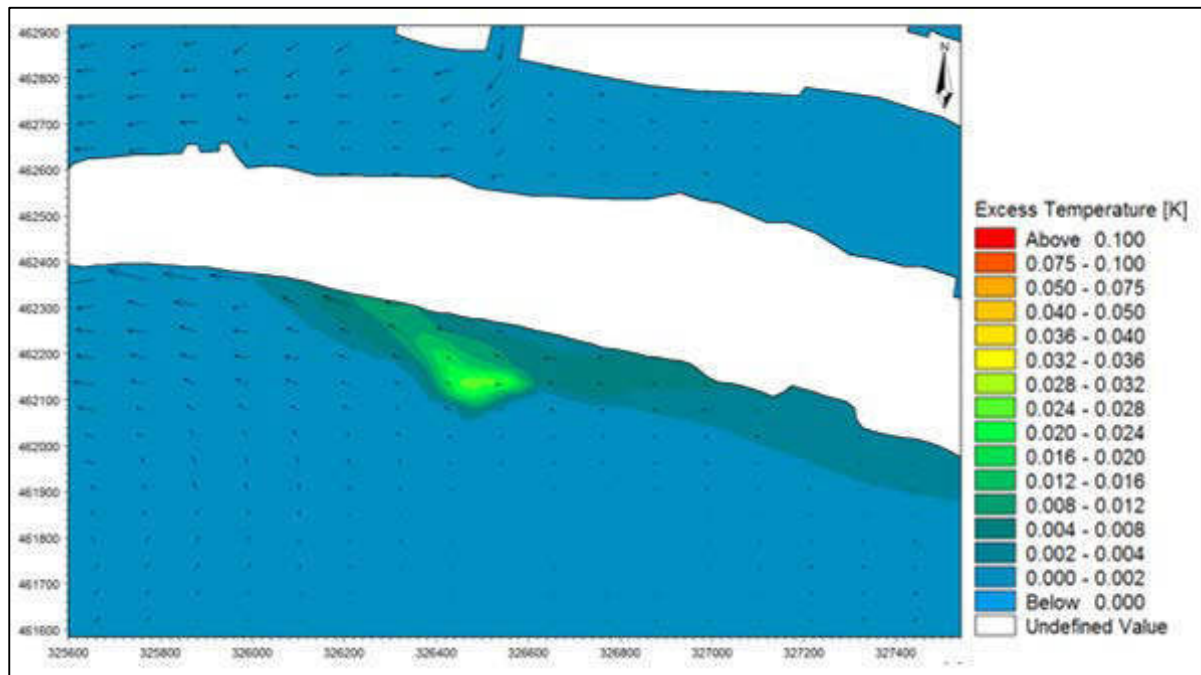


Figure C.1: Thermal Dispersion towards West (NE Monsoon – Spring Tide)

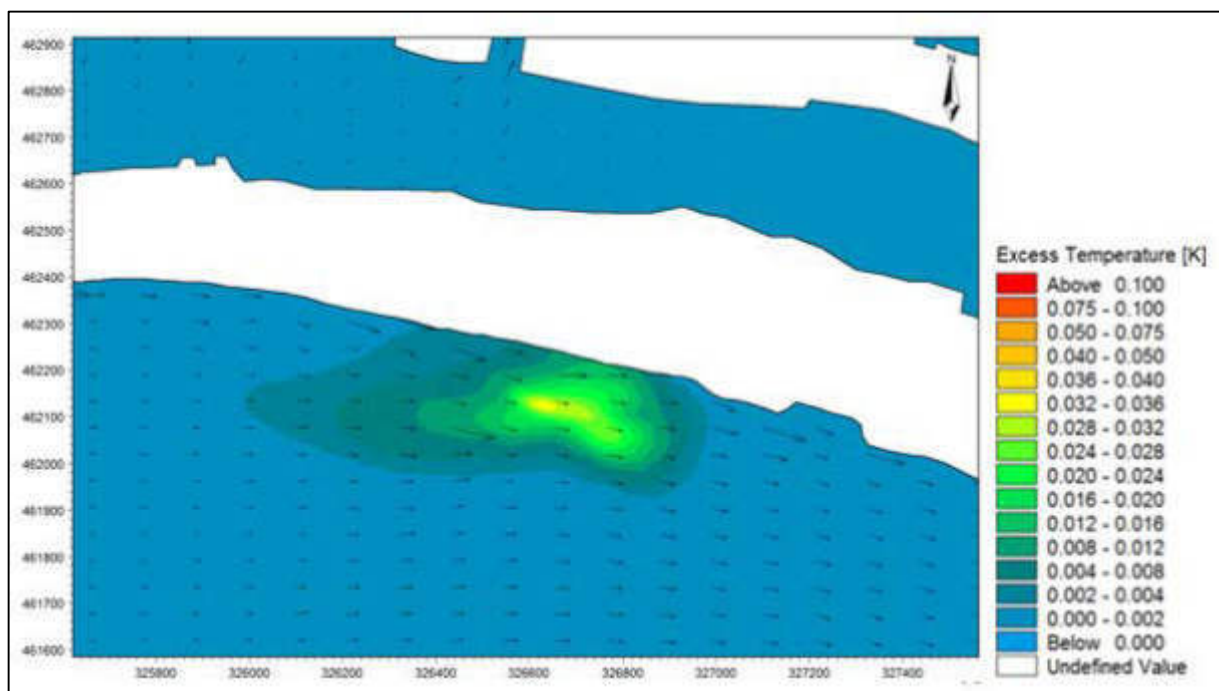


Figure C.2: Thermal Dispersion towards East (NE Monsoon – Spring Tide)

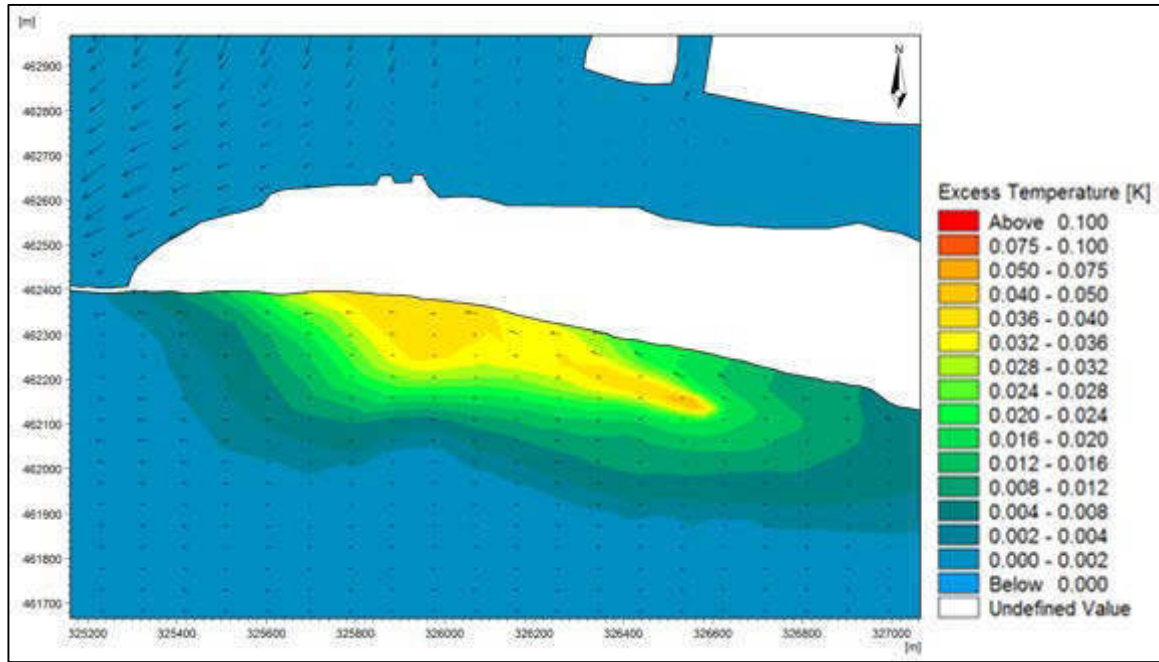


Figure C.3: Thermal Dispersion towards West (NE Monsoon – Neap Tide)

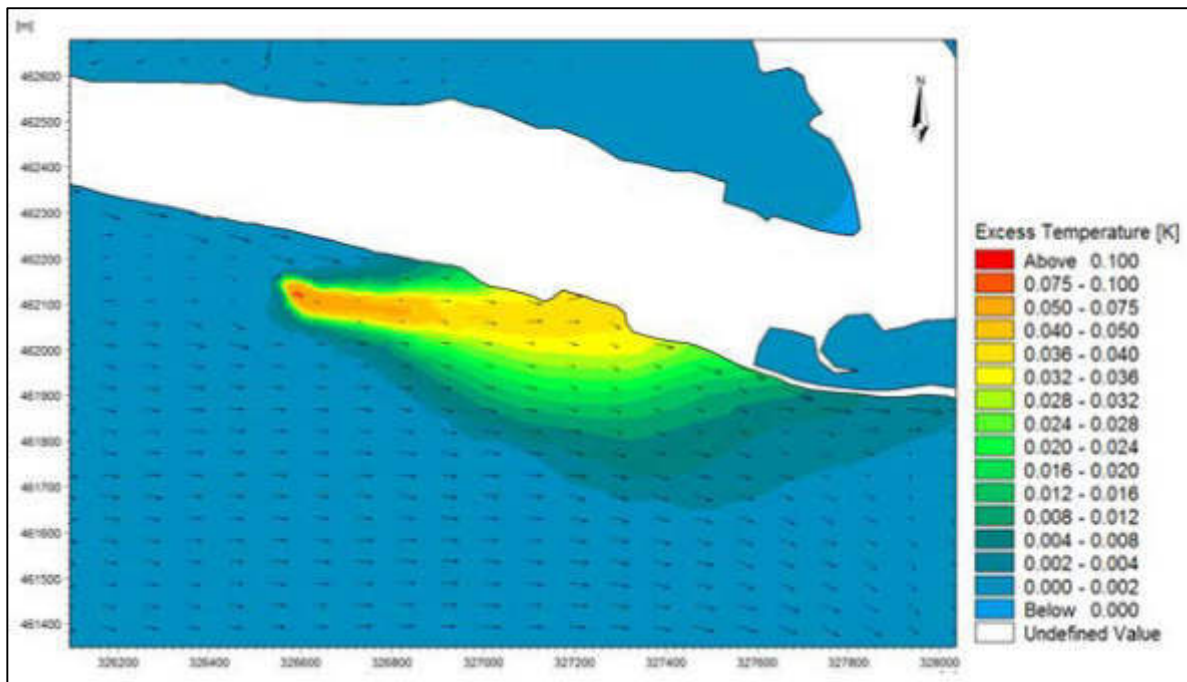


Figure C.4: Thermal Dispersion towards East (NE Monsoon – Neap Tide)

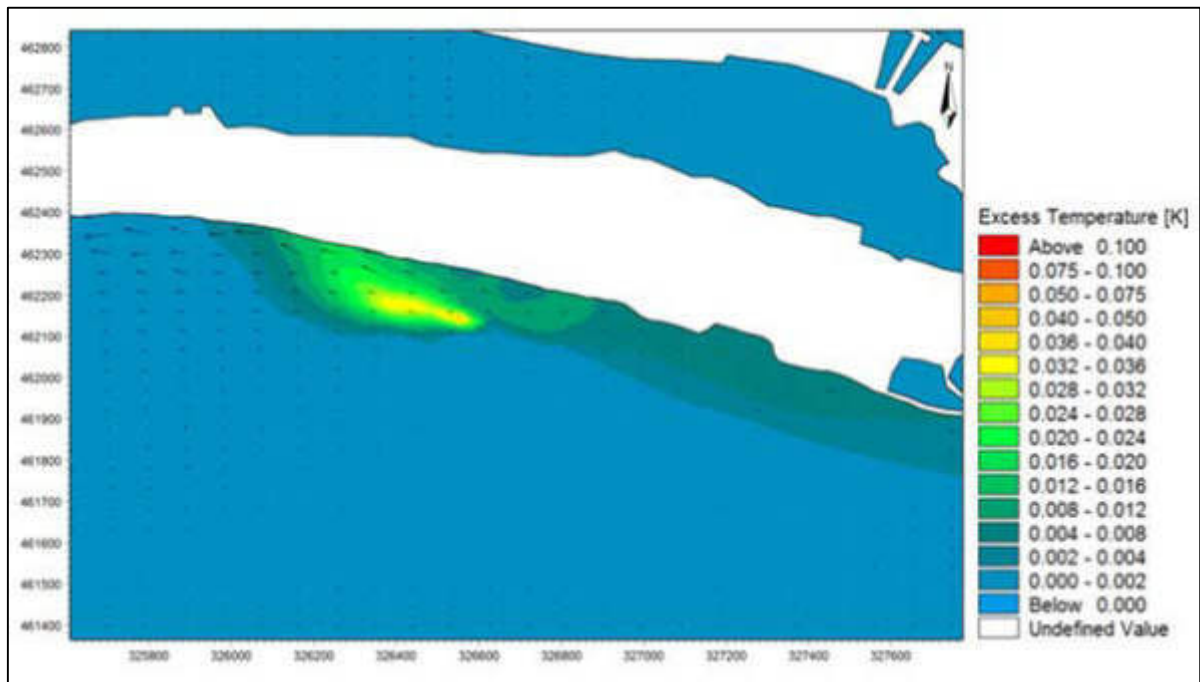


Figure C.5: Thermal Dispersion towards West (SW Monsoon – Spring Tide)

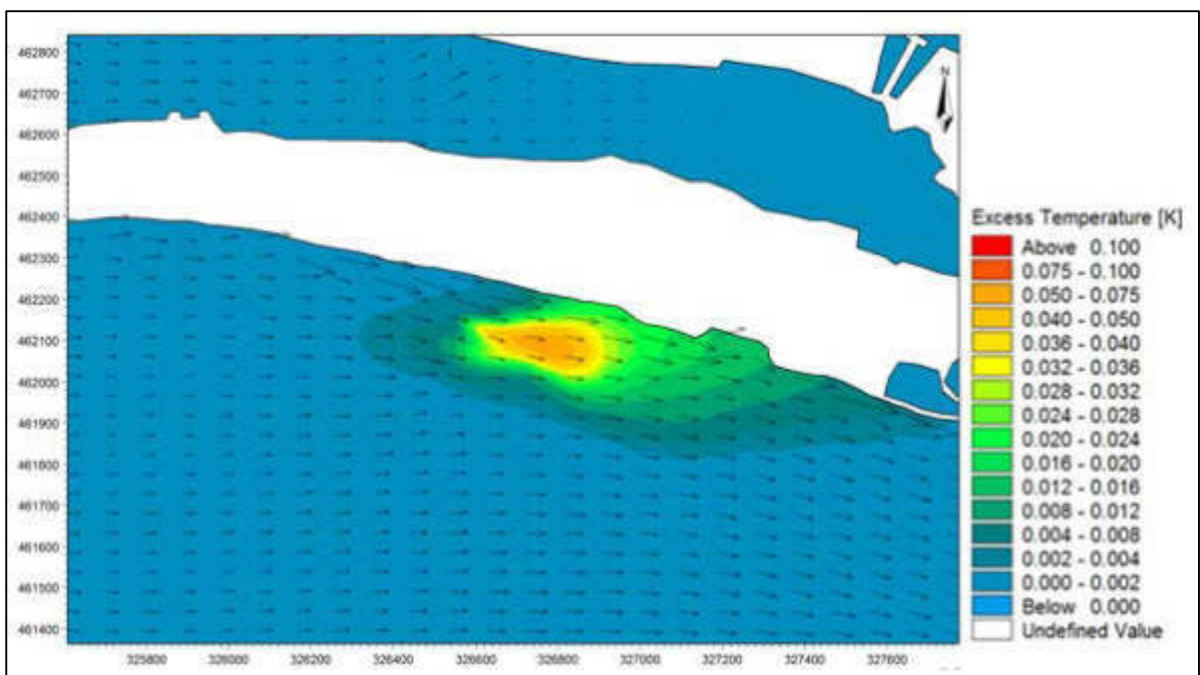


Figure C.6: Thermal Dispersion towards East (SW Monsoon – Spring Tide)

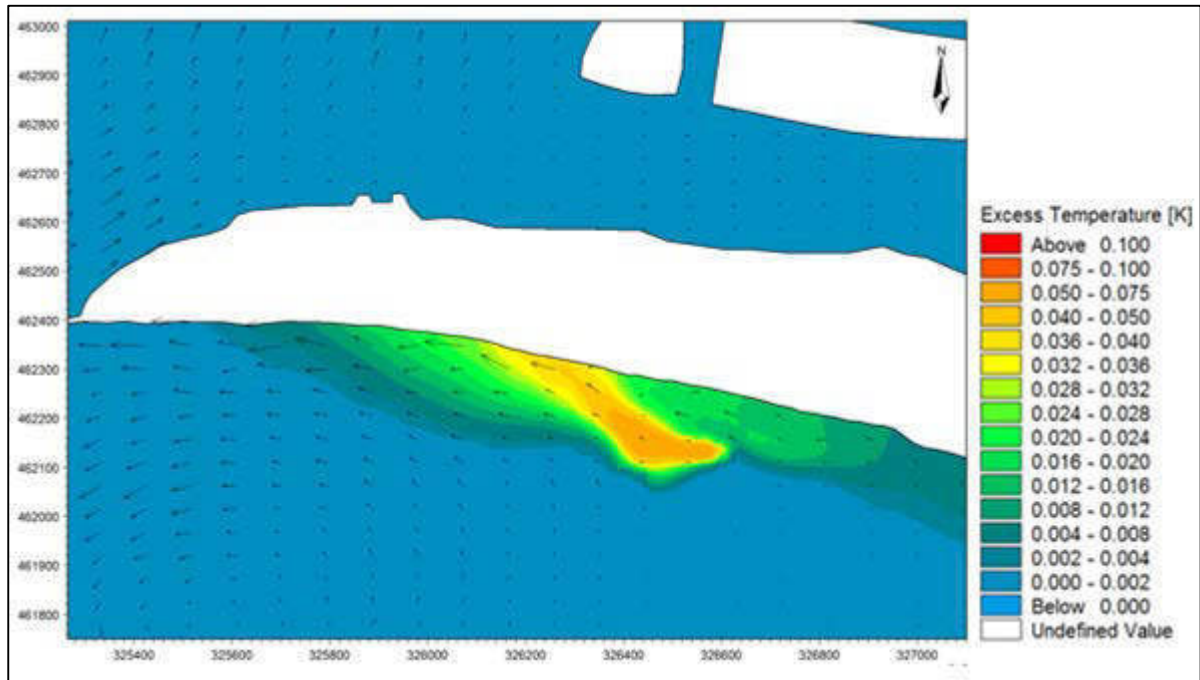


Figure C.7: Thermal Dispersion towards West (SW Monsoon – Neap Tide)

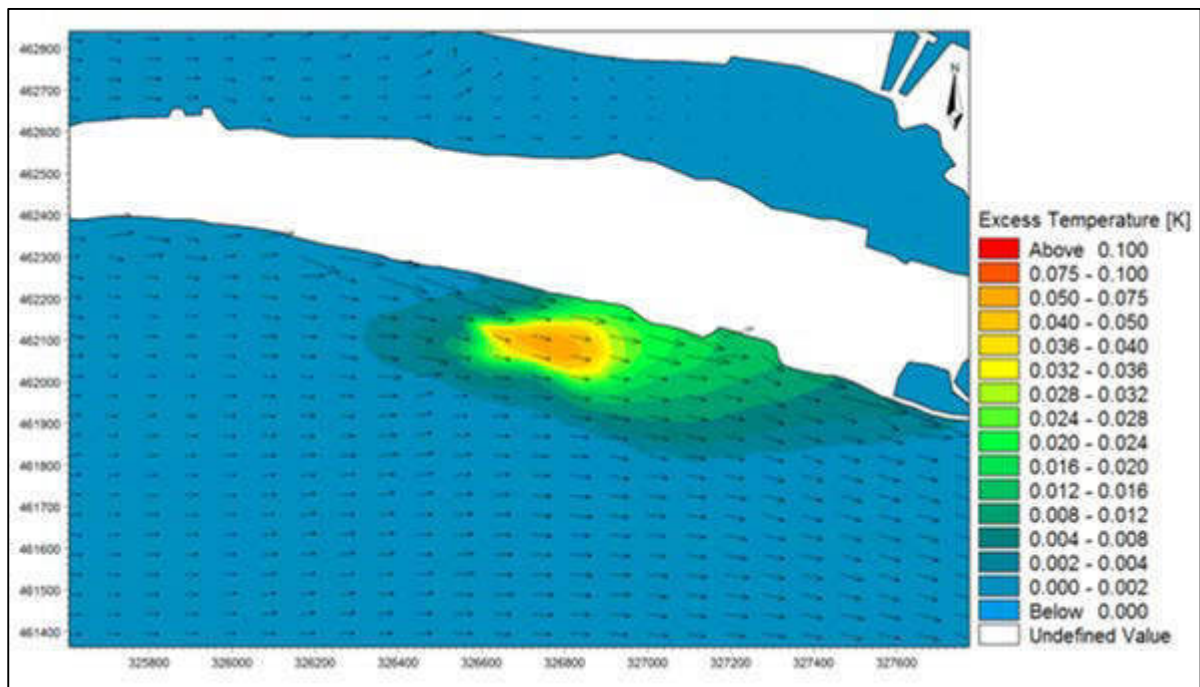


Figure C.8: Thermal Dispersion towards East (SW Monsoon – Neap Tide)

Environmental and Social Impact Assessment for the Regional Solid Waste Management Facility (RSWMF) Thilafushi

## **Noise Level Measurement**

**Prepared by:** Abdul Aleem (EIA P03/2019)



23<sup>rd</sup> September 2019

## Noise Level Measurement

Noise level was measured to establish baseline at five locations: NQ1, NQ2, NQ3, NQ4 and NQ5 by Water Solutions on 25th August 2019 using hand held sound level meter at Thilafushi. Ambient noise levels were measured during the day time from 10:00 am to 12:00 pm and during the night from 10:00 pm to 12:00 pm at 5 locations (see map). 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.

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 harbour. 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.

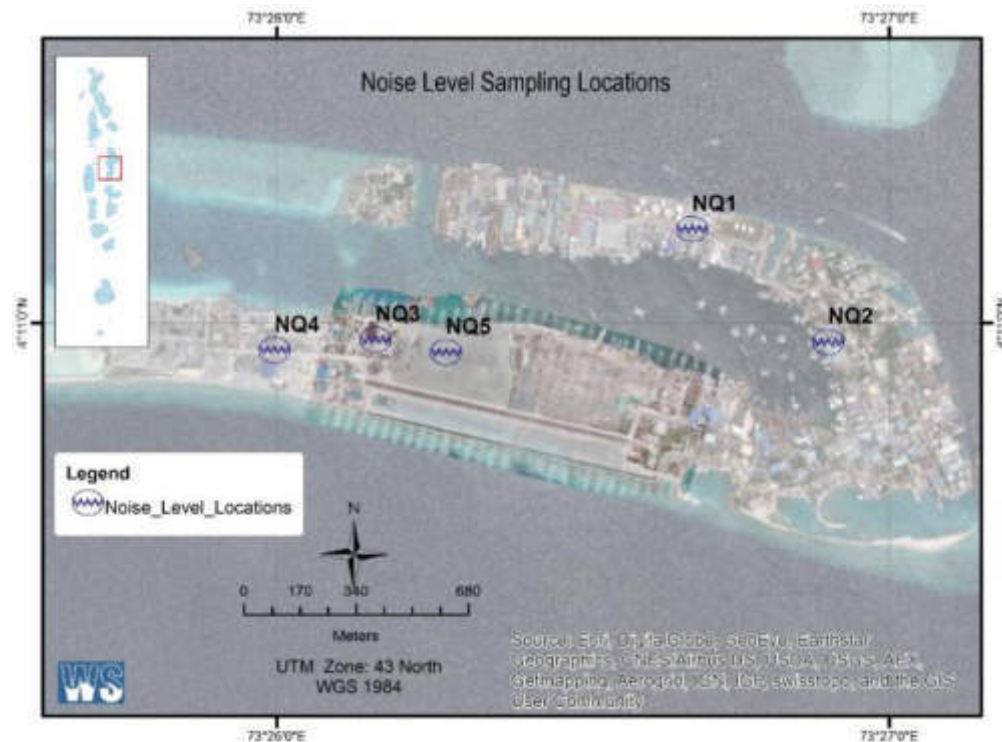


Figure: Locations where noise was monitored for the baseline assessment.

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**Table: Summary of Noise Quality Results for Thilafushi**

<b>S. No</b>	<b>Locations</b>	<b>Noise Level dB (A) Day Time</b>	<b>Noise Level dB (A) Night Time</b>
NQ1	Thilafushi	65.1	53.7
NQ2	Thilafushi	64.2	51.8
NQ3	Thilafushi	56.3	50.0
NQ4	Thilafushi	56.0	48.9
NQ5	Thilafushi	54.6	49.0

The ambient noise levels were moderate to high considering the international standards. The higher background noise can be attributed to the roar from the sea, windy conditions and closely packed industrial areas and movement of boats. Thilafushi was quieter during the night as there are no activity on the island.



Environmental and Social Impact Assessment for the Regional Solid Waste Management Facility (RSWMF) Thilafushi

## **Noise Level Measurement (Additional Measurements)**

**Prepared by:** Abdul Aleem (EIA P03/2019)



24<sup>th</sup> October 2019



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**Table: Noise Measurement Results for Thilafushi**

<b>Date</b>	<b>Time</b>	<b>Noise Level dB (A)</b>	
		<b>NQ3</b>	<b>NQ4</b>
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
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

The ambient noise levels were low considering the international standards. The background noise can be attributed to the roar from the sea, windy conditions areas and movement of boats. Thilafushi was quitter during the night as there are no activity on the island.

Residual Waste Plan which requests the Contractor to assign the landfill areas for the disposal of the APC residues.

- The method of APC residue disposal shall be as detailed in the Contractor's approved Operation and Maintenance Plan and the Contractor's approved Annual Residual Waste Plan. The Contractor shall arrange all APC disposal as necessary to achieve the most efficient use of the available landfill volume.
- The Contractor shall minimize the generation of leachate by applying control measures including, but not limited to, closing gate valves where appropriate, covering landfill areas that are not needed as working face with impermeable liners, preparing an optimized Residual Waste Plan.
- During the Operation Service Period, the Contractor shall prepare a closure plan that shall include the following:
  - A stability calculation of the envisaged final shape of the landfill body demonstrating its stability considering appropriate friction and slippage coefficients of the materials landfilled and the cover layers applied.
  - A contour layer to smoothen the final shape of the landfill body.
  - A complementary dual cover system for the hazardous APC residues so that in the event one layer fails the other layer can withstand the ingress of water. In the event a mineral layer is applied, the layer shall provide a calculated percolation rate similar to a mineral layer of at least 0.5 m thickness having a permeability coefficient of not greater than  $5 \times 10^{-10}$  m/s at a constant water head of 0.3 m. If a geomembrane is used, its thickness shall be not less than 2.0 mm.
  - A leakage control system shall be applied for the dual cover system.
  - A sufficiently dimensioned drainage layer (thickness  $\geq 0.3$  m, permeability coefficient  $> 5 \times 10^{-3}$  m/s).
  - A recultivation layer incl. a natural vegetal cover (thickness  $> 0.5$  m) that meets the local conditions
- The leakage control system shall be operated after closure of the landfill (sub)cells. Samples shall be taken every quarter and fingerprint analyses shall be carried out.
- Samples from the monitoring wells shall be analyzed regularly (at least once per quarter) for parameters such as PAHs, phenols, cadmium, chromium (hexavalent and total), copper, iron, lead, mercury, nickel, zinc.

Requirements towards the APC residues handling and the components necessary to retain APC residues include:

- The Contractor shall handle and dispose of all APC residues and ensure that processing is conducted in a manner that prevents fugitive emissions and escape of dust.
- Bag filter hoses shall be replaced only if the central dedusting system is operational.
- Unloading the silos shall be carried out using dust-tight unloading chutes only.
- The area around the APC residues silo shall be kept clean at all times and spills shall be dealt with immediately.
- The driver of the APC residues transport vehicle shall be required to use personal protective equipment during loading and unloading to prevent the inhalation of dust and fumes.



# TEST REPORT



**Report No:** (7419)080-0561A(S)

May 16, 2019

Page 1 of 4

**Attn: Mr. Nashfa Nashidh**

**Customer:** Water Solutions (Pvt) Ltd

**Address :** MA. Faseri, 1<sup>st</sup> Floor, Ameenee Magu, Male, Maldives

**Date of Sample Received:** Apr 03, 2019

**Date of Testing Started:** Apr 03, 2019

**Date of Report Modified:** May 16, 2019

**Date of Testing Completed:** May 16, 2019

**Sample Description:**

**Sample Received as:**

Approximately 500ml x 3 Nos. of Water sample contained in two sealed plastic bottles & one glass bottle respectively

**Sample Identified by the Client as:**

Ground Water

Thilafushi GW 1

**Sample Drawn By BVCPS** NO

## Photo of the Samples Submitted



## **Bureau Veritas Consumer Products Services Lanka (Pvt) Ltd.**

No. 570, Galle Road, Katubedda, Moratuwa, Sri Lanka  
Tel: (9411) 2350111-115 (dedicated lines), Fax: (9411) 112622198 & 199  
Email: [bvcps.lanka@lk.bureauveritas.com](mailto:bvcps.lanka@lk.bureauveritas.com)

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