# Cost Benefit Study of Disaster Risk Mitigation Measures

## in Three Islands in the Maldives

September 2009

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September 2009

**Courtenay Cabot Venton, Paul Venton and Ahmed Shaig**
**for the United Nations Development Programme Maldives and**
**Government of Maldives, Department of Housing, Transport and Environment**

*"The need to engage fully in disaster risk reduction has never been more pressing... Disaster risk reduction is about stronger building codes, sound land-use planning, better early warning systems, environmental management and evacuation plans and, above all, education. It is about making communities and individuals aware of their risk to natural hazards and how they can reduce their vulnerability. We have a moral, social and economic obligation to act now in building resilient communities and nations… Disaster reduction is everybody's business. All of us can do our part to raise awareness and reduce our vulnerability to future hazards".*

UN Secretary General Ban Ki-moon
(International Day for Natural Disaster Reduction 2007)

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# FOREWORD

**Andrew Cox**

**Resident Representative, UNDP Maldives**

Climate change is a key human development issue. In the absence of urgent steps to combat and adapt to it, it will worsen the quality of life of the poor population and threaten many vulnerable nation states. The United Nations has been instrumental in ensuring that climate change remains a top priority issue globally, and to integrate the issue into national and local development agenda. The United Nations Development Programme (UNDP) is committed to supporting the Government of Maldives in operationalizing the outcomes of the fifteenth Conference of the Parties (COP 15) to the United Nations Framework Convention on Climate Change (UNFCCC), by mainstreaming climate change adaptation and low carbon development in the national Strategic Action Plan. In the Maldives, UNDP advocates Climate Change Adaptation and Disaster Risk Reduction (DRR) at the island, atoll and national level, through policy advice and advocacy, and strengthening human, institutional and system-wide capacities.

The report, Cost Benefit Analysis (CBA) of the Disaster Risk Mitigation Measures in Three Islands in the Maldives is therefore very timely. As the first study of its kind undertaken in the Maldives it supports evidence-based decision making for national policy makers in the reduction of national disaster risk, while strengthening adaptive capacity in the country.

The study also reviews the Safe Island Programme of 1998, and builds upon the practices and lessons of building up Disaster Risk Profiles and developing Detailed Island Risk Assessment to high risk hazards, such as tsunamis, swell waves, and rainfall flooding on three islands - Gaaf Dhaal Atoll Thinadhoo, Gaaf Alif Atoll Villigili, and Thaa Atoll Vilufushi. The report highlights the greatest threat to the Maldives to be sea-level rises, which are slow-onset and can be monitored, while indicating the constant need for additional land for expansion for the major population centres. Hence, the recommendations stress the need to explore "softer" options such as improved settlement planning and early-warning systems that allow us to adjust our approach based on events, while reducing the impact of natural hazards.

The report has been prepared in close cooperation with the Ministry of Housing, Transport and Environment, UNDP and national stakeholders. It is our expectation that putting a figure on costs and benefits would provide opportunities for further research and applying them to learning-by doing activities to strengthen evidence-based decision making and building resilience of the communities impacted by climate change.

Male', Maldives

June 2010

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# EXECUTIVE SUMMARY

## Introduction

The Maldives is a small island nation comprised of coral atolls, located in the central Indian Ocean. While it is comprised of over 1,000 islands, approximately 200 of these are inhabited. With 80 percent of its islands less than 1 metre above sea level, the Maldives is considered one of the countries most vulnerable to the predicted consequences of global climate change. The expected increase in sea level rise and in the intensity of extreme weather events and the seriousness of their adverse consequences has necessitated the Maldives to consider climate change and disaster management in all aspects of its future development. While a tsunami of the magnitude experienced in December 2004 is extremely rare, the event heightened awareness of the vulnerability of the Maldives islands as it provided a 'snap shot' of a potential future dominated by sea level rise.

The government initially raised the concept of the Safer Islands Programme (SIP) following the tsunami. The objectives of the SIP concept as it currently stands are to:

1. Protect the islands from natural and other hazards;

2. Rebuild and improve existing infrastructure and economic facilities; and

3. Develop capacity to plan and implement measures to reduce natural hazard risks and build the community resilience to disasters.[1]

[1] Note on Safer Islands Programme (Draft) January 2005, Ministry of Planning and National Development

## Purpose of the Study

This study is divided into two primary components:

1. A review of the current SIP concept and its contribution to Disaster Risk Reduction (DRR), and the development of a draft conceptual and operational framework for the SIP; and

2. A Cost Benefit Analysis (CBA) of three islands based on implementing a range of risk management measures to develop these as "safer" islands.

It builds upon the Disaster Risk Profile in the Maldives commissioned by the UNDP in 2006, and the Detailed Island Risk Assessment in the Maldives Physical Report (DIRAM1), and the DIRAM Socio-economic Report (DIRAM2), which provide data on hazard, exposure, vulnerability, and losses/impacts for nine selected islands. This study focuses on three islands: GDh Thinadhoo, GA Viligili, and Th Vilufushi.

## Disaster Risk and Climate Change in the Maldives

The Indian Ocean tsunami in December 2004 was the largest disaster in recent times. The tsunami waves, ranging from 1.2 to 4.2 metres in height, swept across most parts of the country. Nearly a third of the Maldives' population was severely affected.

Prior to the tsunami, the Maldives had little experience of disaster impact, although events such as localised flooding, especially due to storm tides, have caused damage and disruption on a more regular basis. Erosion is also cited as a major problem - studies in the Maldives have revealed improperly designed and constructed coastal structures have had a major impact in the exacerbation of the natural process of coastal erosion. Other hazards include strong winds and earthquakes.

Climate change is a major concern for the Maldives, primarily on account of sea level rise. Increases in sea surface temperature pose a threat to the health of the coral ecosystem, and changes to extreme events and climate variability are also of significance. Future sea level is projected to rise between 9 and 88cm by 2100 (Government of Maldives, 2006). While studies offer different perspectives, it is generally argued that the outlook for low lying coral islands is catastrophic under the predicted worst case scenarios of sea level rise, with the entire country predicted to disappear in 150-200 years.

In the Maldives, the two major sources of income, fisheries and tourism, are completely dependent on a healthy ecosystem. Degraded ecosystems can increase exposure and reduce community resilience. This relationship is paramount in the Maldives, where the natural environment – coral reefs, vegetation, and the natural processes of erosion and accretion - have been allowing these islands to exist and adapt for thousands of years.

## Methodology

The study was undertaken between April and August 2009, by a study team comprised of two international consultants specialising in risk management and CBA for disasters and climate change, as well as a local consultant heavily involved in previous similar studies. Three field trips were conducted to Male' and the three study islands, to gather data and for consultation with national and local stakeholders.

### *Review and Development of Framework for the SIP*

The Safer Islands concept was assessed with respect to its contribution to disaster risk reduction for the Maldives, and as such was reviewed in relation to the Hyogo Framework for Action (HFA) Priorities for Action. The methodology was composed of the following steps:

- Definition of the scope of the SIP review – whereas the CBA is more limited in its quantitative analysis of hazards due to data availability, the SIP review considered the full range of natural hazards of relevance to the study islands.
- Review of key documents - a review of existing documents on the SIP and other policy documents pertinent to the concept of developing safe islands in the Maldives was undertaken.
- Development of a questionnaire based on the HFA - a questionnaire was developed to guide interviews and fieldwork, and was framed within the context of the HFA.
- Semi-structured interviews and meetings were undertaken with government ministries, UNDP, various experts, and local communities.
- Fieldwork - all three islands were visited to gather insights into the different perceptions of risk held by various people. Observation, informal conversations and focus group meetings were used to gather data.

The findings from these activities were then analysed to assess both areas of strength and areas for further development within the SIP concept.

### *Cost Benefit Analysis*

A Cost Benefit Analysis for DRR is developed by comparing two scenarios:

Hazards and their impacts on communities "without" any DRR measures; and

The reduction in hazard impact "with" DRR measures.

The benefits accrued from reducing hazard impacts (e.g. reduction in lost assets) are offset against the costs of implementing the protection measures that bring about those benefits, resulting in a Benefit to Cost Ratio. In the case of this study, the analyses for GDh Thinadhoo and GA Viligili are "forward-looking", modelling a range of possible scenarios and mitigation works to protect against disasters. In the case of Th Vilufushi, the island has already been rehabilitated as a "safer island" following the tsunami, and hence the analysis is "backward-looking", and is an assessment of the actual works undertaken and the degree of protection that they will afford. The methodology was composed of the following steps:

Definition of study parameters – the study focuses on hydro-meteorological hazards, namely flooding due to heavy rainfall, swell waves, tsunami, and associated climate impacts on these events. Furthermore, the scope focuses on the impacts of hazards and protection measures on the three islands themselves. So, for instance, the parameters of this study do not include the wider impacts of a safer island programme, such as costs of relocation, decreased infrastructure costs on "abandoned islands", or macro level impacts to GDP.

### *Data collection, including:*

- Hazard assessment: The hazard assessment draws heavily upon DIRAM1, which reconstructed hazard data based on known historical events. The assessment of changes as a result of climate change was based primarily on existing literature. Due to a significant lack of data, the probability of hazard events was presented as a range to account for uncertainty.
- Impact assessment: The impact assessment examines

the risk associated with hazards[2]. In the case of Thinadhoo and Viligili, the data on impacts for each of the three hazards was drawn from both the DIRAM1 and the DIRAM2 studies. Impacts were classified as physical, human, and natural, and both quantitative and qualitative impacts were identified. Impacts were quantified by valuing each island's economy through field surveys and published records, mapping elements at risk, and then determining losses depending on the vulnerability of elements at risk, and the projected impacts of hazards of different magnitude on the specific island. Human losses were also valued using the "income over life" method. In the case of Vilufushi, the island was completely destroyed, and therefore the analysis relied on proxy values for the estimated economic value of the island before the tsunami.

- Identification of risk management options, costs and benefits: For Thinadhoo and Viligili, a range of protection measures was identified building on the analysis in DIRAM1 and DIRAM2, and these were then categorised into four risk management options - no protection, full SIP protection, selected SIP protection, and limited SIP protection - each offering a differing degree of cost and protection.[3] In the case of Vilufushi, those measures actually undertaken were included in the analysis, supplemented in places by additional measures necessary to bring the island up to the full SIP standard, and hence comparable with the other two islands. Both fixed and variable costs for these measures were identified using existing government databases and data from contractors. The benefits of protection were then estimated by assessing the likely percentage reduction in losses, by modifying predicted inundation curves with the anticipated impact of protection.

- Analysis of costs and benefits: The above data and analysis was combined to create a multi-hazard probabilistic risk model. The model for each island is based on a 50-year project lifetime (the lifetime of the longest lived asset – in this case the coastal protection measures). Costs and benefits were discounted at 7.5% to reflect time preferences for money. Models were tested for sensitivities including intangible benefits, discount rate, and project lifetime.

The study faced a number of key limitations, primarily relating to availability of data. First, while DIRAM1 and DIRAM2 provided the most consistent and indepth source of data for the study, they were limited by significant gaps in data on hazard occurrence, modeling of climate impacts (including a lack of downscaling for the region), and physical data for the islands. Furthermore, a CBA of this nature should normally be preceded by detailed feasibility studies and EIAs on the possible physical risk mitigation measures available, and their ability to protect against hazards. This data would then be used to build detailed hazard maps for each island based on what is feasible given the specific island characteristics. In the absence of such studies, the analysis relies on best estimates and assumptions, and uses scenarios and sensitivity analysis to test a range of options. Furthermore, land development in the islands has changed over the course of the studies (particularly in Viligili), and therefore these analyses will need to be updated in the future.

[2] Where risk is a function of both the hazard and the vulnerability of people and assets to that hazard (comprised of both the exposure of people and assets to the hazard, as well as the fragility, or degree of damage).

[3] Measures included, inter alia, coastal protection, Environmental Protection Zones, resilient harbours, evacuation facilities, flood mitigation for lifeline infrastructure, retrofitting, and improved drainage.

## The SIP Review[4]

The findings from the SIP Review are presented according to the HFA priorities for action, and are summarised below:

Priority 1: Ensure that disaster risk reduction is a national and local priority with a strong institutional basis for implementation.

- Concerns regarding sea level rise, combined with the devastating impacts of the 2004 tsunami, are ensuring that developing resilient islands is a national level priority. However, there is often a mismatch between national and local priorities for risk reduction.
- The institutional "home" of the SIP within the Environmental Ministry is a key strength. However, the institutional structure for the implementation of the SIP needs to be further integrated with broader development concerns.
- The institutional structures for systematic coordination for DRR are in their fledgling stages, but this is balanced by government acknowledgement and commitment to developing institutional capacity.
- Methods to improve resilience and mitigate losses and disruption caused by natural hazards have a high level of priority at the local level. However, local capacity to implement risk reduction measures is lacking.

[4] The Safer Island Programme concept has been broadened to Resilient Island Planning as per the current government policy. Resilient Island Planning involves not only physical aspects but also social and livelihood aspects in the communities. The current resilient island concept involves:
- Strengthening climate resilience
- Market driven strategy providing incentives for voluntary migration to alternative islands
- Development of larger islands with potential for expansion with integration of climate resilience and better economic opportunities

- Furthermore, there has been a dearth of engagement with people at the local level in land use planning, land reclamation and other development activities of major relevance to the concept of safer islands.

Priority 2: Identify, assess and monitor disaster risks and enhance early warning.

- A number of significant initiatives have been undertaken to identify risk in the Maldives. However, the findings from these risk assessments have not formed the basis, or even a significant component, of the selection process for potential 'safe islands'. A full understanding of risk is further limited by the lack of historical hazard data and a significant gap in research capacity on climate risks.

- While early warning is clearly a national priority, the lack of a culture of local participation in decision-making will hinder the establishment of an effective system.

Priority 3: Use knowledge, innovation and education to build a culture of safety and resilience at all levels.

- In sharp contrast to national level perspectives that risk awareness is low at an island level, island consultations found that local people are already familiar with hazard and climate risk, as well as the linkages between environment and disaster risk. However large-scale land reclamation on Vilufushi has left people detached from their physical environment and lacking in risk awareness.

- Risk awareness will be an essential component of successful relocation of populations to safer islands.

- There is an urgent need for introducing school safety programmes in all the islands.

Priority 4: Reduce the underlying risk factors.

- Despite a clear awareness of the linkages between environmental degradation and disaster risk, poor environmental management of human activities has increased the vulnerability of islands. The lack of a systematic EIA process is a critical factor in increased risk, and there is a lack of evidence that environmental policy adequately influences practice.

- In particular, human activities are degrading coral reefs and coastal vegetation – and yet these are critical lines of defence against disasters and the reduction of risk.

- The importance of social cohesion for vulnerability reduction currently appears of minor importance in comparison with physical mitigation.

- Stronger connections are needed between all the different elements that contribute to the overall resilience of an island.

Priority 5: Strengthen disaster preparedness for effective response at all levels.

- There is a clear commitment towards implementing disaster preparedness measures, but progress is slow.

- A critical evaluation of the proposed disaster preparedness components of the SIP may be required.

## A Draft Framework for the SIP

A draft framework to take forward the development and implementation of the SIP into national policy is proposed, building upon the strengths identified in the above review, and proposing means to address the challenges.

### *Guiding Principles*

The framework for the SIP should be based upon a number of guiding principles. Most importantly:

1. Widespread consultation and participation in decision-making must be undertaken, with special emphasis upon improving the engagement of stakeholders at island level.
2. Human activities that damage the natural environment must be minimised and where damage has occurred already this is rectified wherever feasible.
3. The SIP must be integral to all development policy and planning and not an optional extra. It should be a multi-sectoral initiative.

It is proposed that three steps are required to develop the SIP framework:

– **Step 1** – Develop a National Level SIP Strategy. This process would need to define the overall objective of the SIP, and an action plan for implementation at a policy level including the necessary legal and institutional framework, the establishment of criteria for selection of potential safe islands, capacity building needs, public awareness campaigns, a framework for international assistance, and plans for monitoring and evaluation. The strategy should be developed through a process of widespread participation.

- **Step 2** Develop a Short List of Potential Safe Islands. This list should be developed through a process of consultation, based on a range of both subjective and objective criteria. Importantly, this will be an iterative process, and lessons learned over the selection of safe islands year on year will need to be incorporated to modify the approach.

- **Step 3** Select Safe Islands and Develop Island-specific SIP Strategies and Implementation Plans. Once the short list of potential safe islands has been agreed under Step 2, a plan will need to be devised for undertaking detailed island level assessments. These should focus upon filling gaps in knowledge and engaging very thoroughly with island officials and the general public. Individual Island-Level SIP Strategies should be developed for those islands that will be developed as safer islands in the first instance. These strategies will need to define specific actions, responsibilities and timeframes, a local institutional framework, plans for capacity building, and detailed mechanisms for monitoring and evaluation. Risk mitigation measures need to vary island by island to suit local conditions, but underpinned by some common themes. These should cover the establishment of the local institutional framework for the SIP, public awareness, measures that reverse impacts of man-made interventions on the environment and strengthen natural protection, land use planning and building practices that integrate risk, and strong links between SIP measures and island development activities (such as health care and protection of water supply).

## Cost Benefit Findings – GDh Thinadhoo

### *Introduction*

Thinadhoo Island is located on the western rim of Gaafu Dhaalu atoll, approximately 410 km from the nation's capital Male'. Thinadhoo is the atoll capital, and has undergone substantial human modifications including land reclamation, dredging activities and coastal infrastructure development projects. There are major variations in topography caused by the reclamation activities, which has resulted in drainage issues and flooding during heavy rainfall.

### *Hazard assessment*

Thinadhoo is exposed to a variety of natural hazards. The island is often flooded during heavy rainfall. However, flooding has only become prominent since the 1990's, coinciding with the land reclamation (which failed to take into account drainage patterns). Flooding has been reported to reach up to 0.6m above ground level. The geographic location of Thinadhoo exposes it to year round swell waves - major swell wave events are likely to occur every 5 years. Thinadhoo is located in a moderate tsunami hazard zone, and the 2004 tsunami had relatively little impact on the island.

### *Impact assessment*

Associated damages or losses were assessed for the main hazard types (tsunami, swell waves or storm surges, and rainfall flooding), based on the value and exposure of economy and assets. The assessment was conducted for severe hazard events, and these figures were then pro-rated for moderate and low hazard events. It was further estimated that, unlike other hazards, severe tsunami would result in loss of life.

**Table ES1:** Estimated Losses in Thinadhoo, by hazard magnitude

| Magnitude | Estimated Losses (RF) | | |
|---|---|---|---|
| | Tsunami losses | Swell waves and storm surge losses | Rainfall flooding losses |
| Low | 8,520,866 | 227,250 | 91,000 |
| Moderate | 34,083,462 | 909,000 | 364,000 |
| Severe | 85,208,655[1] | 2,272,500 | 910,000 |

Identification of risk management options, costs and benefits

The following risk management scenarios and associated costs were identified. The selected safe island protection and limited protection scenarios assume more limited protection, at a lower cost. Variable costs were also assessed for ongoing maintenance.

**Table ES2:** Fixed Costs Associated with Risk Management Scenarios

| Protection Type | Total Cost (RF) |
|---|---|
| No man made protection ("without" scenario) | 0 |
| Safe Island Protection | 205,801,898 |
| Selected Safe Island Protection | 137,357,798 |
| Limited protection | 60,517,975 |

Benefits were estimated as a percentage reduction in losses, based on a number of assumptions.

**Table ES3:** Estimated Reduction in Losses, Thinadhoo

| Protection Type | Reduction in Losses | | |
|---|---|---|---|
| | Tsunami | Swell wave | Rainfall flooding |
| No man made protection ("without" scenario) | 0 | 0 | 0 |
| Safe Island Protection | 90-100% | 95-100% | 95-99% |
| Selected Safe Island Protection | 85-100% | 90-100% | 90-98% |
| Limited protection | 50-95% | 70-99% | 75-85% |

## *Cost Benefit Analysis*

The Cost Benefit Analysis was run for each of the risk management scenarios described above. The analysis used a multi-hazard probabilistic model, and hence the findings account for the full range of impacts associated with three hazard events, of differing severity, weighted by the probability of these events happening.

The following figures are estimated:

The Benefit to Cost Ratio: If the ratio is greater than 1, the benefits outweigh the cost.

The Net Present Value calculates the discounted net benefits (benefits minus costs) year on year. If the figure is positive, there is a financial argument for going ahead with the project.

The analysis used a discount rate of 7.5% and a project lifetime of 50 years.

**Table ES4:** Cost Benefit Findings for Thinadhoo (RF)

| Protection Type | Minimum Hazard Occurrence | Max. Hazard Occurrence | Max. Haz. Climate Change |
|---|---|---|---|
| Safe Island Protection | BCR: 0.39<br>NPV: -161,077,586 | BCR: 1.35<br>NPV: 93,714,442 | BCR: 1.40<br>NPV: 105,180,640 |
| Selected Safe Island Protection | BCR: 0.52<br>NPV: -89,909,427 | BCR: 1.79<br>NPV: 149,251,980 | BCR: 1.85<br>NPV: 160,185,167 |
| Limited protection | BCR: 1.13<br>NPV: 9,731,053 | BCR: 3.54<br>NPV: 191,202,975 | BCR: 3.65<br>NPV: 199,823,621 |

The findings indicate that there is significant variability in the scenarios given, and there is not a clear financial argument for proceeding with full or selected safe island risk management scenarios. The NPV shifts from negative to positive under a maximum hazard scenario; however, one could legitimately raise concerns over the assumption that severe tsunamis and storm surges will both occur once every 10 years (given that the current estimate for the 2004 event is 1 in 219 years) as is the presumption under this scenario. The limited protection scenario does yield a positive result in both scenarios, suggesting that this option may be a more cost effective one.

Because there is so much uncertainty in various factors included in the analysis, for example the probability of a hazard event occurring, sensitivity analysis is used to test the underlying assumptions. Green shading indicates positive findings, whereas blue shadings indicated negative findings.

**Table ES5:** Sensitivity Testing: Minimum hazard probability, Benefit to Cost Ratios

| Protection Type | Double damages (intangible losses) | Discount Rate 0% | Discount Rate 15% | 25 year project lifetime |
|---|---|---|---|---|
| Safe Island Protection | 1.48 | 0.87 | 0.24 | 0.35 |
| Selected Safe Island Protection | 1.98 | 1.07 | 0.27 | 0.47 |
| Limited protection | 4.33 | 2.61 | 0.69 | 1.00 |

**Table ES6:** Sensitivity Testing: Maximum hazard probability under climate change, Benefit to Cost Ratios

| Protection Type | Double damages (intangible losses) | Discount Rate 0% | Discount Rate 15% | 25 year project lifetime |
|---|---|---|---|---|
| Safe Island Protection | 4.67 | 3.08 | 0.86 | 1.24 |
| Selected Safe Island Protection | 6.18 | 3.76 | 1.17 | 1.66 |
| Limited protection | 12.75 | 8.45 | 2.22 | 3.23 |

The factor that creates the greatest variation in the analysis is the doubling of damages. The assumption that benefits could be doubled to account for intangible losses (those factors that can't be valued in the analysis, such as social impacts, the value placed on the existence of the islands, etc) seems reasonable (though no related studies have been conducted in the Maldives to act as a benchmark), and under all scenarios yields a positive BCR, ranging between 1.48 and 12.75.

The greatest benefits are yielded in the limited protection scenario, suggesting that a full suite of measures may not be the most cost effective approach to protection.

## Cost Benefit Findings – GA Viligili

### *Introduction*

GA Viligili Island is located on the eastern rim of Gaafu Alifu atoll, about 380km from the nation's capital Male'. Viligili is the atoll capital, and has undergone substantial human modifications. In particular, it is important to note that the island has had significant amounts of land reclamation during the course of these risk assessment studies, and therefore the analysis is based on the previous island, not the current layout.

### *Hazard assessment*

Viligili is exposed to a variety of natural hazards. It is located in the highest rainfall region of the Maldives, and is amongst the most intensely flooded islands. Heavy rainfall related flooding has been reported to reach up to 0.5m above the ground level. Viligili's exposure to rainfall related flooding is compounded by human activities – land reclamation and harbour development projects have led to a substantial topographic low in the middle of the island establishing a natural drainage into this area. There is a probability of major swell events occurring every 10 years in Viligili, with probable water heights of less than 1.0m and every 5 years with probable water heights of 0.5-0.75m. The intensity of flooding in the inland areas may have been exacerbated by improper wetland reclamation. Viligili is geographically located in a high tsunami hazard zone. The tsunami of December 2004 inundated large parts of Viligili. According to official estimates, the tsunami inundated 33% of the island, while field assessments suggest that nearly 70% of the island was inundated.

### *Impact assessment*

Associated damages or losses were assessed following the same approach as Thinadhoo (see above).

**Table ES7:** Estimated Losses for Viligili, by hazard magnitude

| Magnitude | Estimated Losses (RF) | | |
|---|---|---|---|
| | Tsunami losses | Swell waves and storm surge losses | Rainfall flooding losses |
| Low | 6,300,334 | 432,800 | 21,000 |
| Moderate | 25,201,336 | 1,731,200 | 84,000 |
| Severe | 63,003,340[2] | 4,328,000 | 210,000 |

Identification of risk management options, costs and benefits

The following risk management scenarios and associated costs were identified. Variable costs were also assessed for ongoing maintenance.

**Table ES8:** Fixed Costs Associated with Risk Management Scenarios for Viligili

| Protection Type | Total Fixed Cost (RF) |
|---|---|
| No protection (“without” scenario) | 0 |
| Safe Island Protection | 194,752,845 |
| Selected Safe Island Protection | 161,722,475 |
| Limited protection | 153,033,375 |

Benefits were estimated as a percentage reduction in losses.

**Table ES9:** Estimated Reduction in Losses, Viligili

| Protection Type | Reduction in Losses | | |
|---|---|---|---|
| | Tsunami | Swell wave | Rainfall flooding |
| No man made protection (“without” scenario) | 0 | 0 | 0 |
| Safe Island Protection | 65-100% | 75-100% | 90-99% |
| Selected Safe Island Protection | 45-100% | 50-100% | 85-98% |
| Limited protection | 25-80% | 35-85% | 70-85% |

## *Cost Benefit Analysis*

The findings for the baseline analysis are as follows.

**Table ES10:** Cost Benefit Findings for Viligili (RF)

| Protection Type | Minimum Hazard Occurrence | Max. Hazard Occurrence | Max. Haz. Climate Change |
|---|---|---|---|
| Safe Island Protection | BCR: 0.28<br>NPV: -179,159,791 | BCR: 0.93<br>NPV: -18,202,523 | BCR: 1.00<br>NPV: 1,002,046 |
| Selected Safe Island Protection | BCR: 0.29<br>NPV: -153,708,573 | BCR: 0.89<br>NPV: -22,941,082 | BCR: 0.96<br>NPV: -8,403,115 |
| Limited protection | BCR: 0.42<br>NPV: -58,696,320 | BCR: 1.23<br>NPV: 23,529,219 | BCR: 1.33<br>NPV: 33,690,198 |

The findings indicate that there is significant variability in the findings, and there is not a clear financial argument for proceeding with any of the risk management scenarios, except the limited protection scenario under maximum hazard occurrence. The limited protection scenario does yield a positive result in both the current and climate change scenarios, suggesting that this option may be a more cost effective one.

The sensitivity analyses resulted in the following findings.

**Table ES11:** Sensitivity Testing: Minimum hazard probability, Benefit to Cost Ratios

| Protection Type | Double damages (intangible losses) | Discount Rate 0% | Discount Rate 15% | 25 year project lifetime |
|---|---|---|---|---|
| Safe Island Protection | 1.07 | 0.63 | 0.17 | 0.25 |
| Selected Safe Island Protection | 1.11 | 0.61 | 0.18 | 0.26 |
| Limited protection | 1.64 | 0.71 | 0.29 | 0.39 |

**Table ES12:** Sensitivity Testing: Maximum hazard probability under climate change, Benefit to Cost Ratios

| Protection Type | Double damages (intangible losses) | Discount Rate 0% | Discount Rate 15% | 25 year project lifetime |
|---|---|---|---|---|
| Safe Island Protection | 3.43 | 2.24 | 0.62 | 0.89 |
| Selected Safe Island Protection | 3.38 | 2.03 | 0.60 | 0.86 |
| Limited protection | 4.74 | 2.24 | 0.91 | 1.22 |

All scenarios come out positive once the estimate for intangible losses is added in, yielding BCRs ranging between 1.07 and 3.43.

## CBA – Th Vilufushi

### *Introduction*

Th Vilufushi is located at the southern end of the two chains of atolls in the central Maldives, approximately 187 km from the nation's capital, Male'. The original Vilufushi Island was a small island, and was heavily urbanized. The settlement had expanded to the edges of the coastline and new plots were being developed with ad-hoc land reclamation.

The island was completely devastated by the Indian Ocean tsunami of

December 2004 and the inhabitants were relocated to neighbouring islands.

Since then, the island has been rebuilt, including extensive land reclamation, topographic levelling, coastal protection, new housing and new public infrastructure. All existing structures on the original island have been removed and new land has been reclaimed to make Vilufushi four times its original size. The new land area is 61ha (0.61km2), and the entire island has been levelled to +1.4m above MSL. Vilufushi is the first island developed to the specifications of the new safe island concept, although not all SIP measures have been introduced.

### *Hazard assessment*

According to the available historic records and field interviews, Vilufushi has been exposed to multiple hazards in the past but its exposure was insignificant with negligible impacts. No swell wave related flooding was reported. Although the island received heavy rainfall, flooding has not been an issue due to the arch-shaped topography and the narrow width of the island. The Indian Ocean tsunami of 2004 was the only major event on the island and caused extensive damage and fatalities. The maximum tsunami wave height predicted for Vilufushi is 3.2 – 4.5m (UNDP, 2006). The empirical tsunami flood decay curve for a 4.5m wave predicts inundation across the newly developed island and the first 150-200m from the eastern coastline will be a destructive zone.

### *Impact assessment*

Because the island was completely destroyed in the tsunami, it was not possible to estimate the economic value of Vilufushi through empirical data. Hence proxy values were used from two other islands with similar economic structures, and pro-rated for the population of Vilufushi. The estimated losses without protection are equivalent to the losses that would have been experienced on Vilufushi before the tsunami. It was further assumed that total losses under a severe swell wave would be 50% of the total losses under a tsunami, based on the estimated maximum flood height.

**Table ES13:** Estimated Losses for Vilufushi, by hazard magnitude

| Magnitude | Estimated Losses (RF) | | |
|---|---|---|---|
| | Tsunami losses | Swell waves and storm surge losses | Rainfall flooding losses |
| Low | 22,063,108 | 9,553,804 | 0 |
| Moderate | 88,252,431 | 38,215,216 | 0 |
| Severe | 220,631,078[3] | 95,538,039 | 0 |

### *Identification of risk management options, costs and benefits*

Because this assessment is "backward-looking" (i.e. the work has already been done), this section identifies the actual measures that have been implemented (in contrast to the previous sections, which identified a range of possible measures to be undertaken).

**Table ES14:** Fixed Costs Associated with Risk Management Scenarios for Vilufushi

| | Total Fixed Cost |
|---|---|
| Actual expenditures (minus the cost of rebuilding back the original island) | 491,929,122 |
| Additional Safe Island Protection measures | 38,418,222 |
| TOTAL | 530,347,344 |

Benefits were estimated as a percentage reduction in losses. Reduction in losses is not reported for rainfall flooding, because losses associated with flooding were reported as nil in the island.

**Table ES15:** Estimated Reduction in Losses, Vilufushi

| Protection Type | Reduction in Losses | | |
|---|---|---|---|
| | Tsunami | Swell wave | Rainfall flooding |
| Safe Island Protection | 65-100% | 90-100% | n/a |

### *Cost Benefit Analysis*

The findings for the baseline analysis are as follows.

**Table ES16:** Cost Benefit Findings for Viligili (RF)

| Protection Type | Minimum Hazard Occurrence | Max. Hazard Occurrence | Max. Haz. Climate Change |
|---|---|---|---|
| Safe Island Protection | BCR: 0.50<br>NPV: -271,822,659 | BCR: 1.65<br>NPV: 353,382,832 | BCR: 1.95<br>NPV: 517,500,572 |

The findings indicate that, under current conditions, there is not a financial justification for the measures undertaken on Vilufushi. The projections under climate change are positive, though the probability of hazard events will have to be very high to justify the expenditures on this basis.

The sensitivity analyses resulted in the following findings.

**Table ES17:** Sensitivity Testing: Safe Island Protection Measures, Benefit to Cost Ratios

| Protection Type | Double damages (intangible losses) | Discount Rate 0% | Discount Rate 15% | 25 year project lifetime |
|---|---|---|---|---|
| Minimum hazard probability | 1.01 | 1.66 | 0.28 | 0.43 |
| Maximum hazard probability under climate change | 3.89 | 6.42 | 1.08 | 1.68 |

The findings are mostly positive under the sensitivity testing.

## Discussion of CBA Findings for the Three Islands

The findings from the Cost Benefit Analyses conducted on each of the three islands are mixed. On the one hand, the Thinadhoo analysis is largely positive across a range of risk management scenarios, hazard probabilities, and sensitivity analyses, with the greatest benefits arising in a limited protection scenario. By contrast, the Viligili findings are only positive in the baseline scenarios for limited protection under maximum hazard occurrence. Similarly, in Vilufushi, the baseline findings are only positive under maximum hazard occurrence, but show more positive results under sensitivity testing.

The Thinadhoo analysis is more positive because 1) Thinadhoo has a predicted lower intensity for a tsunami and therefore a standard suite of risk management measures affords more protection, and 2) much of Thinadhoo's infrastructure is located away from high intensity zones and therefore easier and less costly to protect.

The findings are subject to high levels of uncertainty, which introduces more risk into any investment decisions. The three most significant assumptions affecting the analysis are 1) the probability of hazard occurrence (both under current conditions and under climate change), 2) the value of intangible losses, and 3) the discount rate. It could be argued that the maximum hazard scenarios (under the current climate and under climate change) are generous, assuming severe tsunami and storm surges both occur once every 10 years. Doubling of losses to account for intangibles – those benefits that cannot be valued using financial data, such as the existence value of the islands – returns positive BCRs in almost all cases. However, while the doubling of losses is generous, it is arbitrary, in the absence of any studies that can provide a proxy value for existence. For example, if losses are increased by 50% (as opposed to 100%), not all scenarios are positive. Recent economic theory has suggested that discount rates should be lower than normal, if not 0, in the context of environmental and other social projects, given that the benefits to future generations should not be discounted as compared with benefits to this generation. In the case of this analysis, the findings are very mixed depending on the discount rate used, and so again, caution is encouraged before embarking on substantial investment decisions.

The findings are island-specific, and need to be taken within a wider context. The CBA examines the costs and benefits of providing protection to each of the three islands. It does not account for the range of impacts that can accrue between islands, or at a macroeconomic level (for instance, the impact of a tsunami on GDP), or the effects on neighbouring islands which rely on the regional level services offered by these islands. An analysis of safer islands on a more holistic basis, for example the plans for decentralization, or clustering of islands, may change the way that risk reduction is interpreted. However, given that each island will still require physical protection, it is unclear that clustering would have any impact on the CBA findings on an island-by-island basis.

The Maldives has several comparative advantages working in its favour, and hence in light of the findings above, a variety of alternative risk management scenarios may be more appropriate. The greatest threat to the Maldives is sea level rise, which is slow onset (unlike other hazards such as flash flooding), and can be monitored (unlike earthquakes). Hence the Maldives can use time to its advantage to look into alternative protection options, allow for development of new technology, and lower cost innovation, while also allowing natural adaptation processes to work to their full advantage. A variety of alternative risk management scenarios were investigated, as follows.

In the case of severe tsunami, which are highly unlikely, and very expensive to protect against, softer measures such as early warning may be more appropriate. It is estimated that the physical costs of implementing an early warning system, and building evacuation shelters could range between RF 185 and 641m, for an average of 413m. The benefits could include protection of life and moveable assets through timely evacuation, as well as significant intangible benefits through peace of mind and a sense of safety. The benefits of preservation of life alone could accrue to over RF200m, increasing to RF400m when doubled for intangible benefits. Clearly these figures are based on a number of very broad assumptions, and the accrual of benefits will depend on how frequently events occur which require evacuation, but the initial figures suggest that the costs and benefits of early warning are roughly balanced.

Other hazard events are largely reported not to have caused severe damage in the past – rather it appears that they have been exacerbated by man-made activities. Thinadhoo was used as a case study, to investigate the costs and benefits of more stringent settlement planning (including land use, building codes, and high impact developments), to ensure that man-made risk is minimized. The costs of improved settlement planning are estimated at approximately RF 25.5m, accounting for the costs of creating guidance, implementing more stringent engineering and environmental studies, increased cost of contracting, and staff capacity building. Benefits will primarily accrue in relation to flooding from heavy rainfall (which should be more or less eliminated through the use of proper drainage and siting of infrastructure), and low and moderate swell wave events (again, mostly flooding impacts which should be eliminated). The findings suggest that in a range of scenarios, most return a positive BCR. More importantly, because the costs associated with these measures are relatively small as compared with the safer island protection measures, the cost of "getting it wrong" is much less, and therefore the investments carry lower risks.

## Conclusions and Recommendations

### *Conclusions*

- Climate and disaster risk reduction are a national and a local priority, and the SIP will be an important component of any strategy to reduce risk. However, significant progress needs to be made towards developing the SIP concept into a transparent strategy driven by stakeholder participation.

- It is critical that the SIP is integral to all development policy and planning and not an optional extra.

- The findings from the CBA suggest that great caution is required before proceeding with any investment due to significant levels of uncertainty, and because the ratios are not consistently positive, and in most instances where they are positive, the ratios are not very high, and hence any changes in the underlying assumptions could result in a net loss on investment.

- A significant shift in focus needs to take place towards softer protection measures and increases in resilience.

- Human activities that damage the natural environment must be minimised to ensure that the natural resilience of islands is protected.

- The introduction of improved settlement planning (based on principles of disaster risk reduction) should be a priority.

### *Recommendations*

- Develop a SIP framework as part of a National Strategy on DRR. For example, the review and draft framework will provide a sound basis for further development of the recently proposed Strategic National Action Plan (SNAP) for DRR and Climate Change Adaptation 2010 - 2020 supported by UN Maldives Country Office and UNISDR, and it is strongly recommended that these two processes are integrated.

- As part of the SIP framework, introduce a transparent and systematic process for safer island selection, which is based on stakeholder consultation and subject to yearly review.

- Ensure that public awareness and participation are key components of the SIP development process.

- Establish capacity and financing for climate monitoring and research.

- Ensure early warning is implemented in full with adequate capacity for implementation at all levels.

- Develop guidelines for settlement planning (inclusive of disaster risk reduction principles), which are integrated into development processes.
- Conduct further research into viable alternative protection measures. For example, the SEEDS bio-defence project should be followed up to gather information on its effectiveness and possibilities for replication.
- Introduce a more holistic approach to risk mitigation, which puts much greater weight on societal and economic adaptation rather than the current focus on physical mitigation.

# Introduction

# 1. INTRODUCTION

## 1.1 Context

The Maldives is a small island nation comprised of coral atolls, located in the central Indian Ocean. While it is comprised of over 1,000 islands, approximately 200 of these are inhabited. With 80 percent of its islands less than 1 metre above sea level, the Maldives is considered one of the countries most vulnerable to the predicted consequences of global climate change. The expected increase in sea level rise, in intensity of extreme weather events and the seriousness of their adverse consequences has necessitated the Maldives to consider climate change and disaster management in all aspects of its future development. With limitations in terms of feasible and appropriate coastal protection, inhabited islands are highly exposed to the threats of intense wave action, erosion, and flooding. While a tsunami of the magnitude experienced in December 2004 is extremely rare, many islands are vulnerable to much smaller and more frequent natural events.

In order to reduce the social, economic and environmental vulnerability of the widely dispersed population, in 1998 the Government initiated a policy for providing incentives for voluntary migration to larger islands. The long-term objective of this strategy was to ultimately reduce the number of inhabited islands by consolidating the population in smaller groups of settlements.

However, the 2004 tsunami disaster has shown that the strategy of consolidating the population is not in itself sufficient to create the framework for sustainable development. It has become clear that islands are not hazard-free and indeed consolidating people in fewer locations could actually increase risk. For example, if a tsunami happens to strike a densely populated island there is the potential for greater losses than if it strikes a less densely populated one. So, the tsunami experience has highlighted the importance of integrating safety considerations in their widest sense, into planning the development of islands. As such the concept of the Safer Islands Programme (SIP), initially introduced in 2005 after the tsunami, has gained momentum as part of the overall atoll development strategy.

The new Government, since coming to power in 2008, has indicated changes to the Population and Development Consolidation policy and to the Safe Island Programme. There is no written policy on the concept but they are advocating the abandonment of the population relocation activities and moving towards a SIP concept with physical, societal and economic resilience. The new concept is currently being referred to as the 'Resilient Communities Programme'. The old SIP concept is based purely on physical resilience but the new Government appears to be taking a more holistic approach to natural hazard and climate resilience. The discussion on the concept is still ongoing.

### 1.1.1 The Safer Islands Programme (SIP)

The objectives of the SIP concept as it stood were to:

Protect the islands from natural and other hazards.

Rebuild and improve existing infrastructure and economic facilities.

Develop capacity to plan and implement measures to reduce natural hazard risks and build the community resilience to disasters.[1]

[1] Note on Safer Islands Programme (Draft) January 2005, Ministry of Planning and National Development

## 1.2 Purpose of the Study

The purpose of this study is to:

Develop the conceptual and operational framework for the Safer Islands Programme through a review of the SIP concept and its contribution to Disaster Risk Reduction (DRR).

Identify disaster risk issues facing three islands: GDh Thinadhoo, GA Viligili, and Th Vilufushi.

Conduct a Cost-Benefit Analysis (CBA) (see Box 1.1) of development interventions and risk reduction/mitigation measures in the three islands.

**Box 1.1:** What is CBA?

CBA is an economic tool used to compare the benefits against the costs of a given project or activity. CBA aims to value the economic benefits of a project (rather than simply the financial impacts), and therefore takes account of any changes in human wellbeing arising from a given project or activity. It can be used before an investment is made, to choose between project options ("forward-looking"), or after an activity has already been undertaken, to demonstrate the economic value of that activity ("backward-looking").

Climate change is increasing the risk associated with hazards, through more intense and frequent hazards, variability in conditions, as well as through increased vulnerability as natural resources and coping capacities are eroded (for example, through impacts to water supply, or changes in disease vectors). As a result, climate change is increasingly being incorporated into CBA, through probabilistic analysis. In other words, where possible, CBA includes the probability of a given hazard and its resulting impacts increasing under climate change.

This study builds on several studies that have already been undertaken to understand risk in the Maldives, namely:

The Disaster Risk Profile in the Maldives commissioned by the UNDP in 2006, which develops a comprehensive national level assessment of the locations and potential impacts of multiple hazards facing the Maldives and assesses the full range of vulnerabilities (UNDP, 2006).

The Detailed Island Risk Assessment in the Maldives Physical Report (DIRAM1) (UNDP, 2009a), and the DIRAM Socio-economic Report (DIRAM2) (UNDP, 2009b), which provide data on hazard, exposure, vulnerability, and losses/impacts for ten selected islands (of which this study focuses on the three named above).

## 1.3 Structure of the Report

The study is divided into two primary components:

A review of the current SIP concept and its contribution to DRR, and the development of a draft conceptual and operational framework for the SIP; and

A Cost Benefit Analysis of three islands based on implementing a range of risk management measures to develop these as "safer" islands.

This report is structured as follows:

**Chapter 2** provides an overview of disaster risk and climate change in the Maldives, and in particular the linkages between disaster, climate change, and the environment.

**Chapter 3** describes the methodology used to undertake the study, both with respect to the SIP review and the CBA.

**Chapter 4** presents the review and draft framework for the Safer Islands Programme.

**Chapter 5** presents the Cost Benefit Analysis for GDh Thinadhoo.

**Chapter 6** presents the Cost Benefit Analysis for GA Viligili.

**Chapter 7** presents the Cost Benefit Analysis for Th Vilufushi.

**Chapter 8** contains a discussion of the CBA findings and their implications for disaster risk reduction in the Maldives.

**Chapter 9** provides conclusions and recommendations for next steps.

The report is accompanied by a series of Annexes that provide greater detail and which are referenced as relevant throughout the report.

# 2. DISASTER RISK AND CLIMATE CHANGE IN THE MALDIVES

## 2.1 Overview

Prior to the Indian Ocean tsunami in December 2004, the Maldives had little experience of disaster impact, although events such as localised flooding, especially due to storm tides, have caused damage and disruption on a more regular basis. However, concern has been mounting over the impacts of climate change, especially predicted sea level rise. The inundation and damage caused by the tsunami has been referred to as a 'snap shot' of the future. Disaster risk and related climate change impacts are thus high profile concerns.

This chapter provides a brief overview of natural hazards in the Maldives, the potential impacts of climate change, and linkages between disaster and climate risk and the environment.

## 2.2 Disaster Profile

### 2.2.1 Flooding

Since 2000 more than 90 inhabited islands have been flooded at least once and 37 islands have been flooded regularly or at least once a year (Ministry of Environment, Energy and Water, 2007). The severe weather event of May 2004 alone caused flooding in 71 inhabited islands (Government of Maldives, 2006).

*Flooding through heavy rainfall*

Heavy rainfall typically occurs as a result of the monsoons, as well as storms passing through the region. Heavy rainfall tends to occur mostly in islands with depressions, and results in flooding, frequently in reclaimed land due to improper reclamation practices. Heavy rainfall is more common in the southern atolls.

*Flooding through wave action*

Flooding through wave action has a number of causes and it is sometimes hard to differentiate between them. These include storm surge, swell waves, (high) tidal flood and local wind-induced waves. However, regular monsoonal wind generated flooding (also referred to as "udha") is considered the most common according to the NAPA (Government of Maldives, 2006). Waves may overtop natural and man-made island defences due to local or distant conditions. Furthermore, different conditions may converge to create a threat, for example local wind-induced waves and a high tide (referred to as a 'storm tide', which can result in waves exceeding 4-5 metres).

### 2.2.2 Strong Winds

At times, tropical cyclones[1] hitting the Maldives are destructive with winds that exceed a speed of 150 kilometres per hour. However cyclones are rare. Available data indicates that only 11 cyclones crossed the islands during a 128-year span and there has been no cyclone in the country since 1993. Typically cyclones affect the more northern part of the country. Strong winds however can damage vegetation, houses, communication systems, roads and bridges. They are also dangerous in terms of their ability to create storm surge. A storm is also likely to result in heavy rainfall.

### 2.2.3 Erosion

Studies on the Maldives have revealed improperly designed and constructed coastal structures have had a major impact in exacerbation of the natural process of coastal erosion (P.S. Kench et al., 2003; Readshaw, 1994; Shaig, 2006a, Shaig 2006b). In 2004, 97% of inhabited islands in the Maldives experienced coastal erosion and 64% of them had severe erosion.

### 2.2.4 Tsunami[2]

The tsunami of December 2004 was the most significant disaster in the history of the Maldives. Indeed it altered the perception of policy makers and the general public alike regarding the vulnerability of this small island nation.

[1] It should be noted that these may more accurately be referred to as "storms of cyclonic strength", as these are very different to the kind of high intensity cyclones that you may find in the Bay of Bengal.

[2] Source UNDP (2006)

Waves ranging from 1.2 to 4.2 metres in height swept across all parts of the country. Out of the 198 inhabited islands, 13 islands required evacuation, 56 sustained major physical damage and 121 were impacted by moderate damage due to flooding. Over 2,500 houses were destroyed and more than 3,500 others were severely damaged. Vegetation and top-soil were washed away from agricultural land and fresh water sources were contaminated by sea water.

Nearly a third of the Maldives' population was severely affected. About 30,000 residents were displaced and around 12,000 were rendered homeless. Several fishermen lost their boats and women's home-based fish processing businesses were badly affected. Furthermore, nearly 15,000 farmers lost a year's harvest due to salt-water contamination of agricultural land. In all, economic losses were estimated at 62 per cent of GDP (World Bank, 2006).

As the December 2004 event highlighted, the islands lying along the eastern side of the Maldives are most exposed to the risk of tsunami. In fact 95 per cent of tsunami risk is generated to the east of the country. Whereas a tsunami with wave height of 2 meters has an estimated return period of 50 years, the return period of the 2004 tsunami has been estimated at 219 years.

### 2.2.5 Earthquake

Seismic risk mapping indicates that there are number of seismic sources (faults) in the Indian Ocean, although most are not in the immediate vicinity of the Maldives. Furthermore there have been just three major events on record for the entire region.

## 2.3 Impacts of Climate Change

Climate change is a major concern for the Maldives, primarily on account of sea level rise. Sea surface temperature rises also pose a threat to the health of the coral ecosystem. Changes to extreme events and climate variability are also of significance (and anecdotally are being observed at island level). The links between climate change and disaster risk are therefore important from the perspective of furthering these two mutually supportive agendas towards a safer and more resilient country.

#### *Sea level rise*

Over 80 per cent of the land area of the Maldives is below 1 meter above mean sea level (MSL). A variety of impacts can be expected from sea level rise besides the obvious loss of land and flooding of low-lying areas. These include loss of crop yield, salinization, impacts on coastal aquaculture and erosion of sandy beaches.

Future sea level is projected to rise within the range of 9 to 88cm by 2100 (Government of Maldives, 2006). On the one hand, it is generally argued that the outlook for low lying coral islands is catastrophic under the predicted worst case scenarios of sea level rise, with the entire Maldives predicted to disappear in 150-200 years. On the other hand, a piece of research in the Maldives suggests that "Maldivian islands have existed for 5,000 years, are morphologically resilient rather than fragile systems, and are expected to persist under current scenarios of future climate change and sea-level rise" (Kench et al., 2005). The study anticipates that coral will grow, and natural erosion and accretion processes will adapt to the prevailing conditions.

However some notes of caution are relevant in response to this perspective. Firstly, the rate of sea level rise and sea surface temperature rise may be unprecedented, and indeed since this study in 2005, estimates have been revised upwards. Hence it is not clear whether natural processes will be able to keep up. Secondly, these Maldivian studies were predominantly undertaken on uninhabited islands. The inhabited islands of the Maldives are highly modified and their natural ability to adapt to any future climate change is yet to be determined. Degradation of coral and the inability of beaches to respond naturally to changes as a result of human modification, are sure to limit the ability of the islands to respond naturally to such significant threats as sea level rise.

#### *Precipitation*

No significant long-term trends are evident in the observed daily, monthly, annual or maximum daily rainfall for the Maldives. Some of the more extreme rainfall events are, however, predicted to become more frequent but remain relatively rare (Government of Maldives, 2006).

### *Temperature*

The annual maximum daily temperature is projected to increase by around 1.5°C by 2100. A maximum temperature of 33.5°C is currently a 20-year event. It will likely have a return period of three years by 2025 (Government of Maldives, 2006). Furthermore an increasing trend in sea surface temperature has been observed.

### *Extreme events*

Greater extremes of drying and heavy rainfall are projected, increasing the risk of droughts and floods especially during El Nino events. Tropical cyclones are predicted to increase in intensity by 10 to 20 per cent (Government of Maldives, 2006). Currently an extreme wind gust of 60 knots has a return period of 16 years. It is estimated that this will reduce to 9 years by 2025. However, cyclones are rare and those that have occurred are predominantly in the northern Maldives as already noted (not in the vicinity of the islands focused upon within this report). With regard to storm surge, sea level rise clearly would increase impacts. Regular tidal inundations in most islands can be anticipated even at the medium sea level rise prediction. The high prediction could cause inundations recurrently in almost all islands.

## 2.4 Linkages between Disasters, Climate Change, and the Environment[3]

[3] Information presented here is based upon the ISDR Partnership for Environment and Disaster Risk Reduction (PEDRR) and Disaster Environment Working Group for Asia (DEWGA) special event held at the Global Platform for Disaster Risk Reduction in Geneva in June 2009 (http://www.preventionweb.net/globalplatform/2009/programme/special-events/v.php?id=42)

Healthy ecosystems provide natural defences to human communities by regulating hazards. In other words, they can act as barriers that reduce impacts and help avert disaster. Conversely degraded ecosystems can increase exposure and reduce community resilience. This relationship is paramount in the Maldives, where the natural environment – coral reefs, vegetation, and the natural processes of erosion and accretion have been allowing these islands to exist and adapt for thousands of years.

As described above, climate change increases the frequency and intensity of climate-related hazards such as storms, floods, fires and droughts and thus increases the risk of disaster. Furthermore, ecosystems can themselves be damaged by disasters and by poorly undertaken post-disaster reconstruction. Climate change is also a cause of ecosystem degradation (e.g. coral bleaching). Thus there is a mutually reinforcing relationship that exists between disasters, climate change and degraded ecosystems: an ecosystem that has been degraded on account of the impacts of a past disaster, climate change or human activities has a reduced resilience against hazard impacts and thus increases the likelihood of future disaster.

Therefore the protection of ecosystems can save lives and protect assets. They can also be critical, as they are in the Maldives, for providing other benefits (referred to as ecosystem services) through providing a source of income or the support of a livelihood activity. In the Maldives, the two major sources of income, fisheries and tourism, are completely dependent on a healthy ecosystem.

These linkages are further compounded by poverty. Poor communities must be able to access tangible benefits to sustain livelihoods, and hence the benefits of protecting ecosystems must be overt. From a policy perspective, this necessitates the integration of ecosystems management with sustainable livelihoods development, in order for communities to effectively tackle growing risks of disasters and climate change. Furthermore, development plans must be based upon a thorough environmental impact assessment.

# 3. METHODOLOGY

## 3.1 Introduction

The study was undertaken between April and August 2009, by a study team comprised of two international consultants specialising in risk management, and CBA for disasters and climate change, as well as a local consultant heavily involved in previous similar studies.

The study was conducted in relation to three islands - GA Viligili, GDh Thinadhoo, and Th Vilufushi. The first two islands are potential islands for development as "safer islands", whereas Vilufushi is the first island developed to the specifications of the safe island concept. Three field trips were conducted to the Maldives capital, Male', and to two of the study islands – Viligili and Thinadhoo. Vilufushi was added to the analysis part way through the study, and hence the fieldwork was undertaken with the support of the local consultant. The field trips were used for gathering data and consultation with relevant stakeholders, at both a national and local level.

The methodology described here is presented in two parts, the first section in relation to the review of the SIP and development of the SIP framework, and the second in relation to the CBA, including the identification of disaster risk issues as this forms a core component of a CBA.

Annex A contains a full listing of all stakeholders consulted as a part of this study.

## 3.2 Review and Development of Framework for the SIP

### 3.2.1 Introduction to methodological approach

The Safer Islands concept was assessed with respect to its contribution to disaster risk reduction for the Maldives, and as such was reviewed in relation to the Hyogo Framework for Action (HFA). The HFA is the international 'blue print' for achieving disaster risk reduction, based on five key priorities.

| HFA Priorities for Action: |
| --- |
| **Priority 1:** Ensure that disaster risk reduction is a national and local priority with a strong institutional basis for implementation |
| **Priority 2:** Identify, assess and monitor disaster risks and enhance early warning |
| **Priority 3:** Use knowledge, innovation and education to build a culture of safety and resilience at all levels |
| **Priority 4:** Reduce the underlying risk factors |
| **Priority 5:** Strengthen disaster preparedness for effective response at all levels |

It is an internationally agreed set of standards and benchmarks for countries to develop plans for managing disaster risk, and as such is very applicable to the development of the SIP in the Maldives.

The HFA influenced the design and practice of both desk-based research and fieldwork. The tasks recommended to aid implementation of the HFA under each of the priority areas, as outlined by the United Nations International Strategy for Disaster Reduction (UNISDR) in 'Words into Action: A Guide for Implementing the Hyogo Framework for Action', were used as a basis for analysing how the SIP connects with this broad framework. In this way a comprehensive awareness of the strengths of the SIP (based on already identified risk mitigation proposals - such as environmental protection zones, improved building codes, safe zones and emergency supplies) could be highlighted, and areas where further progress may be required could be indicated.

Despite the growing call for an internationally agreed framework that links disaster risk and climate change together, at present no such framework exists. However, consideration of the SIP under the HFA as used here has been undertaken in light of climate change risks.

The methodology was composed of the following steps:

- Definition of the scope of the SIP review;
- Review of key documents;
- Development of a questionnaire based on the HFA;
- Semi-structured interviews and meetings; and
- Fieldwork.

The findings from these activities were then analysed to assess both areas of strength and areas for further development within the SIP concept.

### 3.2.2 Scope

Whereas the CBA is more limited in its quantitative analysis of hazards due to data availability, the SIP review considered the full range of natural hazards of relevance to the study islands. Furthermore, special attention was given to issues of environmental management as a core component of the SIP.

### 3.2.3 Document Review

A review of existing documents on the SIP and other policy documents pertinent to the concept of developing safe islands in the Maldives was undertaken. This was approached within the context of the SIP's relevance to the new government manifesto. The manifesto provides a broad indication of how the future direction of the SIP concept may develop beyond the earlier seventh national development strategy, as declared by the previous government.

### 3.2.4 Development of a Questionnaire based on the HFA

Ahead of the first mission, a questionnaire was developed to guide interviews and fieldwork. This was later refined for the subsequent missions and fieldwork.

The SIP/HFA table below highlights examples of how a consideration of the HFA priorities for action was used to form questions pertinent to the SIP concept. Annex B contains the full questionnaire.

**Table 3.1:** HFA Priorities and Linkages with SIP Review Questions

| Safer Islands Programme / Hyogo Framework for Action | |
|---|---|
| Priority 1 | Who should be involved in the development of the SIP?<br>Who has responsibility for sustaining the SIP at island level?<br>How should the proposed risk mitigation measures be adapted to suit specific islands?<br>What capacity needs will there be?<br>Who should have oversight for the development and implementation of the SIP, and what powers/authority will they need to integrate with other development issues?<br>What are the competing development concerns? |
| Priority 2 | How does the SIP support the linkages between risk knowledge, monitoring of hazards, dissemination of warning and response capability so as to ensure any early warning system is effective? |
| Priority 3 | How aware are local communities regarding the range of natural hazard risks they are exposed to and the implications of climate change?<br>Where are the priorities for training on DRR/SIP (which sectors, levels)?<br>How can the links between environmental management, livelihoods and DRR be strengthened (especially at the local level)?<br>How is the SIP concept shared among the population to raise awareness of the need for enhanced DRR? |
| Priority 4 | What are the barriers preventing national level policy on environmental protection from being implemented on the ground?<br>Can man-made environments mimic existing natural defence, what examples?<br>Who is most vulnerable to hazards, and why? |
| Priority 5 | What measures are already undertaken at island level to protect assets against damage?<br>How will disaster preparedness plans be implemented and sustained over the long term (e.g. drills)? |

### 3.2.5 Semi-Structured Interviews and Meetings

Semi-structured interviews and meetings were undertaken with government ministries, UNDP, various experts, and local communities to develop a sense of where development of the SIP concept has reached (see Annex A for a list of interviewees). Interviews and fieldwork were guided by the use of the questionnaires.

During the second mission, a draft SIP review was presented to the Ministry of Housing, Transport and Environment and UNDP in Male' on 26th May 2009. At this time the 'Framework' was also discussed and although no details were provided, agreement was reached that this should be a 'forward looking' document. A 2nd draft of the review with a draft framework was presented during the final mission to the Maldives in July. Feedback was used as a basis for the development of the final documents.

### 3.2.6 Fieldwork

Regardless of the level of commitment at national and policy level, the actual impacts of climate change and disasters will always be most acutely felt in the lives of people at the local level. Vulnerability, rather than hazard occurrence, is the most significant determinant of impacts in most situations. While most natural hazards can be mapped on a large-scale (e.g. typical cyclonic activity, predicted rainfall, fault lines), vulnerability varies island-by-island and household-by-household. Therefore, national strategies intended to manage risk are highly dependent upon the engagement of local stakeholders.

All three islands were visited to gather insights into the different perceptions of risk held by various people. Observation, informal conversations and focus group meetings were used to gather data during the fieldwork.

Transect walks with island officials were undertaken as an initial method of gaining an awareness of the risk context of each island. Discussions and observations of this nature provided a wealth of information. For example it was possible to observe the extent of natural vegetation, the area, height and shape of land reclamation, location of key infrastructure, road layout, and people's daily activities (i.e. tending to backyard crops, fishing off the beach, meeting in the restaurants, dumping household waste).

Group meetings were also organised. These were well attended with a range of between 10 and 50 people. The largest meeting comprised a mixed group of people including:

- Key officials, Island and Atoll chiefs;
- Teachers, religious leaders, boat owners (representing those with influence);
- Vulnerable groups (e.g. women-headed households, those engaged in specific low income livelihoods); and
- Development committees and NGOs (e.g. Island Women Development Committee (IWDC) and Island Development Committee (IDC)).

A group meeting of this nature has many benefits, including the opportunity to discover whether different people have opposing or similar views, and people's willingness or reluctance to express themselves openly. Such social aspects have strong implications in terms of developing community resilience.

Photographs were also taken to help capture key findings and observations.[1]

[1] All photographs presented in this report by Paul Venton.

## 3.3 Cost-Benefit Analysis (CBA)

### 3.3.1 Introduction to Methodological Approach

A Cost Benefit Analysis for DRR is developed by comparing two scenarios:

- Hazards and their impacts on communities "without" any DRR measures; and

- The reduction in hazard impact "with" DRR measures.

The benefits accrued from reducing hazard impacts (e.g. reduction in lost assets) are offset against the costs of implementing the protection measures that bring about those benefits, resulting in a Benefit to Cost Ratio.

In the case of this study, the analyses for GDh Thinadhoo and GA Viligili are forward-looking, modelling a range of possible scenarios and mitigation works to protect against disasters. In the case of Th Vilufushi, the island has already been rehabilitated as a "safer island" following the tsunami, and hence the analysis is backward looking, and is an assessment of the actual works undertaken and the degree of protection that they will afford.

The CBAs for all three islands are multi-hazard – in other words, the modelling takes account of the impacts of a number of different types of hazards, and different size of hazard event. Furthermore, the analysis is probabilistic – it weights the estimated impact of a given event by the probability of that event occurring. As such, the analysis accounts for the fact that the risk management measures provided under the SIP will provide protection against a range of possible events occurring in any given year.

For all of its benefits, CBA also presents a variety of challenges, which should be duly noted:

- CBA requires a quantitative analysis of benefits of DRR. However, many benefits are often not quantifiable and have a moral imperative – such as social changes and gender impacts – and therefore CBA must be taken as part of a wider qualitative assessment and not as a stand-alone tool.

- Further, disasters often result in the loss of people's lives, particularly among the poor, marginalized and most vulnerable groups. CBA calls for a quantification of such losses. This of course can be controversial because it requires placing a value on human life, and thus can be interpreted as assigning less importance to the poor in comparison to the rich.

- Where data are available, issues can arise over quality and reliability, especially in a local context where triangulation with other sources can be difficult.

- CBA analyses the total impact to a community – it does not differentiate between impacts to different groups and as such does not directly highlight differential benefits to gender groups or the most vulnerable. It is thus important that these types of impacts can be described qualitatively as part of a wider analysis.

- CBA requires a good understanding of the nature and impact of hazards, their magnitude and frequency. However, natural hazards may be highly unpredictable, and are ever more uncertain due to exogenous factors influencing their characteristics, such as climate change.

Nonetheless, CBA is about risk assessment – no one can predict future weather and hazard patterns with certainty, but decisions need to be made in light of the best data available. Furthermore, there is a great deal of value in not only the product (e.g. CBA ratios), but also the process of actually conducting the CBA, as it helps decision-makers and other interested parties to think through and weigh up a variety of options under differing scenarios.

The steps required to complete the CBA are described in detail below. It should be noted that this analysis was preceded by detailed risk assessments for nine islands in the Maldives (of which this study covers three islands): a Detailed Island Risk Assessment in the Maldives Physical Report (UNDP, 2009a), and the DIRAM Socio-economic Report (UNDP 2009b). The data presented in these studies is relied upon heavily in this CBA. Therefore, where applicable, the descriptions below include a summary of the methodology that was used in the DIRAM reports.

The methodology was composed of the following steps:

- Definition of study parameters;

- Data collection, including hazard assessment, impact assessment, and identification of risk management options, costs and benefits; and

- Analysis of costs and benefits.

### 3.3.2 Definition of Study Parameters

The first step in any CBA is to define the study parameters. In any economic analysis, there will always be wider ranging impacts and costs, which are beyond the scope of the analysis, and it is important to define this scope clearly.

Because the focus of this cost benefit analysis is on disaster and climate risk, this assessment focuses on hydro-meteorological hazards.

The primary hazards for the study islands, as stated in the UNDP DIRAM reports and confirmed through stakeholder meetings, are flooding from swell waves, flooding from heavy rainfall, tsunami and windstorms. Beach erosion was mentioned numerous times in meetings - it has been increasing at a rapid rate, exposing island communities to greater risk through loss of houses and increased proximity to wave surges. Climate change is projected to not only increase the intensity of these hazards, but also to introduce a new hazard through sea level rise.

Data is only available at the level needed for a CBA for: flooding due to heavy rainfall, swell waves, tsunami, and associated climate impacts on these events, and therefore these are the focus of this study. Indeed, these appear to be the hazards with greatest impacts on the islands, and therefore most relevant to a CBA.

Furthermore, the scope focuses on the impacts of hazards and protection measures on the three islands themselves. So, for instance, the parameters of this study do not include the wider impacts of a safer island programme, such as costs of relocation, decreased infrastructure costs on "abandoned islands", or macro level impacts to GDP. The scope does include the full range of safer island measures, most of which are more structural measures, such as coastal protection and resilient harbours, but also includes some softer measures such as raising risk awareness.

### 3.3.3 Data Collection

Data collection can be divided into three phases, each of which is discussed in greater detail in the following section:

- The Hazard Assessment: Data on the frequency and magnitude of relevant hazards is recorded.
- The Impact Assessment: The impact assessment examines the risk associated with hazards; risk is a function of both the hazard and the vulnerability of people and assets to that hazard (comprised of both the exposure of people and assets to the hazard, as well as the fragility, or degree of damage). Data is gathered on the impacts of hazards "without" any protection measures. Ideally, the impacts are defined for low, moderate and severe hazards, and include both qualitative and quantitative data.
- Identification of Risk Management Options, Costs and Benefits: Also referred to as the "with" scenario, this step gathers data on the mitigation and protection options, the costs to put them in place, and the benefits, or reduction in losses, associated with protection.

It is important to note that data limitations often required that estimates were calculated based on a number of assumptions as described in the following steps. In particular, estimates for hazard return periods (particularly under climate change), and benefits from risk management, had to rely on relatively scant data (as outlined in the limitations section at the end of this section), and hence are best estimates and in some cases presented as ranges to account for high levels of uncertainty. Data on costs associated with risk management were more readily available through government, contractors, and other similar projects that have been undertaken previously.

#### *Hazard Assessment*

The hazard assessment draws heavily upon DIRAM1 (UNDP 2009a), which presents details on the frequency and magnitude of hazard events for the three study islands. DIRAM1 reconstructed hazard data based on known historical events, as evidenced through field reviews and a review of historical records. The assessment of changes as a result of climate change was based primarily on existing literature – no attempt was made to undertake site-specific assessments, or to undertake modelling or downscaling of regional impacts.

Hazards can be defined, within the context of this study, in terms of their magnitude and severity:

- Magnitude is used here to describe the size of the hazard, defined as low, moderate or severe, based on the wave height or quantity of rain in a 24 hour period.
- Severity is used to define the intensity of the impact of a hazard on an island.

Based on this research, event scenarios were developed for low, moderate and severe magnitude hazards, including return periods (the likelihood of a given hazard in any given year) for each island studied. These event scenarios were further elaborated for the likely change in probability as a result of climate change (where data was available), using existing studies on potential climate impacts. The findings from these studies were used to assess the likely increase in probability of certain events under climate change, for 2050.

Because historical data is not systematically recorded, and rigorous analysis of regional climate impacts on hazard frequency and severity was not available, the return periods are presented as a range (e.g. 10-30% probability of a given hazard in any given year), to account for the significant levels of uncertainty, for existing hazard return periods, and even more so under changing climate scenarios. These ranges were tested in the sensitivity analyses contained in the island specific sections below.

DIRAM1 then developed hazard intensity zones for individual islands using a Hazard Severity Index. The index is based on a number of variables, including historical records, topography, reef geomorphology, vegetation characteristics, existing mitigation measures and hazard impact threshold levels. The index ranges from 0 to 5 where 0 is 'no impact' and 5 is 'very severe impact'. In other words, a given hazard event (e.g. a severe magnitude tsunami) will have severe impacts in zone 5 (along the coast), and more moderate impacts further inland. This zoning was only undertaken for severe magnitude hazards (not low or moderate equivalents). These hazard zones were then mapped into a Geographic Information System (GIS), to present a map identifying five hazard intensity zones for a severe magnitude hazard for each island.

### *Impact Assessment – without mitigation measures*

In the case of Thinadhoo and Viligili, the data on impacts for each of the three hazards was drawn from both the DIRAM1 and the DIRAM2 (UNDP, 2009b) studies. Impacts were classified as physical, human, and natural, and both quantitative and qualitative impacts were identified.

Quantitative data was available for physical and human impacts for inclusion in the CBA. DIRAM2 estimates total financial losses as a result of severe magnitude hazard events. All losses throughout the study are presented in Maldivian Rufiyaa (RF) unless otherwise noted.

The estimates for physical losses (economic and infrastructure) were made as follows:

- The value of each island's economy was assessed through field surveys and published records. First, an inventory of economic establishments and socio-economic infrastructure was taken. Second, information on employment, income, expenditure and investment costs was gathered through field interviews. Finally, the cost of private and public investments, their production values and expenditure were calculated for all economic establishments using average values from the survey.

- Key economic establishments and infrastructure were identified and mapped in GIS for each island.

- Each of the elements at risk was assessed for its overall vulnerability (exposure, e.g. in a high risk zone, and fragility, e.g. poor construction).

- Hazard maps were created identifying five hazard intensity zones for a severe magnitude hazard (as described above), overlaid with the location of key infrastructure and economic assets. This was done for each of the three hazards – swell wave, tsunami and rainfall flooding.

- The potential losses associated with a hazard were then predicted using the hazard zoning map, hazard scenario, elements at risk and vulnerability (fragility and exposure) characteristics of a given sector/asset. Only tangible losses were included. For each of the five risk zones, it was assumed that total loss would occur in the most severe risk zone, with a 25% reduction in loss for each of the following risk zones (i.e. hazard intensity index 4 will have a 75% loss, index 3 will have 50% loss and so on). These loss percentages were fixed values based on the 2004 tsunami. Baseline data for these calculations were derived from various post-tsunami reports and field interviews. In general, establishments and assets in 'high intensity' zones (rating of 5) involved total loss and areas with 'lowest intensity' had negligible losses. This was however dependent on the construction quality of the asset or infrastructure. It was therefore assumed that there would be an incremental decrease in losses in various intensity zones. This assumption was verified in three islands by triangulating the facts using reports from the island office/Disaster Management Centre regarding losses, interviews with persons affected and interviews with other community members. While there were no clear cut-off points for various intensities, the average values showed an inverse relationship between intensity and damage. The percentages should therefore be treated as indicative, yet a reasonable estimate of the losses in a given hazard zone.

In the case of Vilufushi, the island was almost completely destroyed by the tsunami, and hence it was not possible to assess the value of the Vilufushi economy and infrastructure through field visits and empirical data (as was done with the other two study islands).

In order to estimate economic losses under no protection, proxy values were used from two other islands – Kudhuvadhoo and Viligili - taken from the ten islands assessed for the socio-economic risk assessment

(UNDP, 2009b) that have similar economic profiles to Vilufushi (in its original state). All three islands have economies predominantly based on fishing. The total economic value of these islands was divided by their population to arrive at an economic value per capita, which was then averaged and applied to the total population of Vilufushi before the tsunami.

In order to estimate infrastructure losses under no protection, records of infrastructure on the island were used to reconstruct the value of that infrastructure using standard rates and assumptions.

For all three islands, the estimates for human losses were made as follows:

- The Value of a Statistical Life (VSL) for the Maldives (See Box 3.1) was calculated using the "income-over-life" method. This data was then combined with the number of estimated lives lost due to a severe tsunami: this was assumed to be 0.1% fatalities and 5% injuries within the population based on data from the 2004 event.

- The cost of injury was estimated at 15% of VSL (as this was the maximum value reported during the tsunami), and multiplied by the estimated number of injuries from a severe tsunami event based on data from the 2004 event.

## Identification of risk management options, costs and benefits

### *Identification of risk management options*

For Thinadhoo and Viligili, a range of protection measures were identified building on the analysis in DIRAM1 and DIRAM2. These range from more structural measures such as coastal protection and resilient harbours, to softer measures such as disaster risk awareness programmes.

The range of measures were further categorised into four risk management options, each varying in cost and level of protection. These four scenarios form the basis for the cost benefit analysis:

- No protection: the "without" scenario.

- Safe Island protection: the full suite of safe island measures, offering a high level of protection.

- Selected safe island protection: a more limited range of measures, offering somewhat less protection.

- Limited Protection: a bare minimum of measures, affording limited protection.

**Box 3.1:** Calculation of the Value of a Statistical Life

The two most frequently used methods for valuing loss of life are foregone earnings and consumer willingness-to-pay methods. This study uses the foregone earnings approach, and calculates the Value of a Statistical Life (VSL) based on a person's lifetime net earnings. Average annual income in the outer islands (US$2,451.83) was used to avoid discriminating against income groups or employment status. A life expectancy of 73 years and the legal working age of 16 years were used to determine working age (the difference between the two). This was then multiplied by average annual income, giving a final figure for VSL based on income-over-life at US$139,754.

As a benchmark, an attempt to use the willingness-to-pay method, by evaluating the cost of coastal protection in the capital Male' against the probability of lives saved, derived a value of US$179,462. Interestingly, a climate change impact study undertaken by the Intergovernmental Panel on Climate Change valued a life in a developing country at US$150,000 (Fankhauser et al., 1997). The VSL calculated here sits just below these. In effect, these three values represent an appropriate high, median and low Value of Statistical Life for the Maldives.

Adapted from Shaig, 2009

The risk management options were partly highlighted in DIRAM1, Environment Section. There are no clear-cut guidelines for the use of 'safe island measures' other than using all measures on all islands. However, DIRAM1 highlighted that some islands did not require selected mitigation measures as there were natural defences in place. For example, a coastal protection was not recommended for S.Hithadhoo Island as it already had a 3.0m high natural ridge. This was the basis for recommending selected safe island measures.

### *Financial costing*

The data for financial costing comes from the Public Sector Invest Programme database, various bid proposals, information from the Disaster Management Centre, Housing and Infrastructure Reconstruction Unit and personal communications with contractors. The spatial calculations (e.g. length of coastline and roads) were done using the GIS system used in DIRAM1 and DIRAM2. Both fixed and variable costs were calculated for each protection measure. Annex C contains a generic explanation of the rates and assumptions that were used for costing mitigation measures (subsequent annexes contain detailed costings for each island).

The limited protection option targeted most critical facilities and infrastructure at risk and assumed that impacts on all other structures could be reduced using a seawall. The costing for the seawall is also based on the most common construction method (i.e. sand-cement bags).

In the case of Vilufushi, the island has been completely reconstructed, and therefore the actual measures undertaken are costed, based on data on actual reconstruction. These costs were then modified to account for the fact that Vilufushi was completely destroyed, and therefore the island would have to be re-built in any case. In other words, the analysis looked at the additional costs of rebuilding Vilufushi as a safer island.

### *Benefits of risk management*

Benefits, or the reduction in losses, were assigned to each of these scenarios. Given the limited data availability, it is very difficult to reconstruct the benefits that will be brought about by physical mitigation measures, such as sea walls, under different hazard scenarios. Each mitigation measure will affect each island differently, depending on specific physical and geomorphological characteristics. And the associated decrease in losses will also vary, depending on the location of assets. Without detailed feasibility studies for each of the physical mitigation measures, specific to each island, it is not possible to estimate the exact benefits that will be realised.

An alternative approach is to estimate the total value of exposed assets, and multiply this by an estimated percentage reduction in losses as a result of a given suite of protection measures. Following this approach, as a proxy, an estimate was made for the percentage reduction in losses associated with each of the four risk management scenarios, for low, moderate, and severe magnitude events, for each hazard type.

More specifically, the percentage reduction in losses was calculated by using the predicted inundation curve (which begins at the coastline and ends at the furthest extent of flooding), for each of the severe, moderate and low hazard magnitude scenarios. These were then modified using the coastal structure heights in the mitigation scenarios, using a simple analysis in the GIS maps. For example, if the predicted maximum tsunami height without protection is 4.0m on the coastline, the floodwater may travel up to 500m. But when a 2.5m wall is erected, the net overtopping is 1.5m. A wave of 1.5m may only travel say to 200m inland. The establishments, infrastructure and households that fall into these zones, and those that were at risk, were established, to arrive at percentage of losses avoided.

These percentages were then multiplied by the absolute losses calculated for each magnitude of hazard, to arrive at total benefits under each scenario. Because these calculations rely on the estimates of tangible losses estimated above, the benefits also only represent tangible benefits.

### 3.3.4 Analysis of Costs and Benefits

The above data and analysis was combined to create a multi-hazard probabilistic risk model. The model for each island is based on a 50-year project lifetime (the lifetime of the longest lived asset, the coastal protection measures). Because the other measures typically have a much shorter lifetime, it is assumed that these measures need to be re-built at the end of their lifetime, and hence these additional costs are included in the model. Furthermore, this assumption is tested in the sensitivity analyses (see below).

Costs and benefits were discounted over the project lifetime, to reflect time preferences for money. The discount rate was estimated at 7.5%, ranging from 6.5-10%. There are no government suggested discount rates in the Maldives, and so the estimate was derived by looking at rates for long term borrowing in the Maldives, as well as the discount rates used in other small island Indian Ocean states (Shaig, 2009).

The models were run as appropriate for each of the three islands, under different hazard probabilities, to provide a baseline analysis. These models were then run again using "sensitivity analyses" to test for areas of uncertainty in the analysis. The sensitivity analyses test the following assumptions:

- Probability of hazard occurrence;
- Discount rate;
- Intangible benefits; and
- Project lifetime.

## 3.4 Limitations

*SIP Review*

The main limitation affecting the SIP review and framework was the lack of meetings with stakeholders at a national level, particularly among government ministries. This was despite numerous efforts to arrange for consultations with the international consultants. Numerous strategies were adopted to overcome this, including contact by both phone and email, the help of the local consultant to meet with stakeholders, and the invited participation of stakeholders to meetings and presentations.

Also, it was not possible to visit Vilufushi in May, as hoped, due to poor sea conditions that prevented long distance travel by boat coupled with a lack of seats to fly to the nearest domestic airport. This constraint was addressed by engaging and briefing the local consultant to travel to Vilufushi and collect data at a later date.

The SIP concept is also in a state of flux on account of the change in government. For instance, there is talk of changing the name of the concept to reflect the development of a more holistic approach to safer islands incorporating economic and societal resilience as well as existing physical protection. Thus the exact terminology and components of the SIP are sometimes confusing and mean different things to different people.

*CBA*

The DIRAM1 and DIRAM2 provided the most consistent and in-depth source of data for conducting the CBA. Nonetheless, the reports acknowledged a number of significant data gaps in their analysis and it is important that these are repeated here, as this data is an important component of the CBA. Throughout this study, every effort was made to verify the data and update the figures in these two reports to the extent possible. This was most successfully undertaken through the engagement of the local consultant, who was involved in the first two reports, and hence able to readily identify and proactively refine figures, particularly in relation to the impact assessment and analysis of costs of protection.

The most significant limitations were as follows:

- The DIRAM1 and DIRAM2 studies were limited by a lack of physical data. For example, the lack of existing survey data on critical characteristics of the island and reef, such as topography and bathymetry data, and wave patterns, limits the amount of empirical assessment that could be done.
- Furthermore, a CBA of this nature should normally be preceded by detailed feasibility studies and EIAs on the possible physical risk mitigation measures available, and their ability to protect against hazards.

This data would then be used to build detailed hazard maps for each island based on what is feasible given the specific island characteristics. In the absence of such studies, the analysis relies on best estimates and assumptions and uses scenarios and sensitivity analysis to test a range of options.

- The lack of data extends to climate change estimations. Very little downscaling of climate impacts has been done for the region, and hence analysis of possible changes to hazards as a result of climate change were based on the few studies that do exist. While estimations were made in DIRAM1 for the increased return period of hazards, these estimates are based on a range of assumptions and have high levels of uncertainty.

- Land development in the islands has changed over the course of the DIRAM1 and DIRAM2 studies, as well as this study. Further, future development plans for the island are not finalised. It was thus impractical to assess the future hazard exposure of the islands, and in the case of Viligili, the island has had significant land reclamation since DIRAM1/DIRAM2, but it is not possible to make an assessment on this basis as this report relies on the analysis done in DIRAM1 for its data. It is recommended that this study be extended to include the impacts of new developments, especially land reclamations, once the plans are finalised.

- Vilufushi suffered complete devastation from the tsunami, and therefore it was not possible to conduct empirical analyses of the situation before the tsunami (the "without scenario") and hence proxy data and assumptions were required. Furthermore, the Vilufushi population only moved back to the island during the course of this study, and hence the island is very much in a state of transition. Finally, it was noted in DIRAM1 that locals may have understated previous hazard events during field consultations for two reasons: 1) public concern over the large amounts of money being spent to rebuild a very vulnerable settlement may have biased inhabitants to make Vilufushi appear a very safe island in the past and 2) the intensity of the tsunami may have made all other flooding events appear irrelevant and minor by comparison.

**Box 3.2:** Specific Limitations Highlighted in DIRAM1 and DIRAM2

**Hazard assessment (adapted from DIRAM1):**

- The hazard assessment was limited by a lack of historic data on hazard events. Data is not collected in a systematic manner at the island level, and there is no monitoring of coastal and environmental changes caused by anthropogenic activities such as road maintenance, beach replenishment, causeway building and reclamation works.
- Long-term meteorological data from the region, critical for predicting trends and calculating the return periods of events specific to the site, was inaccessible (the Department of Meteorology levied a substantial charge for acquiring the data). The lack of data has been compensated by borrowing data from alternate internet based resources Furthermore, there are uncertainties in climatic predictions, and the predictions used in the study are based on specific assumptions which may or may not be realized.
- The meteorological records in the Maldives are based on 5 major stations and not at atoll level or island level. Hence all hazard predictions are based on regional data rather than localised data. Hence, it should be noted that there is a high degree of estimation and the actual hazard events could vary from what is described. However, the findings are the closest approximation possible based on available data.

**Impact assessment (adapted from DIRAM2):**

- Much of the data relevant to the economic characteristics of islands is only available at a national level, and cannot be disaggregated to an island level.
- DIRAM2 contains a detailed assessment of the economic value of each island. However, while It attempts to value both direct and indirect impacts of a hazard, the analysis only includes tangible losses - those that could be reasonably measured using monetary values. Intangible costs involve a high degree of estimation which may or may not represent the true value – for example, the lost working days, lost reputation, opportunities or competitiveness.
- Any estimation of economic values prior to a disaster will have a significant level of ambiguity, even in tangible costs. This is because it is impossible to predict the exact damage that will be caused by a disaster as it depends on a number of natural factors. For example, it is impossible to state exactly which percentage of a power house will be damaged or how many engines will become inoperable, and for how long.

**The following data and assessments need to be included in future analyses:**

- Detailed feasibility and EIA studies for any proposed measures on each island, to determine what is possible, and what sort of protection it could offer.
- A topographic and bathymetric survey for all assessment islands.

# 4. THE SAFER ISLANDS PROGRAMME[1]

The following sections present the findings from a review of the SIP, and present a draft proposed framework to help guide the future development of the concept.

## 4.1 The SIP Review

The review of the SIP was conducted in relation to the five priorities for action as outlined in the Hyogo Framework for Action (HFA), while also ensuring that climate change risks were considered. This section, therefore, is divided into the following five sections:

**Priority 1:** Ensure that disaster risk reduction is a national and local priority with a strong institutional basis for implementation.

**Priority 2:** Identify, assess and monitor disaster risks and enhance early warning.

**Priority 3:** Use knowledge, innovation and education to build a culture of safety and resilience at all levels.

**Priority 4:** Reduce the underlying risk factors.

**Priority 5:** Strengthen disaster preparedness for effective response at all levels.

The UNISDR[2] outlines specific tasks recommended to aid implementation under each of the priority areas, and these have been used as a basis for analysing how the SIP connects with this broad and comprehensive framework. Each of the following sections begins by highlighting these tasks; however it should be noted that the discussion that follows highlights points of key importance and may not cover every task included.

[1] The Safer Island Programme concept has been broadened to Resilient Island Planning as per the current government policy. Resilient Island Planning involves not only physical aspects but also social and livelihood aspects in the communities. The current resilient island concept involves:
- Strengthening climate resilience
- Market driven strategy providing incentives for voluntary migration to alternative islands
- Development of larger islands with potential for expansion with integration of climate resilience and better economic opportunities

[2] Words into Action: A Guide for Implementing the Hyogo Framework for Action

| **Priority 1** | Ensure that Disaster Risk Reduction is a National and Local Priority with a Strong Institutional Basis for Implementation |
|---|---|

- Engage in multi-stakeholder dialogue to establish the foundations for disaster risk reduction
- Create or strengthen mechanisms for systematic coordination for disaster risk reduction
- Assess and develop the institutional basis for disaster risk reduction
- Prioritize disaster risk reduction and allocate appropriate resources

Concerns regarding sea level rise, combined with the devastating impacts of the 2004 tsunami, are ensuring that developing resilient islands is a national level priority.

The tsunami disaster of 2004 was considered a 'snap shot' of the future, in terms of the debilitating effects caused by mass inundation of seawater. This specific event, combined with a sharp awareness of the consequences of climate change, and in particular sea level rise for small island nations such as the Maldives, are helping to ensure that disaster risk reduction remains a pillar of the national agenda for future development in the country. For example, while some detail set forth in the Seventh National Development Plan 2006-2010 (NDP7) may alter under the new administration, the essence of the goal to "protect the natural environment and make people and property safer" remains the same. Furthermore, the National Environment Action Plan (NEAP 3) is one of the few policy documents established thus far by the new government, and it clearly states the government's priority to act in response to both climate change mitigation and adaptation – two of its six pillars are to establish resilient islands and create a carbon neutral nation.

However, there is often a mismatch between national and local priorities for risk reduction.

For example, the warranted national concern to protect islands from inundation on account of sea level rise in the future needs to be linked to the current local need for improved drainage to allow run-off. Currently there appears to be an understandable emphasis at the national level on coastal defences aimed at keeping the sea out. While this is acknowledged locally as important, it dwarfs other local concerns surrounding existing problems such as releasing water from an island into the sea through better drainage.

*Puddles on Viligili highlighting the lack of drainage*

**Box 4.1:** Examples of the Need for Both Improved Sea Defence and Drainage

An apparent design flaw in both the old and new Viligili harbour is easily observable. The public land next to the harbour is noticeably lower than the harbour front and has no gradient towards the sea or drainage channels. Any water that accumulates on the harbour front road, on account of waves overtopping the wall or through rainfall, is unable to drain back into the sea.

An illuminating example of the need for a multi-purpose system for coping with too much water is shown in the photograph below.

*Dug channel on Thinadhoo that is opened to allow water to escape, and at other times closed to prevent water from entering.*

The institutional "home" of the SIP within the Environmental Ministry is a key strength.

It is clear that environmental protection and disaster risk reduction go hand-in-hand in the Maldives. The health of the coral reefs, presence of vegetation on the islands, and the ability of the islands to go through natural accretion and erosion processes are an essential line of defence against disaster and climate risk. Indeed, these natural protection measures may prove to be the islands' last defence against sea level rise. As such 'soft' mitigation measures are beginning to gain more credence. Therefore an institutional framework that interlinks environmental protection and risk reduction is highly appropriate.

However, the institutional structure for the implementation of the SIP needs to be further integrated with broader development concerns.

Disaster and climate risk management are cross-cutting issues, and hence the SIP must not be considered solely as an environmental concern. If this is the case, some of the inter-connectedness of broader development concerns may be lost. This is especially a danger if environmental protection is not given a suitably high level of importance nationally, for example within the financial and planning ministries.

One of the objectives listed under NDP7's goal to protect the natural environment and make people and property safer is to 'develop 10 safer islands'. However, all development that takes place on islands (whether designated as safer or not) can reduce risk if it integrates climate and disaster issues. Conversely development that does not integrate risk assessment and reduction can undermine progress. The table below demonstrates the close links between disaster and climate risk reduction, and sustainable development, in relation to the NDP7 operational objectives for development. It is clear from the table that developing safe islands is not a stand-alone issue or objective. Indeed rather than thinking of it as an objective it ought to be thought of as an outcome of a development agenda that properly integrates risk assessment and reduction principles. In other words, if the other objectives in the table below are achieved, this will contribute significantly to the development of safer islands.

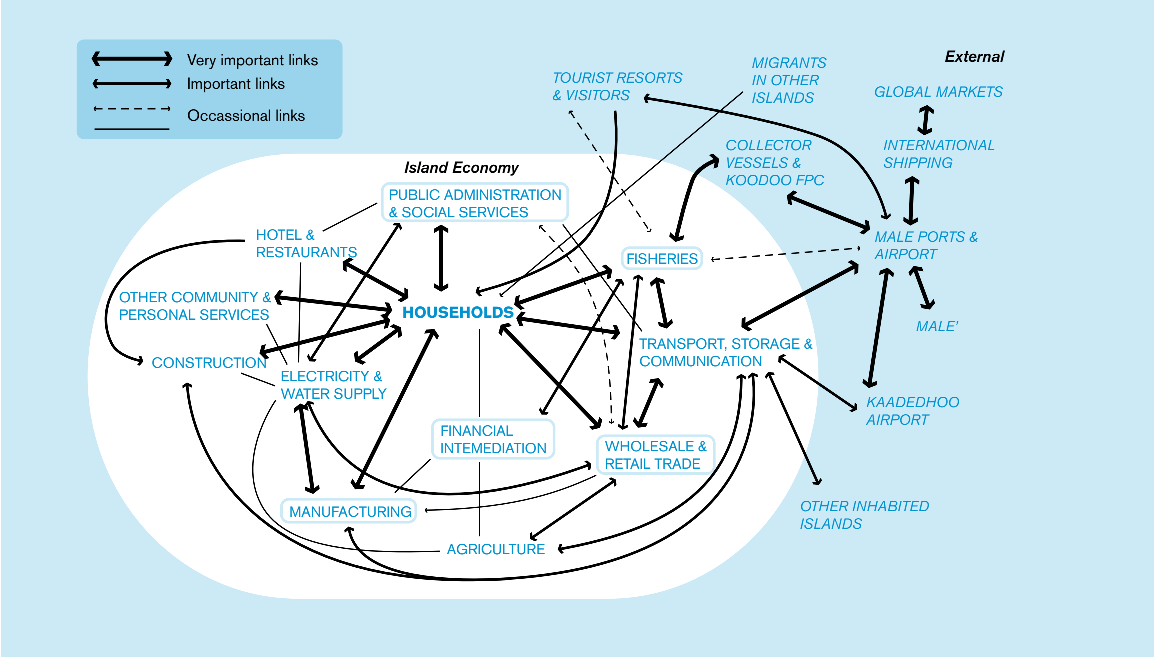
An emphasis upon the safer islands concept rather than the safer islands programme will help to support this message. It will be crucially important as further development policy and planning is agreed under the new government to make clear all such linkages.

**Table 4.1:** Linkages between Disaster and Climate Risk and Sustainable Development Objectives

| Objective | Link with disaster and climate risk |
|---|---|
| Ensure 75 percent of all inhabited islands have adequate solid waste management facilities | The study islands of Thinadhoo and Viligili have inadequate solid waste management. This was especially evident on Thinadhoo where a high level of waste disposal was observed across much of the island, despite there being a specific waste disposal site. Without the proper disposal and treatment of solid waste, drainage channels become blocked, increasing disaster risk, and health impacts increase vulnerability to impacts. Furthermore, improper waste disposal can result in pollution that causes deterioration of the coral reefs and thus defence against natural disasters. |
| Increase access to safe drinking water for 100 percent of the population | Local communities prioritized flooding (due to heavy rainfall and through wave action) as the biggest natural hazard concern they face. The worst impact of the flood water was expressed in terms of health impacts, as the freshwater lens becomes contaminated. Therefore the strategy to increase access to safe drinking water will require managing the flood risk. On the positive side, water harvesting with large water tanks is widespread. However with a prolonged lack of rainfall, access to safe drinking water can become compromised. An increase in dry spells is anticipated under climate change scenarios, and thus water harvesting will only increase in necessity. |
| Ensure all islands with population over 2,000 have adequate sewage treatment facilities | During flood events, sewage overflows and contaminates the freshwater lens, leading to health impacts for the community. As an example of the need for holistic solutions, Thinadhoo had sewage outlets on the north side of the original island but these were simply blocked when land was reclaimed. No alternatives were provided, and so the remaining sewage outlets now had to cope with additional requirements. As this did not work, and no new sewage pipes were installed, households took it upon themselves to dig their own sewage pits. Unfortunately these led to the contamination of ground water, with impacts on the wider community.<br><br>Improper treatment and disposal (many islands simply pump sewage directly into the lagoon) also contributes to a deterioration in reef health (as discussed above). |
| Give protected status to 5 percent of the coral reef areas | The health of coral reefs has direct affects upon the two most significant economic sectors in the Maldives: tourism and fisheries. Although the study islands do not have direct links with the tourism industry (although soon to be completed resorts in Huvadhu atoll could change this), the overall economy and thus the level of infrastructure and services in each individual island is closely affected by this industry. Fishing does account for the majority of people's livelihoods in the study islands. Furthermore, unlike public sector work (another very significant form of employment) that is relatively protected from fluctuations in income, if fishing is weakened this has knock-on secondary affects throughout the entire island community increasing islanders' vulnerability. Figure 4.1 below highlights these linkages.<br><br>Besides the livelihood benefits of a healthy coral reef, coral is the first line of defence against the impact of waves striking land (it acts to dissipate wave energy) and may also be the only realistic line of defence the Maldives has against sea level rise. |

*The dumping of waste in areas where the tide will wash much of it away*

**Figure 4.1:** Demonstration of the Economic Interlinkages within and between Islands




**Source:** Shaig (2009a)

## The institutional structures for systematic coordination for DRR are in their fledgling stages…

Many of the mechanisms for DRR have been established as a result of the tsunami and hence are fairly new, such as the National Disaster Management Centre. These initiatives will require strengthening, and more work will be required to develop the institutional structure and emphasise prevention. Box 4.2 below describes some of the numerous institutional challenges that are faced at the national level as found in the Maldives National Capacity Self Assessment Report and Action Plan for Global Climate Change, Biodiversity and Land Degradation Conventions. While these are not specific to the SIP, they will nonetheless be very relevant.

**Box 4.2:** Institutional Challenges at the National Level in the Maldives

**National Policy, Legal and Regulatory Frameworks** - The policy frameworks are not effectively synchronized across sectors, leading to a lack of coherence and sometimes contradictory regulations and policy guidelines.

**Institutional Mandates, Coordination and Cooperation** - Responsibility is spread across different ministries, often with overlapping mandates, or gaps in mandates.

**Management and Performance** - Weak management and inadequate human resources limit organizational effectiveness. Lack of transparency and accountability is also a concern.

**Financial Resources** - Financial resource allocations at all levels, within organizations, at national levels, and at atoll levels, are inadequate.

**Information Management** - The access to and delivery of critical and timely information for decision-making and public awareness is seriously limiting.

**Monitoring and Observation** - There are no arrangements for the systematic collection of data and analyses for reporting purposes.

**Source:** Maldives National Capacity Self Assessment Report (Government of Maldives, 2009)

## … but this is balanced by government acknowledgement and commitment to developing institutional capacity.

There is acknowledgement of the shortfalls and the need for progress at a national level. The Maldives National Strategy for Sustainable Development (2009) plainly states: “The main challenge is to change the…non-integrated approach to policy-making. This requires all levels of government to support, and to cooperate with each other, taking into account the different organisational settings and strategic objectives. An Impact Assessment (IA) process of development must have adequate and meaningful public and stakeholder consultation and participation.” This is most welcome and a good platform from which to build.

## Methods to improve resilience and mitigate losses and disruption caused by natural hazards have a high level of priority at the local level.

Focus groups in the study islands suggest that local people have a strong understanding of impacts and vulnerabilities related to climate and disaster risk (although this was seriously undermined due to the radical changes made to the physical environment on Vilufushi). Indeed, some people expressed strong insights into causes of risk and methods to alleviate this – not based solely on hazard control (such as sea walls) but also on the strengthening of livelihoods and reduction in illness.

> *“If we take measures regarding the priority risks (by concentrating efforts to alleviate risk and damage caused by flooding whether through heavy rainfall, wave action or both), then we will be better able to deal with tsunami (which was low on the list of islanders priorities).”*
>
> *- principal of a school on Thinadhoo*

However, 'disaster' is a term that can appear too strong for the experience of people on most islands. Other than a few unusual experiences in recent years and the tsunami that is recognized as a rarity, inhabitants have not traditionally thought of the islands as disaster prone. However they do experience hardship due to their vulnerability to natural hazards that cause damage and disruption. As a consequence, reducing impacts is a high priority at the local level. This was evident by the high turnout of people (approximately 50), representing a very broad cross-section of communities on the island of Thinadhoo, at short notice (less than 24 hours) for a meeting on disaster and climate risk that ended at 11pm. Thinadhoo was not seriously impacted by the tsunami.

However, local capacity to implement risk reduction measures is lacking.

The National Capacity Self Assessment Report (Government of Maldives, 2009) highlights, through experiences with the Atoll Ecosystem Conservation Project, a limited capacity at the local level to deliver projects. The potential to use community-based models will therefore, it is argued, require added capacity to coordinate local and regional initiatives in conjunction with decentralisation policies. Picking up on this issue, the commencement of the NAPA programme 'Integration of Climate Change Risks into the Maldives Safer Island Development Programme' helpfully focuses on major improvements in technical capacity and information for climate change adaptation and 'Safer Islands'.

Furthermore, there has been a dearth of engagement with people at the local level in land use planning, land reclamation and other development activities of major relevance to the concept of safer islands.

For example, on Viligili, the Island Councillor had not been consulted on the land reclamation activities recently undertaken and did not know what facilities were planned, or where they were to be sited. This implies a serious lack of local participation across the population of the island. It appears islanders passively wait on the decision-making process rather than have the opportunity to engage in it. On Thinadhoo, it was reported that people raised their concerns at the national level regarding land reclamation proposals, but nothing was done. From a local perspective, despite the large sums of money spent on land reclamation, there was a negative impact on local communities.

The participants at a community meeting on Thinadhoo felt that a replication of this meeting with its diverse representation of different social groups on the island would be an appropriate starting point for national level planning and resource allocation decisions to connect with local agendas and concerns (see Section 3.2.6).

At the national level there is acknowledgement that former actions were dominated by top-down thinking and lack of participation, including with regard to the relocation of residents back to the newly reclaimed Vilufushi, and a new willingness to now engage in a more consultative process as part of the decentralisation agenda. Coordinated planning between national and local levels will require a process to nurture and develop relationships between stakeholders.

| **Priority 2** | Identify, Assess and Monitor Disaster Risks and Enhance Early Warning |
|---|---|

- Establish an initiative for countrywide risk assessments
- Review the availability of risk-related information and the capacities for data collection and use
- Assess capacities and strengthen early warning systems
- Develop communication and dissemination mechanisms for disaster risk information and early warning

A number of significant initiatives have been undertaken to identify risk in the Maldives.

The UNDP, in collaboration with the Government of the Maldives, undertook a comprehensive assessment of risk for all islands in the Maldives in 2006 (UNDP, 2006). The study determined the probability of hazards occurring across different regions of the Maldives, and then assessed physical and social vulnerabilities to these hazards, to identify those islands most (and least) at risk. This study has been followed up by the two risk assessment reports, DIRAM1 and DIRAM2, which conducted detailed risk assessments for nine of the islands.

However, the findings from these risk assessments have not formed the basis, or even a significant component, of the selection process for potential 'safe islands'.

There appear to be at least two major agendas that form a vision for the future of the country: the development of regional hubs as part of a decentralisation process, and the protection of islands against disaster and climate risk (the underpinning of the safer islands concept and the rationale behind developing carbon neutral islands). However, it appears that the first is in the 'driving seat'. From the outset of the SIP concept the criteria for island selection was laid out as being[3]:

- Ease of access to an airport;
- Sufficient space and potential for reclamation and/or the possibility for connection with another island;
- Viable economy and social services; and
- Sufficient space for subsequent population growth.

Of course it is important to be pragmatic. The existence of large population bases in certain islands/atolls (Thinadhoo has a population of 4,442[4] making it one of the largest population bases in the country and Viligili has a population of 1,976[5]) with the accompanying services, industry and infrastructure cannot be sidelined and ignored in favour of relocating to islands offering the potential for greatest safety. Indeed, relocating to an uninhabited or sparsely habited island currently deemed to be safest would no doubt significantly alter exposure to risk. Furthermore, it is more financially feasible to protect islands that have a greater population base.

However the down side is that 'developed' islands are not necessarily top choice for a safe environment. For instance, the DIRAM project highlights that Thinadhoo may be particularly vulnerable to sea level rise due to the artificial nature and the substantial alterations brought to the natural processes around the island. Development could well have increased risk. The subsequent land reclamation and dredging around Viligili presumably will have similar consequences. This latest development activity further aggravates the earlier startling findings by UNDP (2006) that Viligili had the highest physical vulnerability risk on a multi-hazard basis.

*Newly reclaimed land on Viligili showing the uniform height and straight line of the sea defence, combined with a lack of vegetation or 'environmental protection zone'. The original natural island is visible to the left of the picture, where vegetation is established. The reef edge is visible to the right, where the waves are breaking, indicating the increased exposure of the new land.*

[3] Draft concept note safe islands, 21 January 2005

[4] Figure based on 2006 census

[5] Figure based on 2006 census

High levels of physical risk are not the only drawback in selecting these islands as suitable safe ones. Of the nine ‘safer islands’ studied during the DIRAM project, Viligili was found to have a particularly poorly diversified economy: yet a diversified economy and livelihood base is a common and effective method of reducing risk. Hence any efforts at improving resilience begin from a lower starting point.

These issues are further complicated by the designation of “carbon neutral” islands. But again, the selection process appears not to be based on or influenced by hazard exposure and risk profile criteria. The development of carbon-neutral islands, as a ‘flagship’ demonstration to no doubt encourage international commitment to climate change mitigation and presumably commitment to supporting adaptation among the Maldives, has obvious overlaps with the safer islands concept - there is little point in a carbon-neutral island suffering flooding on a regular basis and eventually becoming inundated by the sea. But are these islands most appropriate as ‘safe islands’ or most appropriate as ‘carbon-neutral islands’?

A full understanding of risk is limited by the lack of historical hazard data and a significant gap in research capacity on climate risks.

It is not clear that there is any government team with primary responsibility for monitoring and modelling future climate risk for the Maldives, and yet this type of information will be critical to understand risk and design effective response strategies. This is compounded by difficulties in accessing historic hazard information.

While early warning is clearly a national priority, the lack of a culture of local participation in decision-making will hinder the establishment of an effective system.

NEAP3 states a clear priority “to make Maldivians safe and secure from natural disasters through information dissemination and planning and co-ordination of national response actions”. Box 4.3 describes some of the specific targets in relation to this priority, including the establishment of an early warning system.

**Box 4.3:** NEAP3 Targets on Information Dissemination and Planning

- By mid 2010, establish a national early warning system to disseminate warnings of natural disasters
- By 2010, establish website and public information systems including fact sheets and awareness materials on natural hazards and disasters
- By mid 2010, develop a National Disaster Management and Mitigation Plan

Early warning is most effective when it links scientific and macro level data with indigenous knowledge and local aspects, and it must be ‘people-centred’. Science based prediction is of little use if it cannot be disseminated in a way that is clear and understandable to the people who are being affected. And those people need to have means to avoid the threat – options for protection of assets and evacuation. Therefore this process could be hindered by the current lack of a culture of local participation in decision-making processes.

| **Priority 3** | Use Knowledge, Innovation and Education to Build a Culture of Safety and Resilience at all Levels |
|---|---|

- Develop a programme to raise awareness of disaster risk reduction
- Include disaster risk reduction in the education system and the research community
- Develop disaster risk reduction training for key sectors
- Enhance the compilation, dissemination and use of disaster risk reduction information

In sharp contrast to national level perspectives that risk awareness is low at an island level, island consultations found that local people are already familiar with hazard and climate risk.

On the one hand, it is documented that there are "extremely low levels of awareness and knowledge" regarding disaster and climate change risks (for example in the National Capacity Self Assessment report (Government of Maldives, 2009) and the NAPA), and this opinion also appears to be a common perception articulated during meetings at a national level. However, this was not the impression gleaned from discussions on the study islands of Thinadhoo and Viligili. For example, representatives of Viligili attending a meeting to discuss the safer islands concept were first asked to discuss with their neighbour which of the natural hazards was of most concern, and prioritise them. Very quickly the group responded that it was not necessary to discuss this first, as people regularly discussed these matters and they already had a shared opinion to report.

**Box 4.4:** Examples of Local Awareness and Action to Reduce Risk

The tsunami, although a rare event, acted as a catalyst for action to deal with more common seasonal threats. Although representing a small proportion of total housing stock, the non-traditional building of taller houses (2-3 storeys) and other buildings is now quite common on Thinadhoo and Viligili islands. No doubt much of this change to building style is un-related to tsunami risk (or sea level rise) and the need for vertical evacuation; or perhaps tsunami risk is of less importance than a desire to have a larger house in its own right. But tall buildings represent a change in custom. This bodes well for the development of the SIP. If awareness of need is present, then a willingness to alter traditional approaches can occur. The incentive is improved safety, but coupled with other aspirations.

Another example of people's willingness to adapt to changing circumstances is apparent on Viligili where the majority of houses and shops have a raised plinth. This has been a design modification to help deal with the regular problem of flooding, largely caused by poor drainage: Again, first awareness then action.

*Typical street on Viligili with an example of the construction of taller buildings*

It was interesting to note that climate change – often portrayed and thus perceived as a future problem (as opposed to a current day problem) – was already understood to be a pressing concern. This was due to observed variability in the weather. For example, one person offered anecdotal evidence that whereas in the past it was fairly safe to assume that the winds would predominantly blow strongly in a certain direction at one time of year and then blow strongly in the opposite direction at a later period (used by Maldivians in the past to aid passage to and from Sri Lanka), now it is much harder to predict the weather. However, this local awareness of risk has not been supported and build upon through the dissemination of information obtained through national level studies (for example, UNDP reports).

However large-scale land reclamation on Vilufushi has left people detached from their physical environment and lacking in risk awareness.

In contrast with the other study islands, Vilufushi has undergone major land reclamation activities that have dramatically altered the original natural island size, shape and height. As a result, the relocated population have little awareness and appreciation of the disaster and climate risks that they may now be exposed to. It remains to be seen which areas are most exposed to wave and wind action, flooding and drainage problems. This seriously undermines local coping capacity. More positively however, the upheaval that the Vilufushi community have shared collectively in the immediate aftermath of the tsunami and during the subsequent period of uncertainty has generated a strong community bond.

There is an awareness at the local level of the linkages between environment and disaster risk.

A very significant relationship exists between environmental management, sustainable livelihoods and disaster/climate risk reduction. Encouragingly, there is an awareness of environmental sustainability issues at the local level. For example, on Thinadhoo a school principal made the following statement: "Environmental degradation may be the cause of the flooding." A fisherman also articulated the links between the environment, his livelihood and disaster - following the land reclamation on Thinadhoo and the dredging of a channel, he expressed two concerns:

1. There is now a lack of natural defence;

2. There are now significant erosion and accretion problems, with the latter affecting the health of the reef on the west and north sides of the island. In turn this affects the reef fish, which then undermines his livelihood. Furthermore, he noted that an unhealthy fishing industry is bad news for the island as a whole that depends on it so much.

He advocated for environmental impact studies to be undertaken before any activity like this is implemented.

Risk awareness will be an essential component of successful relocation of populations to safer islands.

Relocation, no matter how voluntary, will be a contentious issue. Here again, heightened awareness of the risks combined with the development of safer islands could be deployed as an incentive to relocate, as well as acting as an entry point for discussion with existing populations to gain consensus.

The government's successful birth control awareness campaign may be able to provide useful lessons. It was suggested that highlighting the costs of a large family was the 'tipping point' in terms of people's willingness to engage in birth control to reduce family size – awareness was key to successful engagement with the programme. Likewise, awareness raising and dissemination on the benefits of relocation and population consolidation for all involved (for example evidence on the improved standards of living and protection against regular disruption through natural hazard impacts, which currently account for an estimated staggering 60% of household income per year[6]) could help to gain buy in. 'Demonstration projects' highlighting benefits was mentioned by the Ministry of Housing, Transport and Environment as one tool that could be deployed to aid this process.

There is an urgent need for introducing school safety programmes in all the islands.

School safety programmes have been highlighted in numerous parts of the world as a highly effective means for promoting a culture of safety in the community, as aside from applying knowledge in their own lives, school children share lessons learned with the rest of the family. It has been proposed by UNDP (2006) that educational programming should cover multiple hazards, and include the following components: training of teachers and students, formal curriculum-based education, non-formal aspects such as school disaster management plans, preparedness drills, and structural and non-structural mitigation exercises.

[6] Figure derived from consensus of opinion of a small group of fishermen and others on Thinadhoo.

| Priority 4 | Reduce the Underlying Risk Factors |
|---|---|

- **Environment** - Incorporate disaster risk reduction in environmental and natural resources management
- **Social needs** - Establish mechanisms for increasing resilience of the poor and most vulnerable
- **Physical planning** - Establish measures to incorporate disaster risk reduction in urban and land-use planning
- **Structures** - Strengthen mechanisms for improved building safety and protection of critical facilities
- Stimulate disaster risk reduction activities in production and service sectors
- **Financial/economic instruments** - Create opportunities for private-sector involvement in disaster risk reduction
- **Disaster recovery** - Develop a recovery planning process that incorporates disaster risk reduction

### Despite a clear awareness of the linkages between environmental degradation and disaster risk, poor environmental management of human activities has increased the vulnerability of islands.

Human activities such as land reclamation, the construction of poorly designed coastal infrastructure, poorly engineered coastal protection measures, removal of coastal vegetation, and sand mining, appear to have been dogged by a narrow 'single purpose' focus rather than upon their potential much more significant and wider negative impacts. Furthermore the multiple benefits of a protected environment appear not to have been considered or were outweighed by a perceived single benefit of an expensive man-made activity (that, unlike the natural environment, also requires regular maintenance).

For example, it is worthwhile noting that for Viligili, the DIRAM project discussed proposed land reclamation and other related activities (see Box 4.5 below), whereas this review was undertaken shortly after the land reclamation had occurred. Although no detailed survey was undertaken, it appears that none of the recommendations made in the DIRAM project were applied to the new land reclamation. The impact seems to be creating risk – for instance the dredged material used to form the reclaimed land on Viligili led to the building of a raised 'road'. This blocked what used to be a fast-flowing channel connecting the open ocean and the atoll, and will among other changes likely result in increased erosion.

Indeed, Shaig (undated) notes that land reclamation and access infrastructure development are two of the most destructive activities carried out in the Maldives but are virtually excluded from environmental assessment regulation. Perhaps ahead of any other issue, it is imperative that risk reduction and environmental management are integrated into land use planning.

**Box 4.5:** Negative Effects of Land Reclamation on Environmental Defence

The DIRAM report highlights the following concerns relating land reclamation and its impact on the environment and associated increase in risk:

- The implications for moving the coastline close to the reef edge may increase the chances of wave overtopping and flooding during severe weather events;
- Rapid onset erosion can occur at specific points, especially at the end points of coastal protection, resulting in a possible prolonged continuation of the erosion and accretion processes;
- Damage to the outer reef can occur, reducing defensive capacity;
- The composition of soil can change in relation to its suitability for vegetation and drainage;
- The elevation of reclaimed land can aggravate existing drainage concerns;
- The artificial shape of reclamation has implications for wave action and foreshore currents;
- The flat elevation of reclaimed land may not be the most efficient topography for a functioning drainage system.

### The lack of a systematic EIA process is a critical factor in increased risk.[7]

Environmental Impact Assessments (EIAs) of proposed land reclamation projects do not appear to be systematically applied, and hence the wider impacts of projects are poorly understood. Thus while achieving one goal, in this case increased space, other development goals (protected ground water and good health, environmental protection, social cohesion, etc.) can be undermined. When links with disaster and climate risk (established through a thorough assessment process) are not factored into decisions, risks may increase.

Out of over 90 inhabited islands reclaimed, only 3 islands have had a formal EIA. Furthermore, environmental impacts on other inhabited islands were ignored or visually assessed based on a single field visit by an Environment Ministry's official (Shaig, undated).

[7] MEMP is supporting a pilot Regional Strategic Environment Assessment along with the national GIS, which will act as a guidance framework for EIAs. The RSEA and GIS installation are expected to be completed by end of 2010. Although the RSEA is focused on the North Province, it is foreseen that the alternatives considered in the RSEA will be similar to other regions.

**Box 4.6:** Example of Physical Risk Creation

A lack of consideration for hazard exposure appears to have occurred regarding the construction of both the older and new[8] harbours on Viligili. The harbours are on the west side of the island. This is the side that is exposed to the prevailing weather and thus most wave action. However, both harbours have very large entrances that expose sections of the harbour front to the force of the natural elements. The effect of this is evident by the dropping / slumping of the paving surface as the hardcore and other material used as foundation is being eroded from beneath the water line. Locals take it upon themselves to rectify the surface from time to time in this constant battle to keep up with nature's forces. Was a modified angled entrance to the harbour considered at feasibility stage? Was a local assessment (environmental impact, bathometry, wave direction, boat owners/users insights etc) undertaken at feasibility stage, and this design agreed upon by all stakeholders?

*Viligili harbour wall and entrance facing the prevailing weather and showing clear signs of wave damage that occurred in January 2008*

[8] The new harbour was built at the same time as the land reclamation project.

In particular, human activities are degrading coral reefs and coastal vegetation – and yet these are critical lines of defence against disasters and the reduction of risk.

Coral reefs have a critical coastal protection function as well as being the basis of a healthy fishing and tourism industry (see Box 4.7 below), yet there have been a number of human stresses on the reef system such as coral mining, reef entrance blasting, dredging, solid waste disposal and sewage disposal that has affected the health, integrity and productivity of the reefs. This history would explain why one of the environmental targets of the 7th National Development Plan was to "reverse the loss of environmental resources". However this history does not explain the continued reliance upon man-made structures developed with scant regard for their environmental impacts as a part of SIP.

**Box 4.7:** The Protective Role of Coral Reefs

The protective role of coral reefs is more evident during storm events than tsunamis (Cochard et al. 2008). Nevertheless, reports from the 2004 tsunami describe that in areas fringed by coral reefs waves were significantly smaller and reached relatively short distances inland when compared to areas without coral reefs (where waves were up to 10m high and reached 1.5km inland) (UNEP-WCMC 2006).

A reef's capacity to protect shorelines during storms by dissipating wave energy depends on the local reef profile (depth, slope and shelf width (Woodley et al. 1981)), reef continuity (Sudmeier-Rieux et al. 2006) and area (UNEP-WCMC, 2006). In addition, the outer structure of the reef, the reef structure itself and the variation of topography along the reef strongly influence wave dispersion along the reef (Brander et al. 2004). Sediment redistribution along coastal areas is related to terrace width. Broad terraces dissipate greater energy than narrow ones (Sheppard et al. 2005; Woodley et al. 1981). Pertinent to the Maldives, it was found during studies in the Seychelles that a reef with width of 500m dissipates most of the wave energy. This statistic challenges the common land reclamation activities that significantly reduce the distance to the reef edge.

The general feeling regarding a reef's capacity to cope with sea level rise, raising sea temperatures, plus storm impacts, pollution and other pressures is pessimistic (Gardner et al. 2005 and Salazar-Vallejo, 2002). However, Salazar-Vallejo (2002) and Rodrigues-Ramirez (2003) do report reefs that have recovered from recent severe disturbances in the Caribbean, particularly in areas under less anthropogenic (i.e. human activity) pressures.

**Source:** ProAct Network (2008)

Furthermore, based on the nine islands studied in the DIRAM project, it was observed that strong coastal vegetation is amongst the most reliable natural defences of an island at times of ocean induced flooding, strong winds and against coastal erosion. This was endorsed during fieldwork on Viligili. In relation to the impact of the tsunami – which was considerable on this island on the eastern rim of the atoll – it was explained that where there was good natural vegetation cover the tsunami had less impact. However the newly reclaimed land on the eastern side of the island currently has extremely minimal vegetation (little more than two small saplings that would have no buffering benefit what so ever – see photograph in section on Priority 2 above).

The removal of naturally occurring wetlands so as to create more habitable space is having negative implications in terms of drainage, flooding and contamination of ground water. Exacerbating these concerns, the proposal under the SIP concept of raising specific areas to form evacuation zones will likely have detrimental affects on other areas through impacts upon already poor drainage.

*Sewage outlets into shallow water above the coral reef on Thinadhoo*

*Vegetation on the north side of Viligili, currently being removed to make space for house building*

## There is a lack of evidence that environmental policy adequately influences practice.

The above points regarding the increase in islands' vulnerability on account of human activities lead us to conclude that rhetoric on environmental protection is in many cases stronger than actions. In broad terms, there is widespread acknowledgement of the need for environmental protection. For example, in 1992, the Maldives ratified the United Nations Convention on Biological Diversity (UNCBD) and a National Biodiversity Strategy and Action Plan of the Maldives (NBSAP) was prepared the same year. Subsequently the Maldives Protected Area System Project (MPAS) commenced design in 2002-03 and the current Atoll Ecosystem Conservation Project (AECP) is intended to further develop this system[9]. However, the lack of integration of environmental concerns into development activity, as evidenced above, suggests that these strong policy positions need to be more clearly put into practice and integrated within other development agendas.

## The importance of social cohesion for vulnerability reduction currently appears of minor importance in comparison with physical mitigation.

Integration of social groups within a consolidated population will be essential for the development of land use plans through a process of full participation with affected groups. Without such a process one can imagine how problems can be introduced or at least exaggerated. On a broader note, anxiety already exists regarding who will 'take advantage' of existing good quality services and facilities: Will a consolidated population mean improved services for all, or just some, or a deterioration in services (at least in the short term)? At first these issues may not appear to be relevant to disaster and climate risk. But influences upon the degree of social cohesion are crucial for disaster management, including the development of shared contingency plans, effective response to disaster, and protection of the most vulnerable.

## Stronger connections are needed between all the different elements that contribute to the overall resilience of an island.

A comprehensive risk management approach is required to ensure that the different measures introduced to improve the safety of islands are self-supporting, dynamic and stronger than their individual elements. In particular, despite their extreme importance, soft measures that emphasise vulnerability reduction are very commonly disregarded, forgotten or not understood. In many respects, trying to 'control nature' has commonly been a more politically comfortable strategy than accepting and dealing with underlying risks and vulnerabilities caused by human activity.

[9] Information based on National Capacity Self Assessment (Government of Maldives, 2009)

**Box 4.8:** Importance of Local Ownership*

The importance of the need for strong connections between social, physical and environmental aspects to achieve resilience have quickly become apparent on Viligili. Here the recently reclaimed land in the east is higher than the original natural island and a channel has been constructed to aid drainage. Unfortunately, while this channel is only months old, it is already becoming overgrown with vegetation in many parts and showing other signs of neglect. Pools of stagnant water are the most obvious signs that the channel is not performing. This example is important. Beyond the construction of mitigation measures as per a standardized safer islands 'toolkit', local populations must be engaged in the importance of such measures and have input into the decision-making process. Otherwise their effectiveness will be compromised. For mitigation measures to be sustainable it is imperative to have local ownership and commitment to ensure success - including through regular maintenance.

Drainage channel on Viligili next to reclaimed land (on left)

Drainage channel on Viligili with water logging

Based on these experiences and international best practice, it is imperative that safe islands are not developed based on a standard set of designs. This applies to both physical mitigation measures (as emphasized in the DIRAM reports) and importantly social mitigation too. For example, a constant ridge height for all safe islands is inappropriate, as it does not account for the complexity of local conditions. Likewise, the decision-making surrounding who should be responsible for sustaining the SIP at island level and representing local needs at the regional and national level can not be determined from anywhere but among the local inhabitants.

*A coastal erosion monitoring system is being setup by EPA, based on study undertaken by Dr. Paul Kench. The final report have been received identifying environment friendly engineering options to prevent coastal erosion. Similar community based monitoring is being designed with consultants for Terrestial Ecosystems, Coastal Zone, Reef fisheries, Coral and bait fisheries targeted at North Province. The monitoring will be undertaken by the community under guidance and training provided by EPA.

| Priority 5 | Strengthen Disaster Preparedness for Effective Response at all Levels |
|---|---|

- Develop a common understanding and activities in support of disaster preparedness
- Assess disaster preparedness capacities and mechanisms
- Strengthen planning and programming for disaster preparedness

### There is a clear commitment towards implementing disaster preparedness measures, but progress is slow.

While specific recommendations to enhance the disaster preparedness capacity of the country have been put forth, especially since the tsunami, these do not appear to be heavily prioritised. For example, an early warning system has been much talked about, but is far from readiness. To a degree this is understandable. While the Maldives is disaster-prone, it is not subjected to regularly occurring hazards that result in loss of lives and livelihoods. Further, the very significant impacts associated with climate change are perceived to occur incrementally over a relatively long period of time, and hence "preparedness" is not as relevant as risk reduction. It may be necessary therefore to re-consider the relevance of 'disaster preparedness' at this juncture and perhaps link response to disaster more directly with other threats to the country.

### A critical evaluation of the proposed disaster preparedness components of the SIP may be required.

The SIP concept includes several components relating to disaster preparedness, as follows:

- Speedy access in emergencies (e.g. distance to an airport);
- Alternative modes of communication and energy in emergencies;
- Established safe zones (e.g. high ground);
- Buffer stock of basic foods and water; and
- Disaster management plans.

The relevance of these measures requires careful evaluation.Table 4.2 highlights some areas for further thought.

**Table 4.2:** Effectiveness and Sustainability Concerns Regarding Current Disaster Preparedness Proposals

| Disaster preparedness component of the SIP | Issues for consideration and debate |
|---|---|
| Speedy access in emergencies (e.g. distance to an airport) | Improved transportation links between islands is an important aspect of sustainable development within the Maldives. Indirectly this will no doubt improve the resilience of individual islands. However assuming, as seems the case in the SIP, that short distance to an airport automatically equates with improved disaster preparedness could result in an over-reliance upon this facility. For example, if the airport itself is damaged or inundated by floodwater itself, then its capacity to offer aid in an emergency will be compromised. Likewise, if boats are damaged in a storm then access to an airport on a nearby island will not be possible. |
| Buffer stock of basic foods and water | The provision of buffer stocks will have very obvious benefits in the case of a part of the world where people are regularly forced to evacuate their homes. In the case of the Maldives this is currently a low likelihood event. Therefore, is this a practical strategy? If so, where will buffer stocks be located and who will be responsible for ensuring their quality and availability when needed? Who will have responsibility for ensuring equitable distribution? Such a system requires detailed forethought, awareness raising, training and community drills. Long-term funding to maximise benefits is thus essential. This investment in regular preparedness activities would be crucial – particularly when disaster events are rare, and to take account of changes in people's roles over time. For this and other similar disaster preparedness activities, lodging their development and maintenance within a body that has a year-round regular function is a key to success. An island development committee could be one such idea. |

## A Draft Framework for the SIP

The Maldives is at a very important crossroads in its history. Never before has it faced such a threat as it does now on account of climate change. Decisions made today will have the most significant of consequences for the country's tomorrow, and no doubt these will be reflected upon internationally many years from now. The opportunity to tackle this threat at this key moment falls upon a new government. Fortunately the new government is fully aware and committed to action in the fight against climate change. The SIP must be at the heart of this action.

The review of the SIP has highlighted numerous strengths and weaknesses in the overall concept and approach to risk management (see Box 4.9 below). This section proposes a draft framework to take forward the development and implementation of the SIP, formalising the concept into policy by building upon the identified strengths and proposing means to address the challenges.

**Box 4.9:** Summary of Key Findings of the SIP Review

- Concerns regarding sea level rise, combined with the devastating impacts of the 2004 tsunami, are ensuring that developing resilient islands is a national level priority. However, there is often a mismatch between national and local priorities for risk reduction.
- The institutional "home" of the SIP within the Environmental Ministry is a key strength. However, the institutional structure for the implementation of the SIP needs to be further integrated with broader development concerns.
- The institutional structures for systematic coordination for DRR are in their fledgling stages, but this is balanced by government acknowledgement and commitment to developing institutional capacity.
- Methods to improve resilience and mitigate losses and disruption caused by natural hazards have a high level of priority at the local level. However, local capacity to implement risk reduction measures is lacking
- Furthermore, there has been a dearth of engagement with people at the local level in land use planning, land reclamation and other development activities of major relevance to the concept of safer islands

- A number of significant initiatives have been undertaken to identify risk in the Maldives. However, the findings from these risk assessments have not formed the basis, or even a significant component, of the selection process for potential 'safe islands'. A full understanding of risk is further limited by the lack of historical hazard data and a significant gap in research capacity on climate risks.
- While early warning is clearly a national priority, the lack of a culture of local participation in decision-making will hinder the establishment of an effective system.

- In sharp contrast to national level perspectives that risk awareness is low at an island level, island consultations found that local people are already familiar with hazard and climate risk, as well as the linkages between environment and disaster risk. However large-scale land reclamation on Vilufushi has left people detached from their physical environment and lacking in risk awareness.
- Risk awareness will be an essential component of successful relocation of populations to safer islands.
- There is an urgent need for introducing school safety programmes in all the islands.

- Despite a clear awareness of the linkages between environmental degradation and disaster risk, poor environmental management of human activities has increased the vulnerability of islands. The lack of a systematic EIA process is a critical factor in increased risk, and there is a lack of evidence that environmental policy adequately influences practice.
- In particular, human activities are degrading coral reefs and coastal vegetation – and yet these are critical lines of defence against disasters and the reduction of risk.
- The importance of social cohesion for vulnerability reduction currently appears of minor importance in comparison with physical mitigation.
- Stronger connections are needed between all the different elements that contribute to the overall resilience of an island.

- There is a clear commitment towards implementing disaster preparedness measures, but progress is slow.
- A critical evaluation of the proposed disaster preparedness components of the SIP may be required.

### 4.1.1 Guiding Principles

The following guiding principles will need to be factored into all steps of the development and implementation of the SIP, and will be essential to improve and sustain the resilience of the country to risk.[10] If these are accepted as core aspects of development policy and practice then the country will have taken a very important step on its roadmap towards a safer future.

In particular the three most significant principles that have emerged through the SIP review are:

1. Widespread consultation and participation in decision-making must be undertaken, with special emphasis upon improving the engagement of stakeholders at island level. Participatory approaches can more effectively capitalize on existing coping mechanisms and are effective at strengthening community knowledge and capacities. They are usually more sensitive to gender, cultural and other context-specific issues.

2. Human activities that damage the natural environment must be minimised, and where damage has occurred already this needs to be rectified wherever feasible. This will help to avoid the creation of risk. A key indicator will be whether all activities are subject to full Environmental Impact Assessments (EIAs) and monitoring.

3. The SIP must be integral to all development policy and planning and not an optional extra. Therefore the SIP should be a multi-sectoral initiative, which will require significant levels of coordination across a number of government ministries and among a broad cross-section of other stakeholders. It is important for its effectiveness and sustainability that the SIP is integral to land use planning, improved natural resource management, upgrading of infrastructure, sound environmental practices, development of transportation and communication routes and the overall decentralisation process to a series of regional/provincial hubs, to name but a few high profile issues. If the SIP is undertaken as a separate agenda, experience concludes that it will undoubtedly struggle to compete with other plans, and some development activities may actually create risk.

Further principles that should be applied include:

4. A multi-hazard approach should be adopted, as this is best suited to reduce disaster and climate risk.

5. Decentralized responsibility and budgets for adaptation and DRR should be used to help respond to specific local needs and bolster local participation.

6. Ensure that the most vulnerable groups are targeted, with particular attention to gender impacts and the provision of appropriate adaptation measures that build the resilience of both men and women.

7. Capacity building should be a central strategy, with a particular focus on key stakeholders at both national and island level.

8. Public-private partnerships for risk reduction should be sought.

9. Reduce existing vulnerabilities to current climate events as an entry point regarding adaptation to climate change and ensure that building climate resilience in the Maldives is not completely dominated by tackling sea level rise alone.

### 4.1.2 The Development of a SIP Framework

It is proposed that three steps are required to develop the SIP framework into national policy, and these are described in greater detail in turn:

- **Step 1** – Develop a National Level SIP Strategy/ Policy.
- **Step 2** – Develop a Short List of Potential Safe Islands.
- **Step 3** – Select Safe Islands and Develop Island-specific SIP Strategies and Implementation Plans.

[10] UNISDR (2007) has documented a set of basic guiding principles.

### Step 1 – Develop a National Level SIP Strategy

Rather than continue with the development of the SIP based upon the current planned and proposed development interventions and risk reduction measures (e.g. means for vertical evacuation, raised ridges, etc.) and the seemingly ad hoc selection of potential safer islands themselves, it is suggested that it is necessary to first gain or enhance widespread commitment to the concept. Therefore the first step would be to develop a concrete national level SIP strategy through a process of widespread participation. A process of consultation, for example, consultation workshops on the development of the strategy for the SIP with representatives from national and local government, NGOs, the private sector, as well as soliciting comments and feedback at key stages, will give the SIP a firmer foundation based on a weight of consensus.

The multiple stakeholder work focused upon the development of the national level SIP strategy would need to define the following:

- The objective of the SIP. This could be aligned with the Hyogo Framework for Action (incorporating climate change aspects) so as to be based upon international best practice.
- An action plan for the implementation of the strategy. This would need to detail who carries out tasks, when these are to be achieved and how this is to be accomplished. Issues that could be covered include:
    - The necessary legal[11] and institutional framework including the mechanism for establishing a national coordination body and clarifying/establishing links with the new Strategic National Action Plan (SNAP) for disaster risk reduction and climate change adaptation (Guzman, 2009);
    - The establishment of criteria for selection of potential safe islands (see Step 2 below), ahead of a more thorough island level assessment. An important element of this for national level debate would be the identification of local governance and capacity necessities. A proper consideration of how the SIP concept dovetails with, or indeed influences, the decentralisation agenda and the proposed island "clusters" idea would also be core;
    - Capacity building needs at national level;
    - The scope of a public awareness campaign linked with a discussion on incentive-based relocation;
    - A framework for international assistance; and
    - Plans for a monitoring and evaluation system.

[11] The new Disaster Management Bill must be fit for purpose based upon a holistic approach to risk reduction with emphasis upon long-term preventative action as well as response and recovery.

### Step 2 – Develop a Short List of Potential Safe Islands

Based upon agreed criteria and through a process of consultation, a short list of potential safe islands should be developed. Some criteria used will be objective (e.g. size of island) whereas other criteria will be subjective (e.g. quality of local governance). It is important to note that the application of subjective criteria in the island selection process will be open to different interpretations (e.g. is the local governance on X island stronger or weaker than on Y island?). This perhaps points to a benefit in having a transparent process of negotiation based upon impartial facilitation. Due to the foreseeable political and other sensitivities that are likely to emerge during island selection negotiations, it may be prudent to adopt an iterative process allowing the island selection process to be refined over time based upon lessons learnt.

A consideration of the benefits of "island clusters" (where different islands in the same vicinity offer different benefits/services to the local inhabitants for collective good) in terms of the relationship between this concept and the potential for developing safe islands ought to be discussed and analysed at this stage.

It is proposed that the selection process should draw on an understanding of issues based on detailed and thorough investigations. Of course, replication of data collection should be avoided. It is proposed that these issues cover, but are not limited to, the following:

Existing information on disaster and climate risk exposure. For example:

- Developing a Disaster Risk Profile for the Maldives (UNDP, 2006);
- DIRAM1 and 2;
- The current NAPA project 'Integration of Climate Change Risks into the Maldives Safer Island Development Programme'; and
- The SIP review and CBA presented here.

Objective criteria, such as:

- Scale and suitability of existing infrastructure, transportation and services;
- Health of the natural environment / degree of damage to ecosystems limiting defence;

- The amount of existing space for redevelopment (e.g. large islands such as Gan) so as to avoid further damaging land reclamation; and
- Options for developing a chain of smaller safe islands, possibly connected by bridges.

Subjective criteria, such as:

- The quality of local governance;
- Local capacity needs; and
- Potential for livelihood diversification / economic resilience.
- It is imperative that the government make all data freely available to aid in the assessment.

## *Step 3 – Select Safe Islands and Develop Island-specific SIP Strategies and Implementation Plans*

### *Selection of Safe Islands*

Once the short list of potential safe islands has been agreed under Step 2, a plan will need to be devised for undertaking detailed island-level assessments. These should focus upon filling gaps in knowledge and engaging very thoroughly with island officials and the general public. As well as a more detailed investigation and refinement of the issues raised in Step 2, island assessments will need to cover local context issues such as:

- Topography;
- Wave action;
- Erosion and accretion;
- Local awareness of disaster and climate risk; and
- Local capacity and willingness to become a safe island.

The results of this process have to be sufficient to equip decision-makers with comprehensive information and an understanding of the suitability of each of the short-listed islands as potential safe islands.

Again, through a participatory process, the stakeholders will then need to agree upon which islands are to be developed as safe islands. For these islands their own SIP strategy and plans of action will need to be devised for the implementation of measures. With limited resources at the national level, it is likely to be helpful to prioritise the islands and phase their development.

### *Individual Island-specific SIP Strategies*

Being pragmatic, it is recognised that the development of detailed strategies for several islands with only relatively small population bases may be resource-intensive. However, 'community-based' plans and planning processes are highly valuable for their dynamic nature, awareness raising capabilities and other secondary benefits. Thus while island level strategies (and action plans) could draw upon more generic templates, the maximum level of locally specific perspectives should be sought. It will be imperative for effectiveness and sustainability that local 'ownership' of the SIP strategies is achieved.

Island-specific SIP strategies will need to define:

- Specific actions (based on the local context), responsibilities and timeframes;
- Local institutional framework;
- Plans for capacity building; and
- Detailed mechanisms for monitoring and evaluation (a mechanism to capture lessons learnt on one island for application in later phases on different islands would be prudent).

### *Action Plans for Implementation*

The choice of mitigation and adaptation measures for the safe islands, although based on similar themes, must not be uniform; rather they should rely heavily on a thorough assessment and understanding of risk at the individual island level.

1. Subject to the detailed feasibility and risk assessments undertaken locally, a suite of measures may be considered in each island. Holding these individual measures together though, all island-level SIP action plans should incorporate:
2. The establishment of the local institutional framework for the SIP, to include the appointment of a local SIP representative / focal point (supported through training) to act as liaison between local and national level stakeholders. Training and support will have to be a continuous activity occurring at regular intervals to account for changes in circumstances and personnel. It should not be a one-off input at the beginning.
3. A public awareness and education programme to cover disaster and climate risk, early warning, appropriate response, as well as the part that everyone needs to play in protecting the environment.
4. Measures that reverse impacts of man-made in-

terventions on the environment: for example, this may require addressing the impacts of land reclamation, and installing proper drainage.

a. Measures that strengthen natural protection, for example:

b. By ensuring that reefs are protected and healthy;

c. Introducing Environmental Protection Zones that extend from the coastline beneath sea level to include reefs; and

d. Re-vegetating coastlines to provide buffers against waves and wind and ensuring their protection from future exploitation and degradation.

5. Provisions to ensure that any new building practices on islands are most appropriate and minimise damage the natural environment: For instance, a strategy of building vertically is less damaging than reclaiming land. Similarly harbour developments, as part of the government's plans to improve transportation networks, should be subject to full feasibility studies and EIAs to gauge the optimal location, design and method of construction.

6. Strong linkages with island level development activities to maximise the populations' resilience to disaster and climate impacts. For example, by:

a. Strengthening health care;

b. Protecting water supply from contamination;

c. Increasing rainwater harvesting;

d. Ensuring that building codes require buildings to be raised on a plinth; and

e. Making sure land-use plans reduce and do not create risk.

# Cost Benefit Analysis

# 5. COST BENEFIT ANALYSIS – GDH THINADHOO

## 5.1 Introduction

Thinadhoo Island is located on the western rim of Gaafu Dhaalu atoll, approximately 410 km from the nation's capital Male'. It is one of the few inhabited islands facing the western Indian Ocean and is exposed to southwest monsoon related wave action. It is located in the heart of the doldrums, which makes the island relatively safe from some of the major climatic hazard events (UNDP, 2009a).

The island forms part of the Huvadhoo Atoll, which is considered the second largest atoll in the world. Thinadhoo is the atoll capital amongst 10 other inhabited islands. Thinadhoo is a highly urbanised settlement, and is considered the main urban centre in Huvadhoo Atoll and amongst the largest population centres in the Maldives (UNDP, 2009a). The settlement footprint already covers almost 90% of the total habitable land area (UNDP, 2009b).

The key economic infrastructure on the island includes the harbour (which contains a large proportion of the islands business establishments), powerhouse, fish market, oil storage and supply facilities, and communications infrastructure (UNDP, 2009b). The Thinadhoo economy is primarily based on the fishing industry, though manufacturing, wholesale and retail businesses, construction and transportation are also present.

Thinadhoo has undergone substantial human modifications including land reclamation, dredging activities and coastal infrastructure development projects. The original island had a land area of approximately 39ha (0.39km2) and had a wetland area covering 16ha (0.16km2). The land reclamation process, which started in the 1980's, reclaimed the entire wetland area and parts of the reef flat. Approximately 71ha or 61% of the present island is reclaimed and the island of Thinadhoomaahutta or Maahutta has also been joined to form the present Thinadhoo.

The reef of Thinadhoo is fairly large with a surface area of 1150ha (11km2). The average distance to the reef edge is approximately 170m. The maximum height on Thinadhoo is 1.94m above mean sea level (ridge along the southwest corner of the island). Coastal vegetation on the island is very scarce. (UNDP, 2009a).

The land reclamation activities have resulted in the modification of the entire coastline, while the vegetation is sparse and almost absent in the newly reclaimed areas. There are major variations in topography caused by the reclamation activities, which has resulted in drainage issues and flooding during heavy rainfall. The newly reclaimed areas do not have a coastal vegetation belt increasing the risk of erosion and impacts from ocean induced flooding events. Environmental issues associated with urbanisation are increasing, including ground water contamination, improper waste disposal, degradation of coastal areas, depletion of vegetation and coastal erosion.

Many of these issues are described in greater detail in Chapter 4 of this report, and the methodology used to derive the figures in the following sections is described in greater detail in Chapter 3.

## 5.2 Multi-hazard Risk Profile for GDh Thinadhoo

GDh Thinadhoo is exposed to a variety of natural hazards. Flooding caused by heavy rainfall, and tidal/storm surges are the most commonly occurring hazards. Other major hazards that have been identified for Thinadhoo include: windstorms, tsunami, earthquakes, and the compounding impact of climate change on these hazards. As explained previously, the focus of this study is on rainfall flooding, swell waves and tsunami.

Risk is composed of hazards, and the vulnerability of populations to those hazards. Hence this multi-hazard risk profile describes the characteristics of the three hazards defined above and their projected probability under climate change, followed by a description of elements at risk to those hazards. It concludes with estimated losses as a result of each of the three hazards, for high magnitude events.

### 5.2.1 Hazard Assessment

This section briefly describes the characteristics of each of the three hazard types, followed by a table presenting the return period, e.g. the likelihood of a given hazard happening in any given year, for each of the hazards, as well as the changes in probability under climate change.

Flooding is considered one of the biggest problems on the island. Indicating the significance of the problem in Thinadhoo, one of the targets outlined in NEAP 3 (2009) regarding the protection of human settlements singles out this island. It states that by 2012, measures for flood prevention and flood control on the island should be implemented.

Heavy Rainfall: Thinadhoo is located in the highest rainfall region of the Maldives, and the island is often flooded during heavy rainfall. However, flooding has only become prominent since the 1990's, coinciding with the land reclamation (which failed to take into account drainage patterns). Flooding has been reported to reach up to 0.6m above ground level.

Swell waves: The geographic location of Thinadhoo exposes it to year round swell waves. The primary concern is the occurrence of abnormal swell waves, which have the ability to overtop coastal ridges and flood the island (which occurred in 1987 and 2005). The site-specific occurrence of abnormal swell waves is dependent on factors such as wave height, location of the original storm event, tide levels and reef geometry.

Major swell wave events are likely to occur every 5 years, with probable water heights of less than 1.0 m and every 3 years with probable water heights of 0.5-0.75m. Events with water heights less than 0.5m and greater than 0.2m are likely to occur annually. These figures are based on the lowest ridge height on the western coastline and hence,the extent of flooding will depend on the actual ridge height at any given location.

The probability of flooding can be partially attributed to human activities, including land reclamation (which has extended the shoreline closer to the reef edge, affording less protection), as well as the absence of coastal vegetation and the low ridge of the modified dune system.

Tsunami: Thinadhoo is located in a moderate tsunami hazard zone, and the 2004 tsunami had relatively little impact on the island. A severe tsunami is most likely to approach from the east, as well as wrap around the island, causing flooding on all sides. The predicted probable maximum tsunami wave height for the area where Thinadhoo is located is 0.8–2.5m (UNDP, 2006). A wave run-up of 2.5m is predicted to inundate at least up to 500m inland. The first 20–50m from the shoreline will be a severely impacted, with the greatest impact on the eastern and southern half of the island. However, it should be noted that Thinadhoo is fairly protected by the eastern rim of Huvadhoo Atoll from the direct impacts of the most likely source of a tsunami wave. Impacts resulting from water level rise in the atoll lagoon are more likely to cause significant damage in Thinadhoo.

Climate Change: Climate change is expected to increase the intensity and frequency of the above-mentioned hazards in the Maldives. Furthermore, a significant impact associated with climate change is rising sea level. Consultation in the Maldives consistently suggested that the measures necessary to protect an island against sea level are so extensive and expensive that they are simply not feasible. It was further suggested that perhaps the only feasible defence is to protect natural processes – development of ridges, accretion and erosion, growth of coral reefs – to the maximum extent possible with the hope that they will be able to protect against this slow-onset disaster, as well as protect against increased sea surges as a result of sea level rise.

Hence the following analysis takes account of climate change impacts on existing hazards, but does not analyse measures to protect directly against sea level rise.

### *Hazard Probabilities for Thinadhoo*

The following table describes the intensity thresholds and return periods (e.g. the likelihood that a hazard of a given severity will occur in any given year). It also provides estimates of the probability of events under climate change.

The data is provided for low, moderate and severe hazard events. Probabilities under climate change are only available for heavy rainfall, and swell waves, due to data availability.

**Table 5.1:** Hazard Assessment for Thinadhoo

| Hazard | Intensity Threshold (rainfall in 24 hours) (wave run up on reef flat) | | | Return Period (%) | | | Probability 2050 (under climate change) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Low | Med | High | Low | Med | High | Low | Med | High |
| Heavy Rainfall | <60mm | >60mm | >175mm | 66-90% | 33-66% | 10-33% | 90-99% | 33-66% | 10-33% |
| Swells waves | <2.0m | >2.0m | >3.0m | 66-90% | 10-33% | 1-10% | 90-99% | 33-66% | 10-33% |
| Tsunami | <2.0m | >2.0m | >3.0m | 33-66% | 10-33% | 1-10% | n/a | n/a | n/a |

**Source:** UNDP, 2009a

## 5.2.2 Impact Assessment

Each of the three hazards impacts on the island in different ways and to different degrees. Some of these impacts can be quantified, while some are more qualitative in nature. The following section provides an overview of the main impacts (both quantitative and qualitative) – physical, human and natural – for each of the hazards. The list is not exhaustive, and DIRAM 1 and 2 (UNDP, 2009a and 2009b) should be referred to for more detail.

Furthermore, it is important to note that the degree of impact will differ depending on the magnitude of the hazard – e.g. whether it is a low, moderate or severe event. However, as explained in the methodology, DIRAM1 and DIRAM2 estimates were only provided for severe magnitude hazard events.

### *Flooding from Heavy Rainfall*

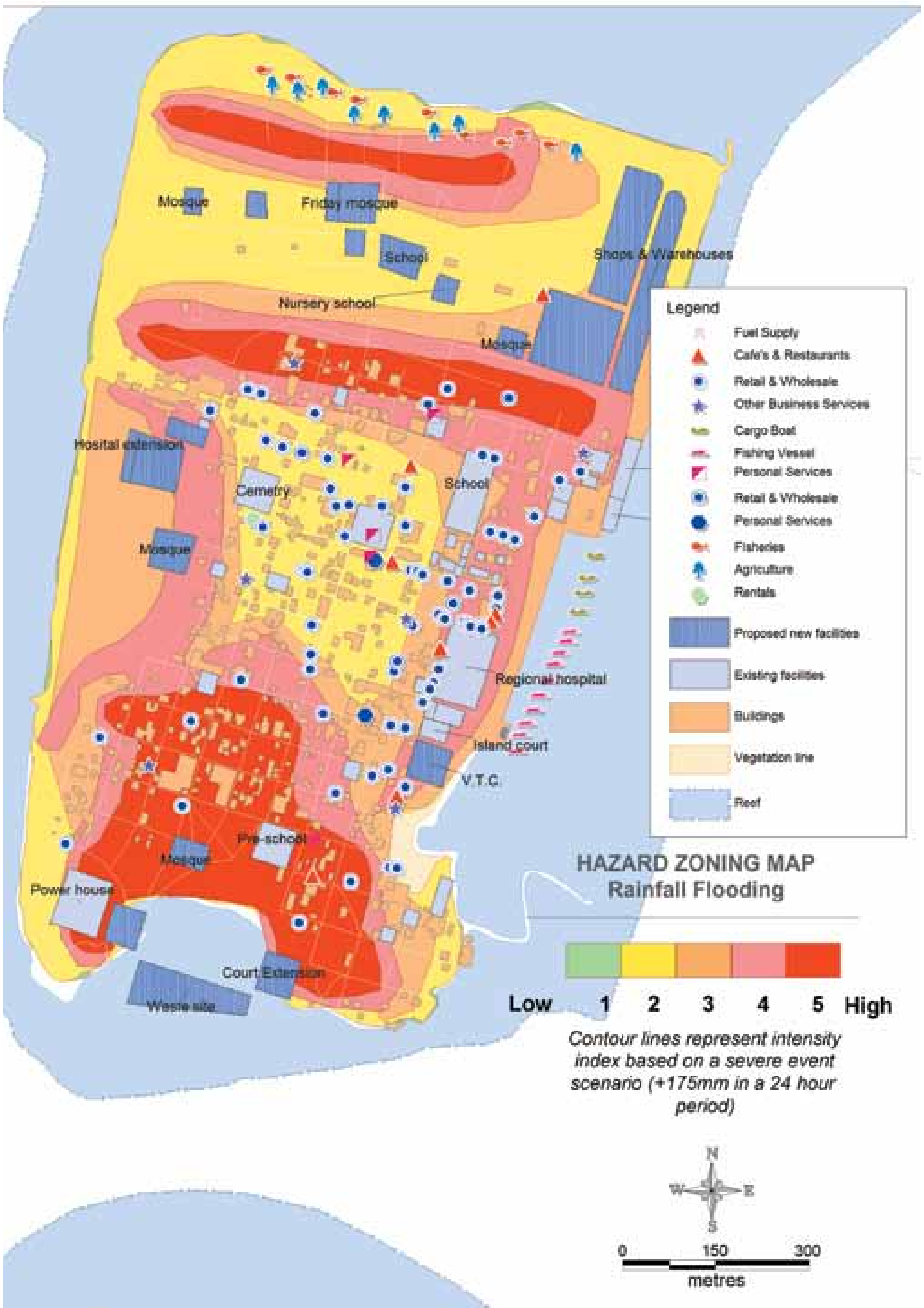
Heavy rainfall is expected to flood most parts of the island, in particular the reclaimed former wetland areas in the south and the low areas along the intersection between the original island and the newly reclaimed land.

The following physical, human and natural impacts were identified:

| Physical Impacts | Human Impacts | Natural Impacts |
|---|---|---|
| • Damage to the powerhouse.<br>• Damage to households and businesses as well as disruption of business activities.<br>• Impact on the school located in the southern zone.<br>• Operational disruptions to business establishments and public administration.<br>Some damage to retail and warehouse stock. | • No injuries or loss of lives.<br>• Disruption to daily activities. | • Damage to vegetation, trees in low-lying areas.<br>• Contamination of groundwater.<br>• Geomorphic changes due to artificial runoff channels. |

The combination of hazard intensity and physical vulnerability is presented in the risk map below.

**Figure 5.2:** Risk Map: Heavy Rainfall, High Magnitude




**Source:** UNDP, 2009b

### *Swell Wave*

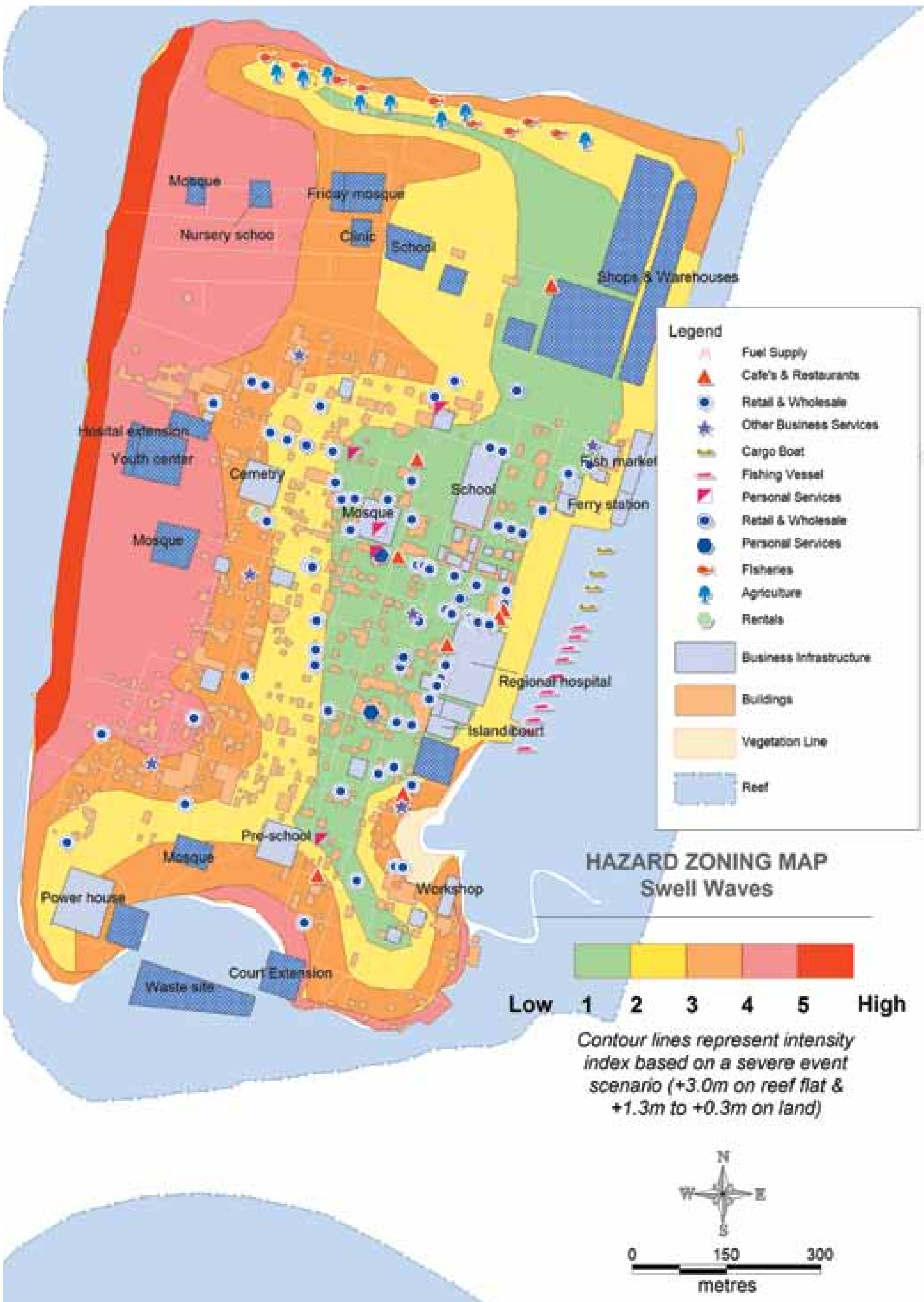
A severe swell wave is most likely to approach from the west, with similar characteristics to a tsunami but with less intensity.

The following physical, human and natural impacts were identified:

| Physical Impacts | Human Impacts | Natural Impacts |
|---|---|---|
| • Damage to harbour, including some key business establishments and productive assets.<br>• Damage to the powerhouse.<br>• Damage to some households. | • No injuries or loss of lives.<br>• Disruption to daily activities. | • Damage to coastal vegetation (north and east sides). |

The combination of hazard intensity and physical vulnerability is presented in the risk map below.

**Figure 5.3:** Risk Map: Swell Wave, High Magnitude




**Source:** UNDP, 2009b

### *Tsunami*

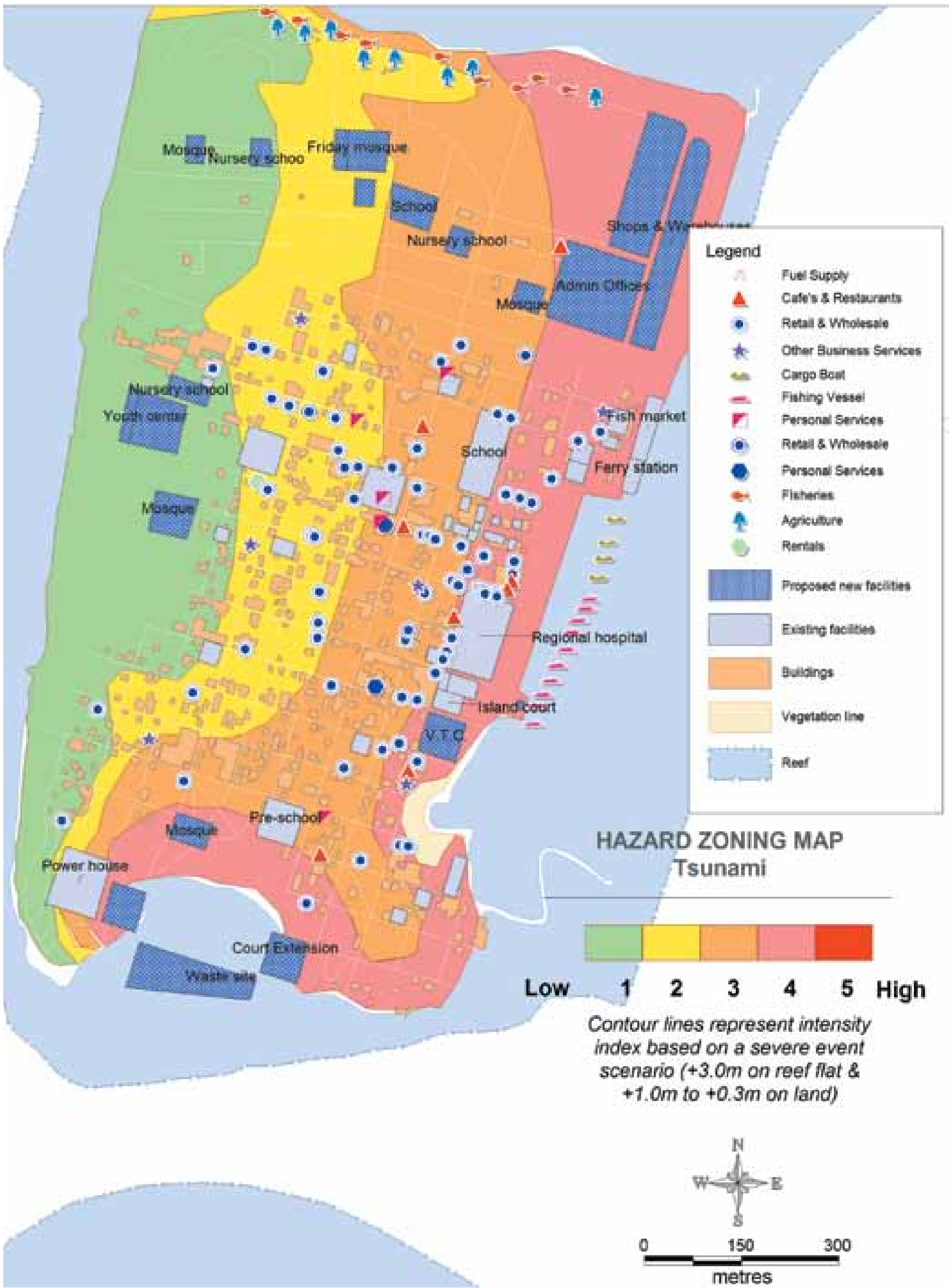
A severe tsunami is most likely to approach from the east and flood the eastern coastline.

The following physical, human and natural impacts were identified:

| Physical Impacts | Human Impacts | Natural Impacts |
|---|---|---|
| • Damage to harbour, including some key business establishment and productive assets.<br>• Damage to the powerhouse.<br>• Damage to regional hospital.<br>• Saltwater damage to crops.<br>• Wholesale and retail stocks very vulnerable and uninsured. | • In a high magnitude tsunami, 0.1% of lives may be lost, 5% may be injured. | • Damage to coastal vegetation.<br>• Long-term damage to low-lying inland vegetation.<br>• Saltwater intrusion into island water lens.<br>• Contamination of groundwater.<br>• Short-term loss of soil productivity.<br>• Minor damage to coral reefs. |

The combination of hazard intensity and physical vulnerability is presented in the risk map below.

**Figure 5.4:** Risk Map: Tsunami, High Magnitude




**Source:** UNDP, 2009b

### 5.2.3 Estimated Losses without Protection Measures

Associated damages or losses were estimated for each hazard type as outlined in the methodology (Section 3.3). These figures represent tangible losses only, in the scenario without any mitigation works. As a benchmark, the total estimated value of the Thinadhoo economy is between RF600 and RF700 million (UNDP, 2009b).

Annex D contains full details of the estimation of losses, as estimated in DIRAM2.

**Table 5.2:** Estimated Losses in Thinadhoo, for severe magnitude hazards, by hazard type

| Sector | Tsunami losses (Rufiyaa) | Swell waves and storm surge losses (Rufiyaa) | Rainfall flooding losses (Rufiyaa) |
|---|---|---|---|
| Infrastructure | 7,428,000.00 | 826,000.00 | 660,000.00 |
| Households | 1,114,000.00 | 560,000.00 | - |
| Fisheries | 2,900,000.00 | 225,000.00 | - |
| Agriculture | 350,000.00 | 110,000.00 | - |
| Wholesale and retail trade | 2,325,000.00 | 120,000.00 | 200,000 |
| Manufacturing | 260,000.00 | 61,000.00 | - |
| Transport, storage and communications | 2,034,000.00 | 66,000.00 | - |
| Construction | 30,000.00 | 14,000.00 | - |
| Hotels and restaurants | 288,000.00 | 13,000.00 | - |
| Public Administration | 2,000,000.00 | 50,000.00 | 50000 |
| Other community, social and personal service activities | 50,000.00 | 15,500.00 | - |
| Real Estate, renting and business activities | 308,000.00 | 12,000 | - |
| Tourism | 480,000.00 | 200,000 | - |
| Total | 19,567,000.00 | 2,272,500.00 | 910,000.00 |

**Source:** UNDP, 2009b

It is assumed, based on consultation with local officials on the islands, that losses are reduced to 40% and 10% of the total loss estimations for medium and low magnitude events respectively.

Furthermore, it is estimated that a severe magnitude tsunami will result in human losses of 0.001% of the population, with injuries to 0.5% of the population. Based on the VSL calculation described in the methodology, and a total population of 4,442[1], this equates to a financial loss of RF 65,641,655. It is assumed that these losses only occur in a severe magnitude tsunami (there are no recorded fatalities associated with other events).

[1] This is based on the census population, rather than the registered population, as the census more accurately reflects the number of people actually present on the island.

Table 5.3: Estimated Losses in Thinadhoo, by hazard magnitude

| Magnitude | Estimated Losses | | |
|---|---|---|---|
| | Tsunami losses | Swell waves and storm surge losses | Rainfall flooding losses |
| Low | 8,520,866 | 227,250 | 91,000 |
| Moderate | 34,083,462 | 909,000 | 364,000 |
| Severe | 85,208,655[1] | 2,272,500 | 910,000 |

## 5.3 Identification of Risk Management Options, Costs and Benefits

A variety of risk management options are available to help mitigate against hazard impacts and reduce the losses outlined above. Risk management can comprise a whole suite of responses, from physical measures such as man-made coastal protection and resilient harbours, to softer measures including risk awareness programmes, preparedness measures such as early warning systems, and vulnerability reduction measures such as livelihood diversification.

This section identifies a range of possible options, both soft and hard, and estimates costs and associated benefits (or reduction in losses) associated with those measures.

### 5.3.1 Risk Management Options

The following measures for Thinadhoo were identified based on the findings of DIRAM1 and DIRAM2:

- Man made coastal protection;
- Most vulnerable houses & buildings retrofitted;
- Flood mitigation for lifeline infrastructure;
- Resilient harbour;
- All rainfall flood prone areas fitted with drainage;
- Environmental Protection Zone (EPZ) around island;
- Evacuation facilities; and
- Risk awareness programmes.

These were further grouped into four risk management scenarios or options, each providing a "package" of protection: 1) No man-made protection; 2) Full Safe Island Protection; 3) Selected Safe Island Protection and 4) Limited Protection. The following table describes each of these scenarios in greater detail.

**Table 5.4:** Risk Management Scenarios for Thinadhoo

| Protection Type | Characteristics of Mitigation Measures | Type of Hazard Mitigated |
|---|---|---|
| No protection ("without" scenario) | Natural or none | None related to man-made measures |
| Safe Island Protection | Coastal protection 2.5m high; most vulnerable houses & buildings retrofitted; flood mitigation for lifeline infrastructure; resilient harbour; all rainfall flood prone areas fitted with drainage; EPZ around island; evacuation facilities. | All hazards but not a severe strength tsunami; waves will over top and flood up to 0.5m on land, enough to cause damage to 10% of the island, but other mitigation measures will ensure damage is limited to 5%; Swell waves may overtop but will cause minimal damage with other mitigation measures in place. |
| Selected Safe Island Protection | Coastal protection 2.5m high; resilient harbour; all rainfall flood prone areas fitted with drainage; EPZ around portion of island. | All hazards but not a severe strength tsunami; waves will over top and flood up to 0.5m on land, enough to cause damage to 10% of the island; Swell waves may overtop and likely to cause moderate damage to 10% of the island. Rainfall flooding will be mitigated. |
| Limited protection | Coastal protection 2.0m high as a revetment (cheaper option); partial EPZ. | Will cause severe-moderate damage during a maximum strength and moderate strength tsunami; waves will over top and flood up to 1.0m, enough to cause damage to 20% of the island; Severe strength swell waves may overtop and likely to cause damage to 20% of the island. Rainfall flooding will be partially mitigated. |

### 5.3.2 Costs

Each of these measures incurs fixed and, in some cases, variable costs (for example, for regular maintenance). The following table summarises the fixed costs associated with each risk management scenario, and this is followed by a description of associated variable costs, annualised.

Clearly, fixed costs can vary depending on the specific parameters of the measure being put in place (size, height) and the materials used. Annex E contains a full description of the criteria used to determine the costs described in the table below.

**Table 5.5:** Fixed Costs Associated with Risk Management Scenarios for Thinadhoo

| Protection Type | Costs (RF) | Total Cost (RF) |
|---|---|---|
| No man made protection ("without" scenario) | 0 | 0 |
| Safe Island Protection | Coastal protection (north and east): 66,049,000<br>Coastal protection (west and south): 66,049,000<br>EPZ around island: 20,000,000<br>Resilient harbour: 37,312,173<br>Evacuation facilities: 3,855,000<br>Flood mitigation for lifeline infrastructure: 2,332,500<br>Houses & buildings retrofitted: 7,600,000<br>Drainage in rainfall flood prone areas: 2,604,225 | 205,801,898 |
| Selected Safe Island Protection | Coastal protection (north, east and south): 72,653,900<br>EPZ around portion of island: 11,000,000<br>Resilient harbour: 37,312,173<br>Evacuation facilities: 3,855,000<br>Flood mitigation for lifeline infrastructure: 2,332,500<br>Houses & buildings retrofitted: 7,600,000<br>Drainage in rainfall flood prone areas: 2,604,225 | 137,357,798 |
| Limited protection | Coastal protection (east): 49,536,750<br>EPZ around island: 7,500,000<br>Flood mitigation for the power house: 875,000<br>Drainage in rainfall flood prone areas: 2,604,225 | 60,515,975 |

Several of these measures will incur maintenance costs, as follows:

The resilient harbour will require maintenance dredging at a cost of RF 5,000,500 every 10 years.

The artificial drainage systems will require maintenance at a cost of RF 426,225.35 every 2 years.

Risk awareness programmes, including creating disaster risk awareness among businesses, insurance awareness among high risk investments, and awareness among the population to use banking facilities to store cash, will be run every three years at a cost of RF 550,000.

### 5.3.3 Benefits (reductions in losses)

The benefits associated with each of the risk management scenarios described in the previous section are equivalent to the reduction in losses.

As explained in the methodology, the benefits were estimated as a percentage reduction in losses. Table 5.6 below provides a detailed explanation of the assumptions used, and the estimated percentage reduction in losses, for each risk management scenario and each magnitude of hazard, based on these assumptions.

Table 5.6: Reduction in Losses Associated with Risk Management Scenarios (%), Thinadhoo

| Protection Type | Severe tsunami | | Moderate tsunami | | Low tsunami | |
|---|---|---|---|---|---|---|
| | Level of protection | Reduction in losses | Level of protection | Reduction in losses | Level of protection | Reduction in losses |
| Safe Island | Severe strength tsunami may over top and flood with a depth of 0.5m on land up to 30m, enough to cause damage to 10% of the island, but other mitigation measures will ensure damage is limited to 5%; rising water table may damage sewerage system. | 90% | Waves may over top and flood with a depth less than 0.5m on land up to 30m, enough to cause damage to 10% of the island, but other mitigation measures will ensure damage is limited to 3%; rising water table may damage sewerage system. | 99% | Full protection. | 100% |
| Selected Safe Island | Severe strength tsunami will over top and flood with a depth of 0.5m on land, enough to cause damage to 10% of the island. | 85% | Waves may over top and flood with a depth less than 0.5m on land up to 30m, enough to cause damage to 10% of the island. | 90% | Full protection. | 100% |
| Limited Protection | Will cause moderate damage during a maximum strength tsunami; waves will over top and flood up to 1.0m, enough to cause damage to 20% of the island without other mitigation measures. | 50% | Will cause severe-moderate damage during a moderate strength tsunami; waves will over top and flood less than 1.0m, enough to cause damage to 15% of the island without other mitigation measures. | 75% | Will cause moderate-low damage during a wave event; waves may over top around the harbour area and damage coastal infrastructure, particularly, harbour and coastal protection. | 95% |
| Safe Island | Severe strength wave may over top and flood with a depth of 0.5m on land up to 20m, enough to cause damage to 10% of the island, but other mitigation measures will ensure damage is limited to 2%; rising water table may damage sewerage system. | 95% | Waves may over top and flood with a depth less than 0.5m on land up to 20 m, enough to cause damage to 10% of the island, but other mitigation measures will ensure damage is minimised. | 99% | Full protection. | 100% |
| Selected Safe Island | Severe strength wave will over top and flood with a depth of 0.5m on land, enough to cause damage to 10% of the island. | 90% | Waves may over top and flood with a depth less than 0.5m on land up to 20m, enough to cause damage to 5% of the island. | 95% | Full protection. | 100% |
| Limited Protection | Will cause moderate damage; waves will over top and flood up to 1.0m, enough to cause damage to 20% of the island without other mitigation measures. | 70% | Will cause moderate damage; waves will over top and flood less than 1.0m, enough to cause damage to 15% of the island without other mitigation measures. | 75% | Wave splashing may occur and damage nearby properties and roads. | 99% |

| Protection Type | Severe tsunami | | Moderate tsunami | | Low tsunami | |
|---|---|---|---|---|---|---|
| | Level of protection | Reduction in losses | Level of protection | Reduction in losses | Level of protection | Reduction in losses |
| Safe Island | Limited flooding and only for a short period (drainage facilities will ensure flow). Drainage clogging may cause occasional low level flooding. | 95% | Limited flooding and only for a short period (drainage facilities will ensure flow). Drainage clogging may cause occasional low level flooding. | 97% | Limited flooding and only for a short period (drainage facilities will ensure flow). Drainage clogging may cause occasional low level flooding. | 99% |
| Selected Safe Island | Limited flooding and only for a short period. Drainage facilities will ensure flow, but occasional clogging may cause occasional low level flooding in households without retrofitting. | 90% | Limited flooding and only for a short period. Drainage facilities will ensure flow, but occasional clogging may cause occasional low level flooding in households without retrofitting. | 95% | Limited flooding and only for a short period. Drainage facilities will ensure flow, but occasional clogging may cause occasional low level flooding in households without retrofitting. | 98% |
| Limited Protection | Moderate level of protection and severe events may cause damage to drainage and cause moderate levels of flooding | 75% | Moderate-low level of protection and moderate events may cause damage to drainage and cause low levels of flooding | 80% | Moderate-low level of protection. | 85% |

## 5.4 Findings: Cost Benefit Analysis

The Cost Benefit Analysis was run for each of the risk management scenarios described above.

The estimated damages described above were weighted by the probability of a given magnitude of hazard occurring. So, for example, while the losses associated with a severe event are higher, these are weighted by the lower probability of this event happening. DIRAM1 provides three ranges in estimates for the probability of a hazard event occurring – a minimum under current conditions, a maximum under current conditions, and a probability under climate change (estimated for 2050). The baseline analysis is run for each of these three scenarios.

This is repeated for all three hazards, and the combined analysis gives an estimate for total yearly risk, as well the total yearly benefits, associated with multiple hazards. These figures are then weighted against the cost figures to derive the following:

The Benefit to Cost Ratio: this figure divides the discounted value of benefits by the discounted value of costs. If the ratio is greater than 1, the benefits outweigh the cost, and therefore there is a financial argument for proceeding with the project. Anything below 1 implies a negative return.

The Net Present Value calculates the discounted net benefits (benefits minus costs) year on year. If the figure is positive, there is a financial argument for going ahead with the project. Anything below 0 implies a negative return.

The analysis used a discount rate of 7.5% and a project lifetime of 50 years (the estimated lifetime of the longest lived asset, the coastal protection works).

Minimum probability of hazard occurrence – current climate

According to DIRAM1 estimates for the minimum probability of a hazard event occurring, a severe tsunami is estimated to occur every 100 years, a severe storm surge every 100 years, and severe flooding from heavy rainfall every 10 years (see Table 5.1 for the full range of hazard probabilities under low and moderate magnitude events).

These conditions yield the following cost benefit results.

**Table 5.7:** Cost Benefit Findings for Thinadhoo: Minimum hazard occurrence

| Protection Type | Benefit to Cost Ratio | Net Present Value (RF) |
|---|---|---|
| Safe Island Protection | 0.39 | -161,077,586 |
| Selected Safe Island Protection | 0.52 | -89,909,427 |
| Limited protection | 1.13 | 9,731,053 |

Maximum probability of hazard occurrence – current climate

According to DIRAM1 estimates for the maximum probability of a hazard event occurring, a severe tsunami is estimated to occur every 10 years, a severe storm surge every 10 years, and severe flooding from heavy rainfall every 3 years (see Table 5.1 for the full range of hazard probabilities under low and moderate magnitude events).

These conditions yield the following cost benefit results.

**Table 5.8:** Cost Benefit Findings for Thinadhoo: Maximum hazard occurrence

| Protection Type | Benefit to Cost Ratio | Net Present Value (RF) |
|---|---|---|
| Safe Island Protection | 1.35 | 93,714,442 |
| Selected Safe Island Protection | 1.79 | 149,251,980 |
| Limited protection | 3.54 | 191,202,975 |

Probability of maximum hazard occurrence under climate change

According to DIRAM1 estimates for the maximum probability of a hazard event occurring under climate change, a severe storm surge is estimated to occur every 3 years, and severe flooding from heavy rainfall every 3 years (see Table 5.1 for the full range of hazard probabilities under low and moderate magnitude events). The analysis did not include an estimate of climate impacts on tsunami events, so the maximum probability under current conditions is taken, and hence it is assumed a severe tsunami will occur every 10 years.

These conditions yield the following cost benefit results.

**Table 5.9:** Cost Benefit Findings for Thinadhoo: Maximum hazard occurrence under climate change

| Protection Type | Benefit to Cost Ratio | Net Present Value (RF) |
|---|---|---|
| Safe Island Protection | 1.40 | 105,180,640 |
| Selected Safe Island Protection | 1.85 | 160,185,167 |
| Limited protection | 3.65 | 199,823,621 |

The findings indicate that there is not a clear or strong financial argument for proceeding with full or selected safe island risk management scenarios. The NPV shifts from negative to positive under a maximum hazard scenario; however, one could legitimately raise concerns over the assumption that severe tsunamis and storm surges will both occur once every 10 years (given that the current estimate for the 2004 event is 1 in 219 years). The limited protection scenario does yield a positive result in all scenarios, suggesting that this option may be a more cost effective one.

## 5.5 Sensitivity Analyses

The baseline analysis presented above is built upon a number of assumptions and uncertainties, but is nonetheless based on the best professional judgement of the authors, given the data available.

Because there is so much uncertainty in factors included in the analysis, for example the probability of a hazard event occurring, sensitivity analysis is used to test the underlying assumptions.

For this analysis, the following assumptions were tested, in order to evaluate the findings under a range of scenarios. The sensitivity analyses are run for the minimum probability of hazard occurrence, and the maximum probability under climate change. The following assumptions were tested:

The damages associated with each hazard event were doubled to account for the fact that intangible losses could not be estimated for this study (and hence greater benefits as a result of risk management were calculated).

The discount rate was varied between 0% and 15%. There is a strong argument that benefits to future generations should not be discounted at all, and this is particularly true in the case of small island states and climate change, where there is a duty of care to avoid adverse consequences to future generations, and therefore fully value future benefit streams.

The assumption of a 50-year lifetime for the CBA is quite long, and so a 25-year lifetime was also assessed.

The following tables show the range of possible estimates that can be derived from the sensitivity testing. Positive Benefit to Cost Ratios (BCR) are highlighted in green, whereas negative ones are highlighted in blue.



**Table 5.10:** Sensitivity Testing: Minimum hazard probability, Benefit to Cost Ratios, Thinadhoo

| Protection Type | Double damages (intangible losses) | Discount Rate 0% | Discount Rate 15% | 25 year project lifetime |
|---|---|---|---|---|
| Safe Island Protection | 1.48 | 0.87 | 0.24 | 0.35 |
| Selected Safe Island Protection | 1.98 | 1.07 | 0.27 | 0.47 |
| Limited protection | 4.33 | 2.61 | 0.69 | 1.00 |

**Table 5.11:** Sensitivity Testing: Maximum hazard probability under climate change, Benefit to Cost Ratios, Thinadhoo

| Protection Type | Double damages (intangible losses) | Discount Rate 0% | Discount Rate 15% | 25 year project lifetime |
|---|---|---|---|---|
| Safe Island Protection | 4.67 | 3.08 | 0.86 | 1.24 |

| Protection Type | Double damages (intangible losses) | Discount Rate 0% | Discount Rate 15% | 25 year project lifetime |
|---|---|---|---|---|
| Selected Safe Island Protection | 6.18 | 3.76 | 1.17 | 1.66 |
| Limited protection | 12.75 | 8.45 | 2.22 | 3.23 |

The factor that creates the greatest variation in the analysis is the doubling of damages. The assumption that benefits could be doubled to account for intangible losses (those things that can't be valued in the analysis, such as social impacts, the value placed on the existence of the islands, etc) seems reasonable, and under all scenarios yields a positive BCR, ranging between 1.48 and 12.75.

The greatest benefits are yielded in the limited protection scenario, suggesting that a full suite of measures may not be the most cost effective approach to protection.

# 6. COST BENEFIT ANALYSIS – GA VILIGILI

## 6.1 Introduction

*Much of the data required for the CBA relies on information obtained through the DIRAM1 (UNDP, 2009a) and DIRAM2 (UNDP, 2009b) studies. It is important to note that Viligili has undergone substantial land reclamation since these studies were conducted. Therefore the data in this CBA is based on the original older island, and not the existing island with its newly reclaimed land.*

GA Viligili Island is located on the eastern rim of Gaafu Alifu atoll, about 380km from the nation's capital Male'. The island forms part of the natural atoll called Huvadhoo Atoll, which is considered the second largest atoll in the world. Viligili is the atoll capital amongst 10 other inhabited islands.

It is also located next to Koodoo Island, the main fish processing centre in the southern region of the Maldives. Huvadhoo Atoll is the nearest atoll in the Maldives to the equator and is exposed to direct wave action in the Indian Ocean. However, its location in the heart of the doldrums makes the island relatively safe from major hydro-meteorological hazards.

Prior to the recent land reclamation, Viligili was a narrow and elongated island, with a total surface area of 54.8ha (0.55km2). The newly reclaimed land is clearly observable, as it is almost completely devoid of vegetation, as well as infrastructure and buildings. The original reef of Viligili was large with a surface area of 3,000ha (30km2), and will only have diminished by a small proportion. The reef also hosts three other uninhabited islands. Viligili is located on the southern tip of the reef system, next to a major reef entrance. The average distance to the reef edge was approximately 300m, but is now considerably closer on the eastern side.

Viligili has undergone considerable erosion during the last 35 years. Much of the erosion and accretion has occurred in the northern part of the island, which was observed to be highly dynamic due to the constant rapid flow of sediments and water in the area. The erosion may have been part of the readjustment process following the harbour development and land reclamation in the early 1990's. Now the fast following channel to the north of the island has been filled in, and thus new patterns of erosion and accretion will be establishing themselves. The inhabitants reported erosion in the southern and eastern coastline as their main concern, possibly due to the proximity of settlements to the coastline in these areas combined with the threat from occasional tidal floods. The original part of Viligili is quite highly urbanised, and due to the narrow width of the island, settlement had expanded to the edges of the coastline.

Much of the original island was covered with wetlands, which have now largely been reclaimed on an "ad hoc basis" by the inhabitants. Hence, much of the existing settlement is located in low-lying reclaimed areas. Over the years these fertile low areas of the island have become productive for backyard agriculture.

Among the most notable features in Viligili in relation to hazard exposure is the retreat of the south-western coastline, which is the closest region to the oceanward reef line. Given the strong wave action in the region and the potential wave exposure from the east, a strong coastal ridge is to be expected. However, the ridge appears to have been depleted to a large extent. At present it appears that the ridge has been gradually eroded and perhaps has undergone geomorphologic change during the tsunami of 2004.

The island only had a thin layer of depleted coastal vegetation around its settlement and the remaining vegetation is being further depleted with planned expansion of settlement. Indeed, some of this was observable on the northern side of the island where post tsunami re-construction was taking place in previously vegetated areas. Environmental issues associated with urbanisation are being experienced by its inhabitants, including ground water contamination, improper waste disposal, degradation of coastal areas, depletion of vegetation and coastal erosion.

Many of these issues are described in greater detail in Chapter 4 of this report, and the methodology used to derive the figures in the following sections is described in greater detail in Chapter 3.

## 6.2 Multi-hazard Risk Profile for GA Viligili

GA Viligili is exposed to a variety of natural hazards. Flooding caused by heavy rainfall, and tidal/storm surges are the most commonly occurring hazards. Other major hazards that have been identified for Viligili include: windstorms, tsunami, earthquakes, and the compounding impact of climate change on these hazards. As explained previously, the focus of this study is on rainfall flooding, swell waves and tsunami.

Risk is composed of hazards, and the vulnerability of populations to those hazards. Hence this multi-hazard risk profile describes the characteristics of the three hazards defined above and their projected probability under climate change, followed by a description of elements at risk to those hazards. It concludes with estimated losses as a result of each of the three hazards, for high magnitude events.

### 6.2.1 Hazard Assessment

This section briefly describes the characteristics of each of the three hazard types, followed by a table presenting the return period, e.g. the likelihood of a given hazard happening in any given year, for each of the hazards, as well as the changes in probability under climate change.

According to the view of the inhabitants of Viligili, the two most significant natural hazards that they are exposed to (in terms of predicted levels of damage and disruption in the future) are flooding through heavy rainfall and flooding through wave action.

Heavy Rainfall: Viligili is located in the highest rainfall region of the Maldives, and is amongst the most intensely flooded islands. Heavy rainfall related flooding has been reported to reach up to 0.5 m above the ground level. One key feature of Viligili is that flood waters recede quite slowly in the low areas due to the shallow depth between the surface and ground water lens.

Viligili's exposure to rainfall related flooding is compounded by human activities. Since the 1960's, land reclamation has been undertaken in the central wetland areas on an ad-hoc basis. Since the late 1980's, harbour development projects facilitated large-scale reclamation. Unfortunately, all these activities led to a substantial topographic low in the middle of the island establishing a natural drainage into this area. As a result, at times of heavy rainfall, the low reclaimed areas are regularly flooded.

Swell waves: The location of Viligili on the eastern rim of Huvadhoo Atoll protects it from the year round swell waves approaching from a west to southerly direction. However, Viligili is also exposed to abnormal swell waves originating from intense extra-tropical storms in the southern hemisphere, causing flooding on the eastern coastline of Viligili. A more consistent pattern of wave exposure exists for monsoonal wind waves around the island. The occurrence of abnormal swell waves and storm surges on Viligili reef flat is dependent on a number of factors such as the wave height, location of the original storm event, tide levels and reef geometry.

There is a probability of major swell events occurring every 10 years in Viligili, with probable water heights of less than 1.0 m and every 5 years with probable water heights of 0.5-0.75 m. Events with water heights less than 0.5 m and greater than 0.2 m are likely to occur once every 2-3 years.

The intensity of flooding in the inland areas may have been exacerbated by improper wetland reclamation. The reclaimed areas are considerably lower than the existing island, causing floodwaters to run-off towards them.

Tsunami: Viligili is geographically located in a high tsunami hazard zone. According to official estimates, the tsunami of December 2004 inundated 33% of the island. The tsunami run-up height at the eastern shoreline of the island was reported to be at approximately 4m above MSL. The field assessment of the site indicated that the inundation reached a distance of approximately 350m inland from the eastern shoreline. In contrast to the official estimates, this suggests that nearly 70% of the island was inundated.

The predicted probable maximum tsunami wave height for the area where Viligili is located is 3.2 – 4.5m (UNDP, 2006). Examination of the flooding that will be caused by a wave run-up of 4.5m for the island of Villigili indicates that such a magnitude wave will flood the entire island.

Climate Change: Climate change is expected to increase the intensity and frequency of the above-mentioned hazards in the Maldives (UNDP, 2009a). Furthermore, a significant impact associated with climate change is rising sea level. If sea levels rise to the levels predicted, Viligili will be submerged. Consultation in the Maldives consistently suggested that the measures necessary to protect an island against sea level are so extensive and expensive that they are simply not feasible. It was further suggested that perhaps the only feasible defence is to protect natural processes – development of ridges, accretion and erosion, growth of coral reefs – to the maximum extent possible with the hope that they will be able to protect against this slow-onset disaster, as well as protect against increased sea surges as a result of sea level rise.

Hence the following analysis takes account of climate change impacts on existing hazards, but does not analyse measures to protect directly against sea level rise.

### *Hazard Probabilities for Viligili*

The following table describes the intensity thresholds and return periods (e.g. the likelihood that a hazard of a given severity will occur in any given year). It also provides estimates of the probability of events under climate change.

The data is provided for low, moderate and severe hazard events. Probabilities under climate change are only available for heavy rainfall, and swell waves, due to data availability.

**Table 6.1:** Hazard Assessment for Viligili

| Hazard | Intensity Threshold (rainfall in 24 hours) (wave run up on reef flat) | | | Return Period (%) | | | Probability 2050 (under climate change) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Low | Mod | Severe | Low | Mod | Severe | Low | Mod | Severe |
| Heavy Rainfall | <60mm | >60mm | >175mm | 66-90% | 33-66% | 10-33% | 90-99% | 33-66% | 10-33% |
| Swells waves | <2.0m | >2.0m | >3.0m | 33-66% | 10-33% | 1-10% | 90-99% | 33-66% | 10-33% |
| Tsunami | <2.0m | >2.0m | >3.0m | 33-66% | 10-33% | 1-10% | n/a | n/a | n/a |

**Source:** UNDP, 2009a

## 6.2.2 Impact Assessment

Each of the three hazard types impacts on the island in different ways and to different degrees. Some of these impacts can be quantified, while some are more qualitative in nature. The following section provides an overview of the main impacts (both quantitative and qualitative) – physical, human and natural – for each of the hazards. The list is not exhaustive, and DIRAM1 and DIRAM2 should be referred to for more detail.

Furthermore, it is important to note that the degree of impact will differ depending on the magnitude of the hazard – e.g. whether it is a low, moderate or severe event. However, as explained in the methodology, DIRAM1 and DIRAM2 estimates were only provided for severe magnitude hazard events.

### *Flooding from heavy rainfall*

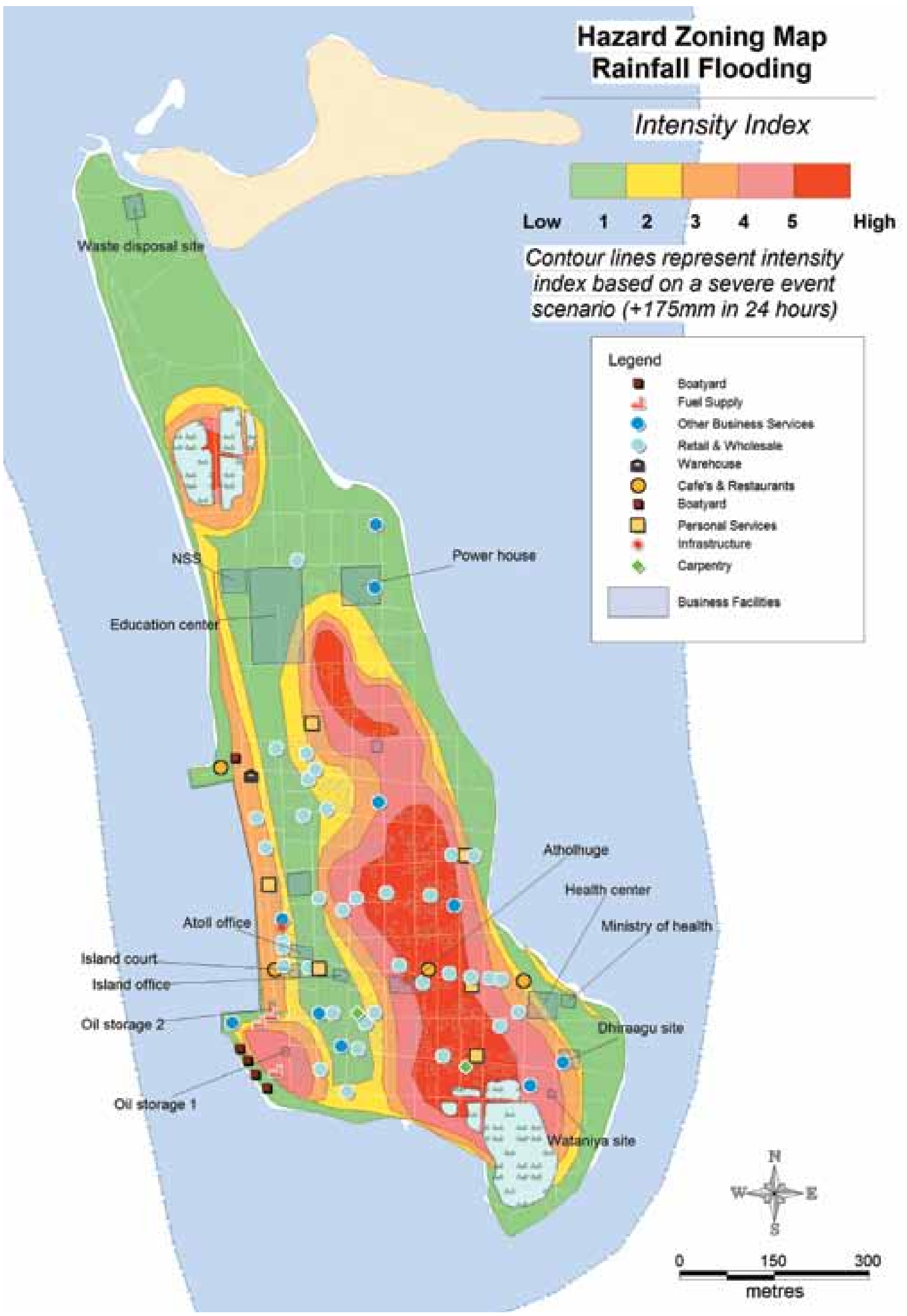
Heavy rainfall above the severe threshold is expected to flood most of the southern parts of the island where much of the settlement is located. The areas predicted for severe intensity are the reclaimed wetland areas in the south and the low areas along the newly reclaimed land adjacent to the harbour. These areas act as drainage basins for the surrounding higher areas.

The following physical, human and natural impacts were identified in relation to a severe rainfall event:

| Physical Impacts | Human Impacts | Natural Impacts |
|---|---|---|
| • Damage to households and personal belongings.<br>• Damage to backyard trees.<br>• Damage to retail and warehouse stocks.<br>• Impacts on harbour, fuel supply and hospital operations. | • No injuries or loss of lives.<br>• Disruption to daily activities. | • None |

The combination of hazard intensity and physical vulnerability is presented in the risk map below.

**Figure 6.2:** Risk Map: Heavy Rainfall, Severe Magnitude




**\Source:** UNDP, 2009a

### *Swell Wave*

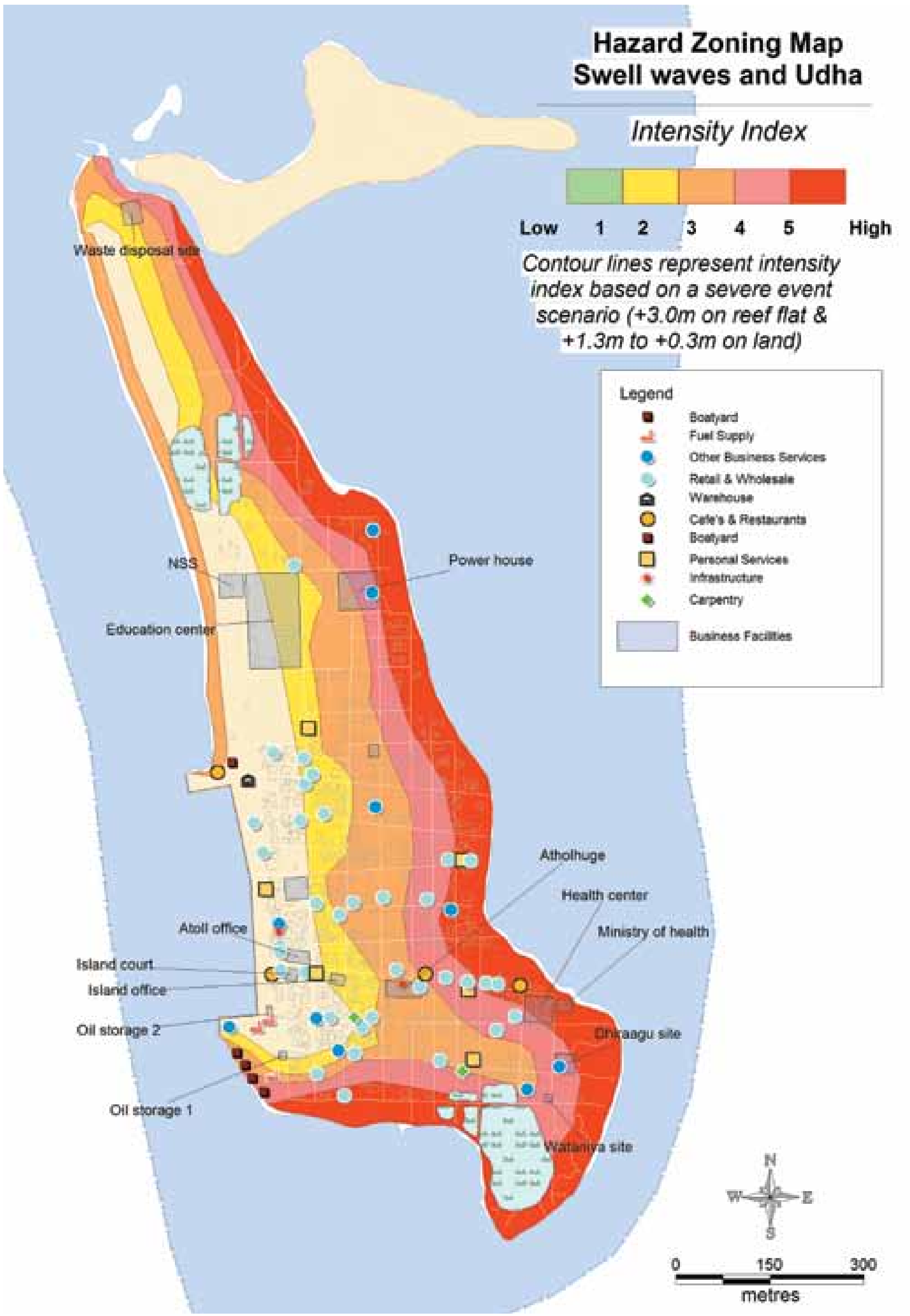
Swell waves higher than 3.0m on the reef flat are predicted to reach the eastern coastline of the island. These waves may penetrate 100 to 300m inland. The western side of the island is relatively protected due to the cumulative effects of higher elevation of the area and the lower drainage basin on the east.

The following physical, human and natural impacts were identified for a severe swell wave event:

| Physical Impacts | Human Impacts | Natural Impacts |
|---|---|---|
| • Lifeline infrastructure at risk, including hospital, powerhouse and communications. | • No injuries or loss of lives.<br>• Disruption to daily activities. | • Damage to coastal vegetation.<br>• Salt water intrusion to wetland and island water lens.<br>• Contamination of groundwater.<br>• Damage to crops.<br>• Loss of soil productivity.<br>• Damage to coral reefs.<br>• Geomorphologic changes in the north western shoreline and lagoon. |

The combination of hazard intensity and physical vulnerability is presented in the risk map below.

**Figure 6.3:** Risk Map: Swell Wave, Severe Magnitude




**Source:** UNDP, 2009b

*Tsunami*

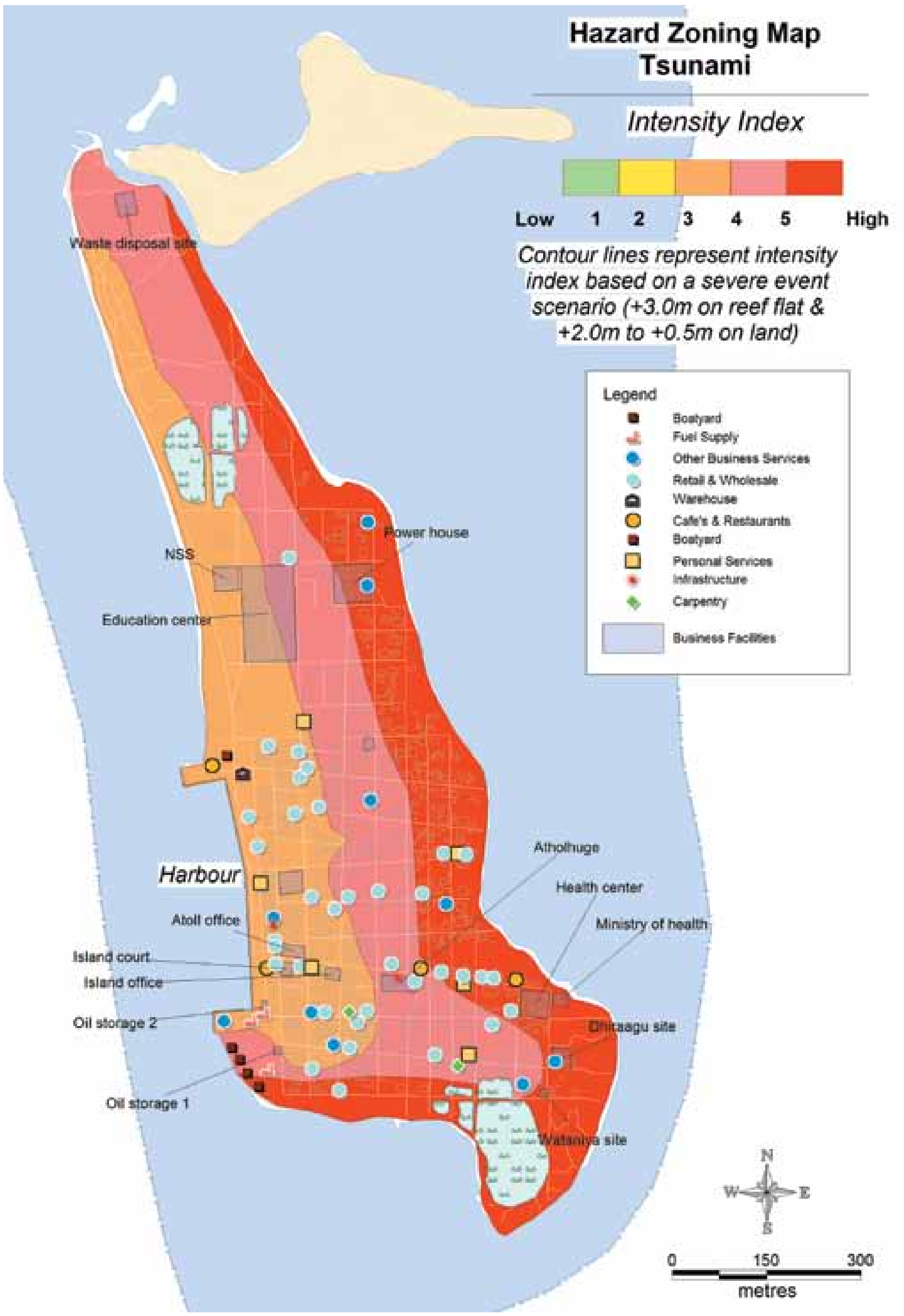
When a severe threshold tsunami event is considered, the entire island is predicted to be affected. The intensity of floodwaters will be most intense 100-150m from the shoreline. Intensity is also expected to be high up to 300m inland where the flood waters will meet relatively higher ground in most of the mid to southern half of the island.

The following physical, human and natural impacts were identified for a severe tsunami event:

| Physical Impacts | Human Impacts | Natural Impacts |
|---|---|---|
| • Very high vulnerability of lifeline infrastructure including harbour, hospital, powerhouse and communications.<br>• Damage to backyard crops.<br>• Damage to wholesale and retail stocks.<br>• Some public administration buildings at risk.<br>• Damage to fuel supply, waste management site. | • In a high magnitude tsunami, 0.1% of lives may be lost, 5% may be injured. | • Damage to coastal and inland vegetation<br>• Salt water intrusion to wetland and island water lens.<br>• Contamination of groundwater.<br>• Damage to crops.<br>• Loss of soil productivity.<br>• Damage to coral reefs. |

The combination of hazard intensity and physical vulnerability is presented in the risk map below.

Figure 6.4: Risk Map: Tsunami, Severe Magnitude




Source: UNDP, 2009b

### 6.2.3 Estimated Losses Without Protection Measures

Associated damages or losses were estimated for each hazard type as outlined in the methodology (Section 3.3). These figures represent tangible losses only, in the scenario without any risk reduction measures. As a benchmark, the estimated value of the Viligilli economy is RF350 to RF450 million (UNDP, 2009a).

Annex F contains full details of the estimation of losses, as estimated in DIRAM2.

**Table 6.2:** Estimated Losses for Viligili, for severe magnitude hazards, by hazard type

| Sector | Tsunami losses (RF) | Swell waves and storm surge losses (RF) | Rainfall flooding losses (RF) |
|---|---|---|---|
| Infrastructure | 12,784,000.00 | 1,517,000.00 | 0.00 |
| Households | 12,020,000.00 | 1,190,000.00 | 80000 |
| Fisheries | 700,000.00 | 60,000.00 | 0 |
| Agriculture | 500,000.00 | 100,000.00 | - |
| Wholesale and retail trade | 3,725,000.00 | 670,000.00 | 130,000 |
| Manufacturing | 830,000.00 | 170,000.00 | - |
| Transport, storage and communications | 101,000.00 | 101,000.00 | - |
| Construction | 165,000.00 | 165,000.00 | - |
| Hotels and restaurants | 144,000.00 | 64,000.00 | - |
| Public Administration | 2,000,000.00 | 200,000.00 | - |
| Other community, social and personal service activities | 230,000.00 | 95,000.00 | - |
| Real Estate, renting and business activities | 204,000.00 | 4,000 | - |
| Tourism | 400,000.00 | 200,000 | - |
| Total | 33,803,000.00 | 4,328,000.00 | 210,000.00 |

**Source:** UNDP, 2009a

It is assumed, based on consultation with local officials on the islands, that losses are reduced to 40% and 10% of the total loss estimations for medium and low magnitude events respectively.

Furthermore, it is estimated that a severe magnitude tsunami will result in human losses of 0.1% of the population, with injuries to 5% of the population. Based on the VSL calculation described in the methodology, and a total population of 1,976[1], this equates to a financial loss of RF 29,200,340. It is assumed that these losses only occur in a severe magnitude tsunami (there are no recorded fatalities associated with other events such as swell waves).

**Table 6.3:** Estimated Losses for Viligili, by hazard magnitude

| Magnitude | Estimated Losses (RF) | | |
|---|---|---|---|
| | Tsunami losses | Swell waves and storm surge losses | Rainfall flooding losses |
| Low | 6,300,334 | 432,800 | 21,000 |
| Moderate | 25,201,336 | 1,731,200 | 84,000 |
| Severe | 63,003,340[1] | 4,328,000 | 210,000 |

[1] This is based on the census population, rather than the registered population, as the census more accurately reflects the number of people actually present on the island.

## 6.3 Identification of Risk Management Options, Costs and Benefits

A variety of risk management options are available to help mitigate against hazard impacts and reduce the losses outlined above. Risk management can comprise a whole suite of responses, from harder physical measures such as man-made coastal protection and resilient harbours, to softer measures including risk awareness programmes, preparedness measures such as early warning systems, and vulnerability reduction measures such as livelihood diversification.

This section identifies a range of possible options, both soft and hard, and estimates costs and associated benefits (or reduction in losses) associated with those measures.

### 6.3.1 Risk Management Options

The following risk management options for Viligili were identified based on the findings of DIRAM1 and DIRAM2:

- Man made coastal protection;
- Most vulnerable houses & buildings retrofitted;
- Flood mitigation for lifeline infrastructure;
- Resilient harbour;
- All rainfall flood prone areas fitted with drainage;
- EPZ around island;
- Evacuation facilities; and
- Risk awareness programmes.

These were further grouped into four risk management scenarios or options, each providing a "package" of protection: 1) no man-made protection; 2) Full Safe Island Protection; 3) Selected Safe Island Protection and 4) Limited Protection. The following table describes each of these scenarios in greater detail.

Table 6.4: Risk Management Scenarios for Viligili

| Protection Type | Characteristics of Mitigation Measures | Type of Hazard Mitigated |
|---|---|---|
| No man-made protection ("without" scenario) | Natural or none | None related to man-made measures |
| Safe Island Protection | Coastal protection 2.5m high; most vulnerable houses & buildings retrofitted; flood mitigation for lifeline infrastructure; resilient harbour; all rainfall flood prone areas fitted with drainage; EPZ around island; evacuation facilities. | All hazards but not a severe strength tsunami; waves will over top and flood up to 2.0m, enough to cause damage to 50% of the island, but other mitigation measures will ensure damage is limited to 20%; Swell waves may overtop but unlikely to cause damage with other mitigation measures in place; partial protection against wind damage. |
| Selected Safe Island Protection | Coastal protection 2.5m high; resilient harbour; all rainfall flood prone areas fitted with drainage; EPZ around island. | All hazards but not a severe strength tsunami; waves will over top and flood up to 2.0m, enough to cause damage to 50% of the island without other mitigation measures; Swell waves may overtop and likely to cause moderate damage to 5% of the island. Rainfall flooding will be mitigated; no protection against wind damage. |
| Limited protection | Coastal protection 2.0m high as a revetment; low cost rainfall flood mitigation measures. | Will cause severe damage during a maximum strength and moderate strength tsunami; waves will over top and flood up to 2.5m, enough to cause damage to 60% of the island without other mitigation measures; Severe strength swell waves may overtop and likely to cause damage to 20% of the island. Rainfall flooding will be partially mitigated; no protection against wind damage. |

### 6.3.2 Costs

Each of these measures incurs fixed and, in some cases, variable costs (for example, for regular maintenance). The following table summarises the fixed costs associated with each risk management scenario, and this is followed by a description of associated variable costs, annualised.

Clearly, fixed costs can vary depending on the specific parameters of the measure being put in place (size, height) and the materials used. Annex G contains a full description of the criteria used to determine the costs described in the table below.

**Table 6.5:** Fixed Costs Associated with Risk Management Scenarios for Viligili

| Protection Type | Fixed Costs (RF) | Total Fixed Cost (RF) |
|---|---|---|
| No protection ("without" scenario) | 0 | 0 |
| Safe Island Protection | Coastal protection (east and south): 92,485,036<br>Coastal protection (west): 33,030,370<br>EPZ around island: 14,000,000<br>Resilient harbour: 37,312,173<br>Evacuation facilities: 3,855,000<br>Flood mitigation for lifeline infrastructure: 2,134,100<br>Houses & buildings retrofitted: 10,200,000<br>Drainage in rainfall flood prone areas: 1,736,166 | 194,752,845 |
| Selected Safe Island Protection | Coastal protection (east and south): 92,485,036<br>EPZ around island: 14,000,000<br>Resilient harbour: 37,312,173<br>Evacuation facilities: 3,855,000<br>Flood mitigation for lifeline infrastructure: 2,134,100<br>Houses & buildings retrofitted: 10,200,000<br>Drainage in rainfall flood prone areas: 1,736,166 | 161,722,475 |
| Limited protection | Coastal protection (east and south, cement bags): 8,400,000<br>EPZ around island: 7,000,000<br>Resilient harbour: 37,312,173<br>Houses & buildings retrofitted: 7,500,000<br>Drainage in rainfall flood prone areas: 236,166 | 60,448,339 |

Several of these measures will incur maintenance costs, as follows:

- The resilient harbour will require maintenance dredging at a cost of RF 5,000,500 every 10 years.
- The artificial drainage systems will require maintenance at a cost of RF 308,165.67 every 2 years.
- Risk awareness programmes, including creating disaster risk awareness among businesses, insurance awareness among high-risk investments, and awareness among the population to use banking facilities to store cash, will be run every three years at a cost of RF 550,000.

### 6.3.3 Benefits (reductions in losses)

The benefits associated with each of the risk management scenarios described in the previous section are equivalent to the reduction in losses.

As explained in the methodology, the benefits were estimated as a percentage reduction in losses. Table 6.6 below provides a detailed explanation of the assumptions used, and the estimated percentage reduction in losses, for each risk management scenario and each magnitude of hazard, based on these assumptions.

**Table 6.6:** Reduction in Losses Associated with Risk Management Scenarios in Viligili (%)

| Protection Type | Severe tsunami | | Moderate tsunami | | Low tsunami | |
|---|---|---|---|---|---|---|
| | Level of protection | Reduction in losses | Level of protection | Reduction in losses | Level of protection | Reduction in losses |
| Safe Island | Severe strength tsunami will over top and flood with a depth of 2.0m on land, enough to cause damage to 50% of the island, but other mitigation measures will ensure damage is limited to 20%; rising water table may damage sewerage system. | 65% | Waves above 2.5 m will over top and flood up to 0.5 m on land, enough to cause damage to 25% of the island. Lack of mitigation measures will ensure damage is limited to 5%; rising water table may damage sewerage system. | 85% | Full protection: 2.5 m high seawall will prevent over topping | 100% |
| Selected Safe Island | Severe strength tsunami will over top and flood with a depth of 2.0m on land, enough to cause damage to 50% of the island. | 45% | Waves above 2.5 m will over top and flood up to 0.5 m on land, enough to cause damage to 25% of the island. Rising water table may damage sewerage system | 70% | Full protection: 2.5 m high seawall will prevent over topping | 100% |
| Limited Protection | Will cause severe damage during a maximum strength tsunami; waves will over top and flood up to 2.5m, enough to cause damage to 60% of the island without other mitigation measures. | 25% | Will cause severe-moderate damage during a moderate strength tsunami; waves will over top and flood up to 1.0m, enough to cause damage to 35% of the island without other mitigation measures. | 40% | Will cause moderate-low damage during a wave event; waves may over top and flood up to 0.25m, which may not cause much damage on land but will affect some coastal infrastructure, particularly coastal protection. | 80% |

| Protection Type | Severe tsunami | | Moderate tsunami | | Low tsunami | |
|---|---|---|---|---|---|---|
| | Level of protection | Reduction in losses | Level of protection | Reduction in losses | Level of protection | Reduction in losses |
| Safe Island | Waves will over top and flood with a depth of 0.5 m on land, enough to cause damage to 20%, but impacts may be reduced to 5% with other mitigation measures. | 75% | Swell waves above 2.5 m will over top and flood up to 0.5 m on land, enough to cause damage to 15% of the island, but other mitigation measures will ensure damage is limited to 3%. | 85% | Full protection: 2.5 m high seawall will prevent over topping. | 100% |
| Selected Safe Island | Waves will over top and flood with a depth of 0.5 m on land, enough to cause damage to 20% of island. | 50% | Swell waves above 2.5 m will over top and flood up to 0.5 m on land, enough to cause damage to 15% of the island. | 70% | Full protection: 2.5 m high seawall will prevent over topping. | 100% |
| Limited Protection | Swell waves will over top and flood over 1.0 m, enough to cause damage to 30% of the island without other mitigation measures. | 35% | Swell waves will over top and flood up to 1.0 m, enough to cause damage to 15% of the island without other mitigation measures | 45% | Will cause moderate-low damage during a wave event; waves may over top and flood up to 0.25m, which may not cause much damage on land but will affect some coastal infrastructure. | 85% |

| Protection Type | Severe tsunami | | Moderate tsunami | | Low tsunami | |
|---|---|---|---|---|---|---|
| | Level of protection | Reduction in losses | Level of protection | Reduction in losses | Level of protection | Reduction in losses |
| Safe Island | Full protection; limited flooding and only for a short period. Drainage clogging may cause occasional low level flooding | 90% | Full protection; limited flooding and only for a short period. Drainage clogging may cause occasional low level flooding | 95% | Full protection; limited flooding and only for a short period. Drainage clogging may cause occasional low level flooding. | 99% |
| Selected Safe Island | Full protection; limited flooding and only for a short period. Drainage clogging may cause occasional low level flooding. Occasional low level flooding in households without retrofitting. | 85% | Full protection; limited flooding and only for a short period. Drainage clogging may cause occasional low level flooding. Occasional low level flooding in households without retrofitting | 90% | Full protection; limited flooding and only for a short period. Drainage clogging may cause occasional low level flooding | 98% |
| Limited Protection | Moderate level of protection and severe events may cause damage to drainage and cause moderate levels of flooding | 70% | Moderate-low level of protection and severe events may cause damage to drainage and cause low levels of flooding | 75% | Moderate-low level of protection and severe events may cause damage to drainage and cause low levels of flooding | 85% |

## 6.4 Findings: Cost Benefit Analysis

The Cost Benefit Analysis was run for each of the risk management scenarios described above.

The estimated damages described above were weighted by the probability of a given magnitude of hazard occurring (see Table 6.1). So, for example, while the losses associated with a severe event are higher, these are weighted by the lower probability of this event happening. DIRAM1 provides three ranges of estimates for the probability of a hazard event occurring – a minimum under current conditions, a maximum under current conditions, and a probability under climate change (estimated for 2050). The baseline analysis is run for each of these three scenarios.

This is repeated for all three hazards, and the combined analysis gives an estimate for total yearly risk associated with multiple hazards, as well the total yearly benefits associated with multiple hazards. These figures are then weighted against the cost figures to derive the following figures:

The Benefit to Cost Ratio: this figure divides the discounted value of benefits by the discounted value of costs. If the ratio is greater than 1, the benefits outweigh the cost, and therefore there is a financial argument for proceeding with the project. Anything below 1 implies a negative return.

The Net Present Value calculates the discounted net benefits (benefits minus costs) year on year. If the figure is positive, there is a financial argument for going ahead with the project. Anything below 0 implies a negative return.

The analysis used a discount rate of 7.5% and a project lifetime of 50 years (the estimated lifetime of the longest lived asset, the coastal protection works).

Minimum probability of hazard occurrence – current climate

According to DIRAM1 estimates for the minimum probability of a hazard event occurring, a severe tsunami is estimated to occur every 100 years, a severe storm surge every 100 years, and severe flooding from heavy rainfall every 10 years (see Table 6.1 for the full range of hazard probabilities under low and moderate magnitude events).

These conditions yield the following cost benefit results.

Table 6.7: Cost Benefit Findings for Viligili: Minimum hazard occurrence

| Protection Type | Benefit to Cost Ratio | Net Present Value (RF) |
|---|---|---|
| Safe Island Protection | 0.28 | -179,159,791 |
| Selected Safe Island Protection | 0.29 | -153,708,573 |
| Limited protection | 0.42 | -58,696,320 |

Maximum probability of hazard occurrence – current climate

According to DIRAM1 estimates for the maximum probability of a hazard event occurring, a severe tsunami is estimated to occur every 10 years, a severe storm surge every 10 years, and severe flooding from heavy rainfall every 3 years (see Table 6.1 for the full range of hazard probabilities under low and moderate magnitude events).

These conditions yield the following cost benefit results.

Table 6.8: Cost Benefit Findings for Viligili: Maximum hazard occurrence

| Protection Type | Benefit to Cost Ratio | Net Present Value (RF) |
|---|---|---|
| Safe Island Protection | 0.93 | -18,202,523 |
| Selected Safe Island Protection | 0.89 | -22,941,082 |
| Limited protection | 1.23 | 23,529,219 |

Probability of maximum hazard occurrence under climate change

According to DIRAM1 estimates for the maximum probability of a hazard event occurring under climate change, a severe storm surge is estimated to occur every 3 years, and severe flooding from heavy rainfall every 3 years (see Table 6.1 for the full range of hazard probabilities under low and moderate magnitude events). The analysis did not include an estimate of climate impacts on tsunami events, so the maximum probability under current conditions is taken, and hence it is assumed a severe tsunami will occur every 10 years.

These conditions yield the following cost benefit results.

**Table 6.9:** Cost Benefit Findings for Viligili: Maximum hazard occurrence under climate change

| Protection Type | Benefit to Cost Ratio | Net Present Value (RF) |
|---|---|---|
| Safe Island Protection | 1.00 | 1,002,046 |
| Selected Safe Island Protection | 0.96 | -8,403,115 |
| Limited protection | 1.33 | 33,690,198 |

The findings indicate that there is not a clear financial argument for proceeding with any of the risk management scenarios, except the limited protection scenario under maximum hazard occurrence, under current and future climate conditions.

## 6.5 Sensitivity Analyses

The baseline analysis presented above is built upon a number of assumptions and uncertainties, but is nonetheless based on the best professional judgement of the authors, given the data available.

Because there is so much uncertainty in certain factors included in the analysis, for example the probability of a hazard event occurring, sensitivity analysis is used to test the underlying assumptions.

For this analysis, the following assumptions were tested, in order to evaluate the findings under a range of scenarios. The sensitivity analyses are run for the minimum probability of hazard occurrence, and the maximum probability under climate change. The following assumptions were tested:

- The damages associated with each hazard event were doubled to account for the fact that intangible losses could not be estimated for this study (and hence greater benefits as a result of risk management were calculated).
- The discount rate was varied between 0% and 15%. There is a strong argument that benefits to future generations should not be discounted at all, and this is particularly true in the case of small island states and climate change, where there is a duty of care to avoid adverse consequences to future generations, and therefore fully value future benefit streams.
- The assumption of a 50-year lifetime for the CBA is quite long, and so a 25-year lifetime was also assessed.

The following tables show the range of possible estimates that can be derived from the sensitivity testing. Positive Benefit to Cost Ratios (BCR) are highlighted in green, whereas negative ones are highlighted in blue.

**Table 6.10:** Sensitivity Testing: Minimum hazard probability, Benefit to Cost Ratios

| Protection Type | Double damages (intangible losses) | Discount Rate 0% | Discount Rate 15% | 25 year project lifetime |
|---|---|---|---|---|
| Safe Island Protection | 1.07 | 0.63 | 0.17 | 0.25 |
| Selected Safe Island Protection | 1.11 | 0.61 | 0.18 | 0.26 |
| Limited protection | 1.64 | 0.71 | 0.29 | 0.39 |

**Table 6.11:** Sensitivity Testing: Maximum hazard probability under climate change, Benefit to Cost Ratios

| Protection Type | Double damages (intangible losses) | Discount Rate 0% | Discount Rate 15% | 25 year project lifetime |
|---|---|---|---|---|
| Safe Island Protection | 3.43 | 2.24 | 0.62 | 0.89 |
| Selected Safe Island Protection | 3.38 | 2.03 | 0.60 | 0.86 |
| Limited protection | 4.74 | 2.24 | 0.91 | 1.22 |

The factor that creates the greatest variation in the analysis is the doubling of damages. The assumption that benefits could be doubled to account for intangible losses (those things that can't be valued in the analysis, such as social impacts, the value placed on the existence of the islands, etc) seems reasonable. All scenarios come out positive once the estimate for intangible losses is added in, yielding BCRs ranging between 1.07 and 3.43.

# 7. COST BENEFIT ANALYSIS –TH VILUFUSHI

## 7.1 Introduction

Th Vilufushi is located at the southern end of two chains of atolls in the central Maldives, approximately 187 km from the nation's capital, Male'. The island forms part of the Kolhumadulu Atoll (Thaa Atoll). Vilufushi is located in a strategic position, due to its access to fishing grounds east of the Maldives. (UNDP, 2009a).

The original Vilufushi Island was a small island with a length of 800m and a width of 270m at its widest points. The total surface area of the island was 15 ha (0.15 km2) and the reef surface area was 3,558 ha (35.6 km2). The reef also hosts nine other islands, of which two are inhabited islands (Madifushi and Dhiyamigili), and one is being developed as a tourist resort (Kalhufahalafushi). The original island had an elevation ranging from +0.8 to +1.5m above MSL.

The original Vilufushi Island was densely populated with over 100 persons per hectare, making it one of the most overcrowded islands in the Maldives. The settlement had expanded to the edges of the coastline and new plots were being developed with ad-hoc land reclamation.

The island was completely devastated by the Indian Ocean tsunami of

December 2004 and the inhabitants were relocated to neighbouring islands.

Since then, the island has been rebuilt, including extensive land reclamation, topographic levelling, coastal protection, new housing and new public infrastructure. All existing structures on the original island have been removed and new land has been reclaimed to make Vilufushi four times its original size. The new land area is 61 ha (0.61 km2) and with a length of 1,260m and a width of over 550m. The entire island has been levelled to +1.4m above MSL.

Vilufushi is the first island developed to the specifications of the new safe island concept. It contains a coastal protection zone, comprised of a revetment, an artificial ridge (+2.4 m above MSL), and a drainage zone. The revetment extends right around the island except for 2 small zones on the western side of the island. A new harbour has been dredged on the eastern side and is protected by boulders. (UNDP, 2009a).

The island is still under construction and a number of new infrastructure is yet to be fully operational at the time of the survey. It has only been two months since the displaced population returned to the island (at the time of writing) and as such economic establishments and economic activity on the island are very limited.

Unlike the previous two island studies which were forward looking, this study is backward looking – in other words, Vilufushi has already undergone major works to make it into a "safer island".

## 7.2 Multi-hazard Risk Profile for Th Vilufushi

According to the available historic records and field interviews, Vilufushi has been exposed to multiple hazards in the past but its exposure was insignificant with negligible impacts. No swell wave related flooding was reported. Although the island received heavy rainfall, rainfall flooding has not been an issue due to the arch-shaped topography and the narrow width of the island. Wind storms were the only hazard with a high frequency and intensity, occasionally causing structural and vegetation damage. The Indian Ocean tsunami of 2004 was the only major event on the island and caused extensive damage and fatalities.

### 7.2.1 Hazard Assessment

This section briefly describes the characteristics of each of the three hazard types, followed by a table presenting the return period, e.g. the likelihood of a given hazard happening in any given year, for each of the hazards, as well as the changes in probability under climate change.

Heavy Rainfall: Historic records show that Vilufushi has not been affected by rainfall flooding. As noted earlier, this can be most likely attributed to the well-established natural drainage system. The high rainfall often led to small gullies along the east-west oriented roads.

The reconstruction of Vilufushi through the extensive land reclamation and topographic profiling will have changed the natural drainage system of the island, and thus the rainfall flooding pattern. Presently, it is hard to predict the impacts of these changes.

Swell waves: The location of Vilufushi makes the island relatively sheltered from possible swell waves approaching from the southern Indian Ocean. Moreover, the shape of the atoll and the atoll's location close to the western line of atolls in the archipelago, also tend to protect the island from abnormal swell waves approaching from a south-easterly direction. There is a probability that swell waves approaching from the southwest could penetrate through the 4km wide western reef pass and propagate to the western shoreline of Vilufushi (Kench et al., 2006). However, the impacts of such waves are expected to be minimal due to the narrow channel width and presence of patch reefs within the atolls. Vilufushi is more likely exposed to wind waves during both NE and SW monsoon seasons, causing low levels of annual flooding.

The reconstructed island is unlikely to be flooded from its eastern side - based on the predicted maximum storm surge scenario of a 1.53m storm tide and a probable maximum swell wave height of 2.0m above MSL. There is a small probability that wave refraction around the island may cause low levels of inundation on the unprotected areas of the western coastline.

Swell waves and storm surges with a wave height of 3.2m (over the reef flat) may hardly impact the island assuming its present coastal protection structures remain intact. The western side of the island is exposed to SW wind waves but their intensity is predicted to be low. Moreover, swell waves or surges could refract around the island or cause a rise in tide level, which could flood the western coastal areas. The intensity of such events is expected to be moderate to low.

Tsunami: According to UNDP (2006), Vilufushi is located in a high tsunami hazard zone. Vilufushi was amongst the worst affected islands in the Maldives in the 2004 tsunami. The entire island was inundated during this event as flood waters travelled from coast to coast with little loss of energy. The wave height was reported to be 2.0m on the eastern coastline of the island and 0.5m on the western coastline of the island. There was extensive damage to the majority of properties on the island and the island also incurred the heaviest casualties and fatalities in the Maldives. Houses and structures located less than 100m from the eastern coastline suffered the most severe damage. The tsunami water level reduced exponentially towards the western coastline.

The maximum tsunami wave height predicted for Vilufushi is 3.2 – 4.5m (UNDP,

2006). The empirical tsunami flood decay curve for a 4.5m wave predicts inundation across the newly developed island and the first 150-200m from the eastern coastline will be a destructive zone. Tsunami waves may also penetrate into the atoll lagoon with a wave height of 1.7m and inundate the island from the lagoonward side with a water depth of 0.3m. In summary, the entire island will be flooded by a 4.5m tsunami. The only predicted area for low impact is the artificially raised 'high ground' for emergency evacuation.

Climate Change: Climate change is expected to increase the intensity and frequency of the above-mentioned hazards in the Maldives. Furthermore, a significant impact associated with climate change is rising sea level. Consultation in the Maldives consistently suggested that the measures necessary to protect an island against sea level are so extensive and expensive that they are simply not feasible. It was further suggested that perhaps the only feasible defence is to protect natural processes – development of ridges, accretion and erosion, growth of coral reefs – to the maximum extent possible with the hope that they will be able to protect against this slow-onset disaster, as well as protect against increased sea surges as a result of sea level rise.

Hence the following analysis takes account of climate change impacts on existing hazards, but does not analyse measures to protect directly against sea level rise.

Hazard Probabilities for Vilufushi

The following table describes the intensity thresholds and return periods (e.g. the likelihood that a hazard of a given severity will occur in any given year). It also provides estimates of the probability of events under climate change.

The data is provided for low, moderate and severe hazard events. Probabilities under climate change are only available for heavy rainfall, and swell waves, due to data availability.

**Table 7.1:** Hazard Assessment for Vilufushi

| Hazard | Intensity Threshold (rainfall in 24 hours) (wave run up on reef flat) | | | Return Period (%) | | | Probability 2050 (under climate change) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Low | Mod | Severe | Low | Mod | Severe | Low | Mod | Severe |
| Heavy Rainfall | <75mm | >75mm | >175mm | 66-90% | 33-66% | 10-33% | 90-99% | 33-66% | 10-33% |
| Swells waves | <3.5m | >3.5m | >4.0m | 33-66% | 1-10% | <1% | 90-99% | 10-33% | <1% |
| Tsunami | <3.5m | >3.5m | >4.0m | 33-66% | 10-33% | 1-10% | n/a | n/a | n/a |

**Source:** UNDP, 2009a

### 7.2.2 Impact Assessment

Each of the three hazards impacts on the island in different ways and to different degrees. Some of these impacts can be quantified, while some are more qualitative in nature. The following section provides an overview of the main impacts (both quantitative and qualitative) – physical, human and natural – for each of the hazards on the original island.

Furthermore, it is important to note that the degree of impacts will differ depending on the magnitude of the hazard (low, moderate, severe). However, it was not within the scope of DIRAM1 (UNDP, 2009a) or DIRAM2 (UNDP, 2009b) to present a detailed assessment of impacts at different magnitudes. Therefore the data presented is only for severe magnitude events.

*Flooding from Heavy Rainfall*

Heavy rainfall has not historically caused damage to the island due to natural drainage patterns.

The following physical, human and natural impacts were identified:

| Physical Impacts | Human Impacts | Natural Impacts |
|---|---|---|
| • None | • None | • None |

*Swell Wave*

According to the UNDP (2006), Vilufushi is located in a moderate storm surge hazard zone, with a probable maximum water level up to 0.6m above MSL or 1.5m under a storm tide, but recent events in the area have not shown any flooding caused by these events.

The following physical, human and natural impacts were identified:

| Physical Impacts | Human Impacts | Natural Impacts |
|---|---|---|
| • None to minimal | • None to minimal | • None to minimal |

*Tsunami*

When a severe threshold tsunami event is considered, the entire island is predicted to be affected, as discussed in the previous section.

The following physical, human and natural impacts were identified:

| Physical Impacts | Human Impacts | Natural Impacts |
|---|---|---|
| • About 85% of all structures and investments on the island damaged or destroyed, including infrastructure (harbour, school, health centre, power and sewerage network), 90% of houses, all business establishments, fishing vessels, fish processing areas and backyard crops. | • Loss of life and injuries | • Extensive damage to vegetation, coastal erosion, soil erosion, and contamination and salinisation of freshwater lens. |

### 7.2.3 Estimated Losses Without Protection Measures

The estimated losses without protection are equivalent to the losses that would have been experienced on Vilufushi before the tsunami. However, as explained in the methodology, because the island was almost completely destroyed by the tsunami, it is not possible to assess the value of the Vilufushi economy and infrastructure through field visits and empirical data (as was done with the other two study islands).

In order to estimate economic losses under no protection, proxy values were used from two other islands. The total economic value of these islands was divided by their population to arrive at an economic value per capita (RF 39k and RF 40k respectively), which was then averaged and applied to the total population of Vilufushi before the tsunami, arriving at an economic value of RF 47,400,000. It is important to note, however, that Kudhuvadhoo and Viligili are both atoll capitals and therefore may have a higher per capita economic value than Vilufushi, and thus this approximation may overstate the value of the Vilufushi economy.

In order to estimate infrastructure losses under no protection, records of infrastructure on the island were used to reconstruct the value of that infrastructure using standard rates and assumptions. The total infrastructure value was estimated at RF 143,676,078.

Hence total physical losses without protection under a severe tsunami are estimated as RF 191,076,078 (the full value of the infrastructure and economy given that the island suffered near complete destruction in 2004). It is assumed that total losses under a severe swell wave would be 50% of the total losses under a tsunami. This estimation is based on the estimated maximum flood height of 1.8m (or 3.0m on reef flat).

**Table 7.2:** Estimated Losses for Vilufushi, for high magnitude hazards, by hazard type

| Sector | Tsunami losses (RF) | Swell waves and storm surge losses (RF) | Rainfall flooding losses (RF) |
|---|---|---|---|
| Infrastructure | 143,676,078 | 71,838,039 | - |
| Economy | 47,400,000 | 23,700,000 | - |
| Total | 191,076,078 | 95,538,039 | - |

**Source:** UNDP, 2009b

It is assumed, as with the other islands, that losses are reduced to 40% and 10% of the total loss estimations for medium and low magnitude events respectively.

Furthermore, it is estimated that a severe magnitude tsunami will result in human losses of 0.1% of the population, with injuries to 5% of the population. Based on the VSL calculation described in the methodology, and a total population of 2,000[1], this equates to a financial loss of RF 29,555,000. It is assumed that these losses only occur in a severe magnitude tsunami

[1] The population before the tsunami

(there are no recorded fatalities associated with other events such as swell waves).

**Table 7.3:** Estimated Losses for Vilufushi, by hazard magnitude

| Magnitude | Estimated Losses (RF) | | |
|---|---|---|---|
| | Tsunami losses | Swell waves and storm surge losses | Rainfall flooding losses |
| Low | 22,063,108 | 9,553,804 | 0 |
| Moderate | 88,252,431 | 38,215,216 | 0 |
| Severe | 220,631,078[1] | 95,538,039 | 0 |

## 7.3 Identification of Risk Management Options, Costs and Benefits

Vilufushi has been reconstructed as a "Safer Island". Because this assessment is "backward looking" (i.e. the work has already been done), this section identifies the actual measures that have been implemented (in contrast to the previous sections, which identified a range of possible measures to be undertaken).

### 7.3.4 Risk Management Interventions

The following risk management interventions for Vilufushi were undertaken:

- Land reclamation and raising of the existing height of the island;
- Man made coastal protection in the form of a revetment around the majority of the island;
- Resilient harbour;
- Reconstruction of houses and infrastructure;
- Reconstruction of all key infrastructure (power, roads, sewerage, mosques, waste management, administrative buildings, school, health centre and communications); and
- Topographically elevated evacuation area.

Furthermore, in order to be consistent with the previous two island assessments, there are a number of additional measures that would need to be undertaken to be consistent with the definition of full SIP protection (as used in this report). These include:

Adding coastal protection along the 600m of western coastline that are currently not protected;

Constructing an EPZ (re-vegetating and establishing drainage);

Retrofitting of most vulnerable houses;

Flood proofing key infrastructure; and

Installing drainage.

### 7.3.5 Costs

Each of these measures incurs fixed and, in some cases, variable costs (for example, for regular maintenance). The costs were estimated for both the existing measures (using actual expenditures) as well as the additional cost of upgrading to full SIP protection (as outlined above).

These costs were then modified to account for the fact that Vilufushi was completely destroyed, and therefore the island would have to be re-built in any case. In other words, the analysis looked at the additional costs of rebuilding Vilufushi as a safer island. Hence the cost of rebuilding back the original infrastructure (but with no safe island protection) was subtracted from the total cost, as this cost would have been incurred regardless. Furthermore, the fact that Vilufushi was rebuilt to four times its original size means the cost of rebuilding it was much higher than replacing "like for like".

The following table summarises the fixed costs associated with each risk management scenario, and this is followed by a description of associated variable costs, annualised.

**Table 7.4:** Fixed Costs Associated with Risk Management Scenarios

| | Fixed Costs (RF) | Total Fixed Cost (RF) |
|---|---|---|
| Actual expenditures (minus the cost of rebuilding back the original island) | Coastal protection, land reclamation and harbour: 295,930,026<br>Infrastructure: 95,379,096<br>Housing: 100,620,000 | 491,929,122 |
| Additional Safe Island Protection measures | Coastal protection (additional 600m on western side): 19,818,222<br>EPZ: 8,000,000<br>Flood proofing lifeline infrastructure: 600,000<br>Retrofitting high risk houses and buildings: 8,000,000<br>Constructing artificial drainage: 2,000,000 | 38,418,222 |
| TOTAL | | 530,347,344 |

Furthermore, variable costs were included for year-on-year maintenance of these measures.

### 7.3.6 Benefits (reductions in losses)

The benefits associated with developing Vilufushi as a "safer island" are equivalent to the reduction in losses.

As explained in the methodology, the benefits were estimated as a percentage reduction in losses. Table 7.5 below provides a detailed explanation of the assumptions used, and the estimated percentage reduction in losses under full SIP protection for each magnitude of hazard. Reduction in losses is not reported for rainfall flooding, because losses associated with flooding were reported as nil in the island. However, the reason flooding hasn't been experienced in the past is because the narrow width and natural drainage pattern of Vilufushi allowed for runoff of rainwater. There are significant concerns that Vilufushi, in its reconstructed state, is now flat, with a revetment that will hold in any floodwaters, and therefore there may be increased losses associated with flooding (in other words, a negative benefit). However, because the island is only newly reconstructed, it is not yet clear whether this will be a problem, and hence no losses are recorded in this analysis.

**Table 7.5:** Reduction in Losses Associated with Safe Island Protection in Vilufushi (%)

| | Severe tsunami | | Moderate tsunami | | Low tsunami | |
|---|---|---|---|---|---|---|
| Protection measures | Level of protection | Reduction in losses | Level of protection | Reduction in losses | Level of protection | Reduction in losses |
| Existing measures: Coastal protection 2.5m high; resilient harbour and evacuation facilities<br>New measures required: most vulnerable houses & buildings retrofitted; flood mitigation for lifeline infrastructure; all rainfall flood prone areas fitted with drainage; EPZ around island. | Severe strength tsunami may over top and flood with a maximum depth of 1.5m on land up to a distance of 50m, and at lower depths up to 300m inland. This is enough to cause damage to 25% of the island, but other mitigation measures will ensure damage is limited to 10%; rising water table may damage sewerage system. | 65% | Moderate strength tsunami may over top and flood with a maximum depth of 0.5m on land up to a distance of 30m, and at lower depths up to 100m inland. This is enough to cause damage to 10% of the island, but other mitigation measures will ensure damage is limited to 5%; rising water table may damage sewerage system. | 85% | Full Protection | 100% |
| | Severe Swell Wave | | Moderate Swell Wave | | Low Swell Wave | |
| Protection measures | Level of protection | Reduction in losses | Level of protection | Reduction in losses | Level of protection | Reduction in losses |
| Existing measures: Coastal protection 2.5m high; resilient harbour and evacuation facilities.<br>New measures required: most vulnerable houses & buildings retrofitted; flood mitigation for lifeline infrastructure; all rainfall flood prone areas fitted with drainage; EPZ around island. | Severe strength wave may over top and flood with a maximum depth of 0.5m on land up to a distance of 20m, and at lower depths up to 75m inland. This is enough to cause damage to 5% of the island, but other mitigation measures may ensure damage is limited to 3%. | 90% | Waves may over top and flood at depths less than 0.5m on land up to a distance of 20m, and at lower depths up to 50m inland. This may cause damage to 3% of the island, but other mitigation measures may ensure damage is limited to 1%. | 98% | Full Protection | 100% |

## 7.4 Findings: Cost Benefit Analysis

The Cost Benefit Analysis was run for the actual works undertaken, as described above.

The estimated damages described above were weighted by the probability of a given magnitude of hazard occurring (see Table 7.1). So, for example, while the losses associated with a severe event are higher, these are weighted by the lower probability of this event happening. DIRAM1 provides three ranges in estimates for the probability of a hazard event occurring – a minimum under current conditions, a maximum under current conditions, and a probability under climate change (estimated for 2050).

This is repeated for all three hazards, and the combined analysis gives an estimate for total yearly risk associated with multiple hazards, as well as the total yearly benefits associated with multiple hazards. These figures are then weighted against the cost figures to derive the following figures:

The Benefit to Cost Ratio: this figure divides the discounted value of benefits by the discounted value of costs. If the ratio is greater than 1, the benefits outweigh the cost, and therefore there is a financial argument for proceeding with the project. Anything below 1 implies a negative return.

The Net Present Value calculates the discounted net benefits (benefits minus costs) year on year. If the figure is positive, there is a financial argument for going ahead with the project. Anything below 0 implies a negative return.

The analysis used a discount rate of 7.5% and a project lifetime of 50 years (the estimated lifetime of the longest lived asset, the coastal protection works).

Minimum probability of hazard occurrence – current climate

According to DIRAM1 estimates for the minimum probability of a hazard event occurring, a severe tsunami is estimated to occur every 100 years, minimal probability of a severe storm surge (<1%), and severe flooding from heavy rainfall every 10 years (see Table 7.1 for the full range of hazard probabilities under low and moderate magnitude events).

These conditions yield the following cost benefit results.

**Table 7.6:** Cost Benefit Findings for Vilufushi: Minimum hazard occurrence

| Protection Type | Benefit to Cost Ratio | Net Present Value (RF) |
|---|---|---|
| Safe Island Protection | 0.50 | -271,822,659 |

Maximum probability of hazard occurrence – current climate

According to DIRAM1 estimates for the maximum probability of a hazard event occurring, a severe tsunami is estimated to occur every 10 years, a severe storm surge every 100 years, and severe flooding from heavy rainfall every 3 years (see Table 7.1 for the full range of hazard probabilities under low and moderate magnitude events).

These conditions yield the following cost benefit results.

**Table 7.7:** Cost Benefit Findings for Vilufushi: Maximum hazard occurrence

| Protection Type | Benefit to Cost Ratio | Net Present Value (RF) |
|---|---|---|
| Safe Island Protection | 1.65 | 353,382,832 |

Probability of maximum hazard occurrence under climate change

According to DIRAM1 estimates for the maximum probability of a hazard event occurring under climate change, a severe storm surge is estimated to occur every 100 years, and severe flooding from heavy rainfall every 3 years (see Table 7.1 for the full range of hazard probabilities under low and moderate magnitude events). The analysis did not include an estimate of climate impacts on tsunami events, so the maximum probability under current conditions is taken, and hence it is assumed a severe tsunami will occur every

10 years.

These conditions yield the following cost benefit results.

**Table 7.8:** Cost Benefit Findings for Vilufushi: Maximum hazard occurrence under climate change

| Protection Type | Benefit to Cost Ratio | Net Present Value (RF) |
|---|---|---|
| Safe Island Protection | 1.95 | 517,500,572 |

The findings indicate that, under current conditions, there is not a financial justification for the measures undertaken on Vilufushi. The projections under maximum hazard scenarios and future climate change are positive, though the probability of hazard events will have to be very high to justify the expenditures on this basis. Most importantly, the variability in the results suggest that caution is required in making any investment decisions.

## 7.5 Sensitivity Analyses

The baseline analysis is built upon a number of assumptions and uncertainties, but is nonetheless based on the best professional judgement of the authors, given the data available.

Because there is so much uncertainty in certain factors included in the analysis, for example the probability of a hazard event occurring, sensitivity analysis is used to test the underlying assumptions.

For this analysis, the following assumptions were tested, in order to evaluate the findings under a range of scenarios. The sensitivity analyses are run for the minimum probability of hazard occurrence, and the maximum probability under climate change. The following assumptions were tested:

The damages associated with each hazard event were doubled to account for the fact that intangible losses could not be estimated for this study (and hence greater benefits as a result of risk management were calculated).

The discount rate was varied between 0% and 15%. There is a strong argument that benefits to future generations should not be discounted at all, and this is particularly true in the case of small island states and climate change, where there is a duty of care to avoid adverse consequences to future generations, and therefore fully value future benefit streams.

The assumption of a 50-year lifetime for the CBA is quite long, and so a 25-year lifetime was also assessed.

The following tables show the range of possible estimates that can be derived from the sensitivity testing. Positive Benefit to Cost Ratios (BCR) are highlighted in green, whereas negative ones are highlighted in blue.

**Table 7.9:** Sensitivity Testing: Safe Island Protection Measures, Benefit to Cost Ratios

| Protection Type | Double damages (intangible losses) | Discount Rate 0% | Discount Rate 15% | 25 year project lifetime |
|---|---|---|---|---|
| Minimum hazard probability | 1.01 | 1.66 | 0.28 | 0.43 |
| Maximum hazard probability under climate change | 3.89 | 6.42 | 1.08 | 1.68 |

The factor that creates the greatest variation in the analysis is the doubling of damages, as well as the change in discount rate. The assumption that benefits could be doubled to account for intangible losses (those things that can't be valued in the analysis, such as social impacts, the value placed on the existence of the islands, etc) seems reasonable.

# 8. DISCUSSION OF CBA FINDINGS FOR THE THREE ISLANDS

## 8.1 Interpretation of Findings

*The findings from the Cost Benefit Analyses conducted on each of the three islands are mixed.*

On the one hand, the Thinadhoo analysis is largely positive across a range of risk management scenarios, hazard probabilities, and sensitivity analyses, with the greatest benefits arising in a limited protection scenario. By contrast, the Viligili findings are only positive in the baseline scenarios for limited protection under maximum hazard occurrence. Similarly, in Vilufushi, the baseline findings are only positive under maximum hazard occurrence, but show more positive results under sensitivity testing.

The Thinadhoo analysis is more positive for a variety of reasons. Firstly, Thinadhoo has a predicted lower intensity for a tsunami as compared with Viligili. Therefore, a standard suite of risk management measures for the two islands will afford greater protection from a tsunami in Thinadhoo. Furthermore, much of Thinadhoo's infrastructure is located away from high intensity zones associated with swell wave hazards, and is therefore easier, and hence less costly, to protect. Clearly these physical factors will play a significant role in any decisions to invest in more structural measures. Interestingly, while Thinadhoo has a larger economy and population than Viligili, the losses associated with hazards, and hence the benefits from risk reduction, are smaller for the reasons mentioned above. These findings emphasise the importance of island specific analysis and decision making.

*The findings are subject to high levels of uncertainty, which introduces more risk into any investment decisions.*

The analysis is based on the best available data, but is nonetheless subject to a high degree of uncertainty, particularly relating to the probable occurrence of hazard events (under current conditions and a changing climate), and the feasibility and associated benefits of protection measures against a range of hazard magnitudes and intensities. The decision to invest in expensive structural protection would typically use a conservative approach, only proceeding with the investment where there is a high probability of a positive return. Hence uncertainties that would yield a negative return need to be ruled out to the extent possible.

The sensitivity analyses test a range of assumptions in the analysis, to get a better understanding of how uncertainty could affect the outcome. The three most significant factors are 1) the probability of hazard occurrence, 2) the value of intangible losses, and 3) the discount rate.

1. The probability of hazard occurrence: It could be argued that the maximum hazard scenarios (under the current climate and under climate change) are generous. In order to get positive results under this scenario, severe tsunami and storm surges would need to occur once every 10 years (which seems high in light of current estimates that the 2004 tsunami is a one in 219 year event). The minimum hazard scenarios (severe tsunami/storm surge occurring once every 100 years, and severe rainfall flooding every 10 years) are not only more likely, but also take a more conservative approach to ensuring positive returns on investment.

2. The value of intangible losses: CBA is not a standalone tool – it relies on a quantification of costs and benefits of protection, and as such one of its weaknesses is that it is not able to account for the range of benefits that accrue as a result of protection, but which cannot easily be assigned a financial or economic value. These are referred to as intangible benefits. In the case of the Maldives, a key benefit is the value that is placed on the fact that the islands exist – their "existence value". While there are economic tools for valuing such a benefit, the studies required are intensive and complex, and no studies have been done to date for the Maldives. The sensitivity analyses include a doubling of losses (and hence reduction in losses, or benefits), to account for these intangibles, which in almost all cases returns positive benefit to cost ratios (under a minimum hazard probability, accounting for intangibles, the CBA ratios range from 1.48-4.33 in Thinadhoo, 0.83-1.11 in Viligili and 1.01 in Vilufushi). However, while the doubling of losses is generous, it is arbitrary, in the absence of any studies that can provide a proxy value for existence. For example, if losses are increased by 50% (as opposed to 100%), not all scenarios are positive.

3. The discount rate: It is traditional to apply a discount rate to benefits and costs that accrue in the future, as a dollar today is valued more highly than a dollar at some future date. However, recent economic theory has suggested that discount rates should be lower than normal, if not 0, in the context of environmental and other social projects, given that the benefits to future generations should not be discounted as compared with benefits to this generation. This case is even more poignant when applied to small island states facing sea level rise. However, the choice of discount rate

is highly debated, and subject to different views. In the case of this analysis, the findings are very mixed depending on the discount rate used, and so again, caution is encouraged before embarking on substantial investment decisions.

*The findings are island-specific, and need to be taken within a wider context.*

The CBA examines the costs and benefits of providing protection to each of the three islands. It does not account for the range of impacts that can accrue between islands, or at a macro-economic level (for instance, the impact of a tsunami on GDP), or the effects on neighbouring islands which rely on the regional level services offered by these islands. The Maldives have been moving towards a policy of decentralisation, with the aim of creating clusters of islands/atolls which are more autonomous, each with a well developed provincial capital. This concept is an important one in terms of risk reduction, as clustering helps to reduce risk through diversification across islands. In other words, a community that is solely reliant on fishing will have little resilience in the face of a disaster that wipes out the fishing industry. However, if this same scenario is viewed within the context of a cluster of islands, which have different levels of development, different industries, etc, risk can be spread more evenly across the population through risk transfer mechanisms (such as insurance, social safety nets). However, given that each island will still require physical protection, it is unclear that clustering would have any impact on the CBA findings on an island-by-island basis.

Furthermore, while more structural protection measures will be appropriate on some islands, they will be completely inappropriate, for example, on resort islands. This industry represents a substantial portion of GDP, and hence a more holistic perspective on reducing risk in the Maldives necessitates a shift towards a wide range of risk reduction measures.

## 8.2 Alternatives to Structural Risk Reduction

*The Maldives has several comparative advantages working in its favour, and hence in light of the findings above, a variety of alternative risk management scenarios may be more appropriate.*

The analysis is very much focused on safer island measures, which are largely structural. The Benefit to Cost Ratios do not provide a strong argument for investment in structural measures in many cases because, on the one hand, structural measures incur high costs, and these are offset by relatively low benefits due to the size of the population and associated economy and infrastructure. In other words, the financial value of the islands does not always justify the cost that would be required to protect those islands using structural measures, particularly in the short to medium term. Furthermore, the current exposure to high risk disasters is limited, given their low probability of occurrence, suggesting that investment in expensive physical measures may be better delayed until the probability of such high risk disasters is projected to increase.

The financial argument for structural protection may be positive if benefits are increased or costs are decreased. An increase in benefits requires a greater population size and/or economic value on the islands. While the ultimate aim is to expand safe islands to hold more of the population (and hence more economic value), the study islands do not yet have the infrastructure, and in some cases the land, to accommodate more people. Hence any increase in population will be offset by an increase in costs, and it is not clear that net benefits will accrue. Furthermore, there is a strong argument that suggests that expanding populations in a small geographic area simply increases risk, as more people are exposed to the same hazard. Of course, this needs to be offset against the increased argument for greater protection in more highly settled areas.

A decrease in costs could come from implementing less expensive measures that result in a reduction in losses. Structural measures may become less expensive by using lower cost materials, but in most cases this will be associated with a decrease in the strength and level of protection (and hence benefits), as well as potentially a short life span and need for more frequent repair/replacement. Alternatively, softer measures can often be inexpensive while decreasing losses substantially.

The Maldives has several comparative advantages working in its favour:

1. The greatest threat to the Maldives is sea level rise, which is slow onset (unlike other hazards such as flash flooding), and can be monitored (unlike earthquakes). Hence the Maldives can use time to its advantage to look into alternative protection options, allow for development of new technology, and lower cost innovation; and

2. The islands have their own natural adaptation processes for protecting against hazards (e.g. erosion/accretion, naturally adapted vegetation as bio-defence, building of natural sand ridges, protection from coral reefs), which have stood the test of time. While it is unclear whether these processes can keep pace with climate change, they offer a natural defence.

Furthermore, the growth of individual islands over the last 30 years has shown that they are in constant need for additional land for expansion. The evidence from the major population centres (for example, Male' and even the three study islands – Thinadhoo, Vilufushi and Viligili) proves that the need for expansion is likely to be present even in the future. Establishing hard and expensive structures like coastal protection may turn out to be a waste of funds if the islands are to be enlarged beyond those physical structures.

Hence a variety of alternative risk management scenarios may be more appropriate in the context of the Maldives. The following discussion investigates a number of softer options by looking at the specific risks facing the Maldives.

### 8.2.1 Tsunami risk

Severe tsunamis are highly unlikely, and very expensive to protect against (in fact the full SIP protection scenario does not even provide complete protection against a severe magnitude tsunami). A range of responses may include softer measures, that can persist over the longer term given the infrequent occurrence of these events, such as improved land use and building codes (see next section), and early warning.

Data was gathered on the costs of implementing early warning, which is a relatively low cost option, and already has government commitment, to give an idea of the costs and benefits that might result. The analysis is not a full CBA, but rather provides indicative figures.

#### *Costs of early warning*

The government figures on the cost of establishing early warning are detailed in Table 8.1 below. Note that other systems are being investigated which may have lower or higher costs.

**Table 8.1:** Costs of Establishment of National Early Warning System

| QTY | | Amount |
|---|---|---|
| 1 | Doppler weather radar | 17,959,330.00 |
| 1 | WIMAX link between Rader and MET | 207,053.34 |
| 1 | Satellite Receiving system | 1,663,875.50 |
| 1 | Short period seismometer | 549,368.70 |
| 3 | Tide station upgrade | 765,000.00 |
| 1 | GTS Systems upgraded | 1,912,500.00 |
| 2 | Installation of 2 Broadband seismometers in 2 Islands | 1,367,454.00 |
| 1 | Satellite phone | 19,125.00 |
| 2 | Automatic weather station | 1,364,437.04 |
| 11 | Automatic weather station | 1,181,043.67 |
| | System Integration | 3,740,302.40 |
| | Display system for real time monitoring | 1,497,490.43 |
| | Sadis workstation | 752,697.16 |
| Total RF | | 32,979,677.24 |
| Total USD | | 2,586,641.35 |

In addition, most islands currently lack a raised shelter to evacuate to in the case of a warning. The cost of building a 2-story evacuation shelter is estimated at RF3.8m. There are 200 inhabited islands, and 80% of these are located on the eastern rim of their atolls and hence most vulnerable to tsunami. At a maximum, the total estimated cost for building evacuation shelters on these islands is RF608m. On the other hand, only a handful of islands lost lives from the tsunami, and therefore it could be argued that evacuation shelters are only needed on islands that are at highest risk. If evacuation shelters are built on the 20% of islands that are most at risk from tsunami, the cost would be RF152m. Also, retrofitting existing tall and strong buildings, such as schools or mosques, so as to provide an additional evacuation service should the need arise could also be a lower cost option. Furthermore this approach will help to ensure that an 'evacuation centre' has a year-round function and thus maintenance costs are absorbed within existing budgets.

Finally, the estimate does not include the cost of training of officials for implementing the EWS and awareness raising so that the public knows what to do in case of a warning.

Total costs are estimated between 185 and 641m RF, for an average of 413m. These costs may decrease if retrofitting of existing buildings is an appropriate/feasible alternative, and equally training/public awareness may elevate these costs slightly.

### *Benefits of early warning*

While early warning and evacuation will not prevent damage to the most significant assets on an island (houses, infrastructure, etc), they will contribute to a significant reduction in loss of life (particularly given that the most likely tsunamis, originating from either the east or the west, are predicted to have a 2.5-3 hour lag time from their onset to the time they reach the Maldives), injuries, and smaller assets which can be transported to the evacuation facility. Furthermore, intangible benefits will be significant, through peace of mind that there is a safe shelter, as well as use of the evacuation facility as a community building.

104 lives were lost in the 2004 tsunami. Using the same calculations used in the island CBAs, and assuming that, with early warning and evacuation shelters, those people could have been brought to safety, the benefit from lives saved would accrue to over RF200m. If this value is doubled to account for intangibles, the total benefit would accrue to RF400m.

Clearly these figures are based on a number of very broad assumptions, and the accrual of benefits will depend on how frequently events occur which require evacuation, but the initial figures suggest that the costs and benefits of early warning are roughly balanced.

### 8.2.2 Risk from Rainfall Flooding and Swell Waves

Other hazard events are largely reported not to have caused severe damage in the past – rather it appears that they have been exacerbated by man-made activities (e.g. improper drainage on land reclamation results in flooding that hadn't occurred previously). The incremental cost of conducting full EIAs and ensuring that any human intervention is done properly, and with regard to decreasing rather than increasing risk, should be minimal compared to the benefit it would bring through limiting negative consequences.

An indicative analysis was conducted on the potential costs and benefits associated with implementing more rigorous land use planning guidelines to reduce man-made risk. Thinadhoo was used as a case study. It was not appropriate to try and conduct a similar analysis for Viligili, as the CBA work on this island is already subject to uncertainty due to the lack of data available on the impacts of the recent land reclamation, and for Vilufushi, as it has only just been completely reconstructed. The analysis of Thinadhoo makes an assessment of the potential costs and benefits if the 1998 land reclamation (approximately 71ha) had been conducted under more stringent land use planning. The scenario works on the assumption that more stringent guidance is introduced for 1) high impact coastal and terrestrial developments (e.g. controls for land reclamation, building of ridges and EPZs), 2) building codes (e.g. raised structures, more resilient building materials and construction methods) and 3) hazard resilient land use (e.g. the use of buffer zones that are not habited, moving critical facilities away from hazard zones).

As with the early warning analysis, this analysis is based on some very broad assumptions, but was made in the best professional judgement of the project team to give an indication of the costs and benefits involved.

#### *Costs of improved settlement planning for Thinadhoo*

The cost of improved settlement planning (incorporating the three key areas of improved guidance mentioned above) will include the cost of developing guidelines at a national level, increased costs associated with doing works to a more stringent standard, as well as staff and capacity costs to ensure that guidelines are carried out as required. Annex H contains a more complete explanation of the assumptions used to arrive at these cost figures. The figures provided are thought to be at the high end of what might be incurred in reality.

**Table 8.2:** Costs of Improved Settlement Planning for Thinadhoo

| Costs for preparing guidelines | Cost (RF) |
|---|---|
| Consultancy costs – pro-rated for Thinadhoo | |
| Developing Guideline for Hazard Resilient Land Use Planning | 8,673.75[1] |
| Developing Guideline for High Impact Coastal Developments | 8,673.75[2] |
| Updating building codes | 5,782.50[3] |
| Recurrent Costs | |
| High Impact Coastal and Terrestrial Developments | |
| Increased costs of surveying and engineering | 514,000.00 |
| Increased cost of environmental studies | 385,500.00 |
| Increased cost of contracting - reclamation leveling and drainage | 8,875,000.00 |
| Compulsory EPZ, natural ridge and re-vegetation | 7,962,500.00 |
| Capacity building to monitor and evaluate projects | 58,000.00 |
| Staffing costs | 324,000.00 |
| Building Codes | |
| Increased costs on surveying and engineering | 625,000.00 |
| Capacity building to monitor and evaluate projects | 74,000.00 |
| Additional cost of contracting | 1,800,000.00 |
| Staffing costs | 1,680,000.00 |
| Hazard Resilient Land Use | |
| Increased costs of surveying and engineering | 10,000.00 |
| Increased cost on environmental studies | 514,000.00 |
| Capacity building to evaluate and enforce development applications | 90,000.00 |
| Staffing costs | 2,520,000.00 |
| | 25,455,130.00 |

Benefits of improved settlement planning for Thinadhoo

The findings from the DIRAM reports suggest that many of the losses incurred as a result of hazards are the result of improper settlement planning – for example, housing and infrastructure are increasingly being located closer to the coastline, improper land reclamation results in a lack of drainage and increased flooding of houses, etc.

Benefits will primarily accrue in relation to flooding from heavy rainfall (which should be more or less eliminated through the use of proper drainage and siting of infrastructure), and low and moderate swell wave events (again, mostly flooding impacts which should be eliminated). However, the relocation of assets out of high risk areas, improved building codes, and establishment of ridges and EPZs will also reduce the impacts of severe swell waves and low, moderate and severe tsunami (it is assumed that these impacts are reduced by 20%).

[1] Note that this figure takes a national estimate of RF 1,734,750, prorated for Thinadhoo

[2] Note that this figure takes a national estimate of RF 1,734,750, prorated for Thinadhoo

[3] Note that this figure takes a national estimate of RF 1,156,500, prorated for Thinadhoo

*Findings*

The analysis used a similar set of scenarios to the analysis in the island-specific CBAs – two baseline scenarios were assessed, one for the minimum probability of hazard occurrence, and one for the maximum probability of hazard occurrence under climate change. The minimum hazard probability scenario was then tested for its sensitivity to a doubling of losses to account for intangibles, and a 0% discount rate. The findings are as follows:

**Table 8.3:** Costs and Benefits of Improved Settlement Planning for Thinadhoo

| Scenario | Benefit to Cost Ratio | Net Present Value (RF) |
|---|---|---|
| Baseline: minimum hazard occurrence | 0.91 | -2,315,138 |
| Baseline: max hazard occurrence under climate change | 3.15 | 54,638,641 |
| Minimum hazard occurrence, doubled losses for intangibles | 3.39 | 60,730,802 |
| Minimum hazard occurrence, 0% discount rate | 1.90 | 22,821,712 |

All scenarios have a positive return, other than the baseline scenario under minimum hazard occurrence. However, the analysis is very sensitive to any changes in the assumptions regarding the reduction in losses as a result of more stringent settlement planning, and therefore this scenario would require greater investigation.

It is also highly relevant and important to note the difference in Net Present Value figures, between this analysis and the findings presented in the sections above for each island. The BCR is a ratio – and therefore doesn't give an indication of the magnitude of loss or gain associated with a specific investment. The NPV, however, is an absolute figure, and therefore represents the amount of money that could be lost or gained. The cost of investment for improving land use planning is significantly less than the estimated costs of investing in safer island measures such as coastal protection. Hence, in the baseline analysis for improved planning, it is estimated that approximately RF2.5m could be lost if the assumptions used here are correct. By contrast, for example, full safe island protection in Viligili under maximum hazard occurrence yields a similar BCR – 0.93. However, this represents a net loss of RF18m – a much higher figure if the assumptions in the Viligili analysis are assumed to be correct.

### 8.2.3 Risk from Sea Level Rise

Sea level rise cannot be protected against using existing technology, except at great cost (e.g. massive sea walls, levelling and raising islands by a number of meters, then completely rebuilding the island). One of the only affordable protection measures at the present moment is to ensure that coral reefs, vegetation, and natural accretion processes can work to their maximum effect and hope that they will protect against SLR. As discussed in the SIP Review (Section 4), environmental protection integrated into development activities (e.g. proper solid waste management) thus becomes paramount. Furthermore, this argument suggests that man-made interventions will only hinder the ability of islands to respond naturally, and thus while providing some protection in the short term, may contribute to a lack of longer-term resilience.

Because SLR is slow onset, it is not imperative to implement structural protection measures immediately. Furthermore, there is a disadvantage in such expenditure due to the rapid development of the islands, and the potential need for future expansion. Rather, a "wait and see" approach for the physical protection measures, particularly in light of the great expense required to protect against sea level, is recommended. In the shorter term, a 'no regrets' approach is required to establish best practices in high impact coastal and terrestrial developments, better land use planning and building socially resilient settlements, while time is used to its maximum advantage to allow for greater analysis and understanding of the likely impacts of SLR, as well as technological advances and development of innovative approaches to protect the islands.

# 9. CONCLUSIONS AND RECOMMENDATIONS

## 9.1 Conclusions

- Climate and disaster risk reduction are a national and a local priority, and the SIP will be an important component of any strategy to reduce risk. However, significant progress needs to be made towards developing the SIP concept into a transparent strategy driven by stakeholder participation. In particular, special emphasis upon improving the engagement of stakeholders at an island level is required.

- It is critical that the SIP is integral to all development policy and planning and not an optional extra. Therefore the SIP should be a multi-sectoral initiative, which will require significant levels of coordination across a number of government ministries and among a broad cross-section of other stakeholders. It will require backing by a strong institutional and legal framework.

- The findings from the CBA suggest that great caution is required before proceeding with any investment as the ratios are not consistently positive, and in most instances where they are positive, the ratios are not very high, and hence any changes in the underlying assumptions could result in a net loss on investment.

- A significant shift in focus needs to take place towards softer protection measures and increases in resilience. The impacts that are regularly experienced from flooding are mostly attributable to man-made activities, and can be reduced through proper feasibility and environmental assessments, at relatively little cost. Importantly, because there is a significant amount of uncertainty associated with hazard occurrence and intensity, as well as the benefits associated with potential protection measures, lower cost options will incur less risk of significant losses under a variety of potential scenarios. Furthermore, it is clear that a range of options will be required. For example, whereas structural protection measures may be appropriate on some islands, they will be completely inappropriate on resort islands. Tourism contributes substantially to GDP, and these islands will need to be "protected" in ways that do not harm this industry.

- Human activities that damage the natural environment must be minimised to ensure that the natural resilience of islands is protected. Historically environmental degradation and poor environmental management of human activities, particularly in relation to land use planning, have only served to increase risk on the islands. Natural processes are the first and may ultimately be the final line of defence against sea level rise. Hence a prioritisation of environmental protection and natural resilience, while monitoring sea level impacts to make a more informed decision regarding costly structural measures, should be employed. A key indicator will be whether all activities are subject to full Environmental Impact Assessments (EIAs) and monitoring, and whether new guidelines on best practices are followed for high impact developments.

- The introduction of improved settlement planning (based on principles of disaster risk reduction) should be a priority. While the analysis included in this report is indicative only, and based on significant assumptions, it is clear that improved guidelines on land use planning, building codes and high impact developments, could be a more cost effective approach to reversing man-made risk, as well as potentially contributing to longer term resilience through improved environmental management. Furthermore, because the absolute cost of these measures is significantly lower than a suite of safer island measures, the cost of "getting it wrong" is substantially lower. This shift in focus is further supported by the fact that the Thinadhoo analysis resulted in a more positive argument for SIP protection, in part because of the location of critical infrastructure away from high intensity zones, and this sort of measure would be a key component of improved land use planning.

## 9.2 Recommendations and Next Steps

The following recommendations and next steps are made based on the findings of this report:

- Develop a SIP framework as part of a National Strategy on DRR. For example, the review and draft framework presented here will provide a sound basis for further development of the recently proposed Strategic National Action Plan (SNAP) for DRR and Climate Change Adaptation 2010 - 2020 as supported by UNDP Maldives Country Office and UNISDR, and it is strongly recommended that these two processes are integrated.

- As part of the SIP framework, introduce a transparent and systematic process for safer island selection, which is based on stakeholder consultation and subject to yearly review. The selection process should include both objective and subjective indicators, and the process should be transparent and flexible, modified year on year as appropriate to add or subtract indicators based on lessons learned from the previous year. Furthermore, any islands that are selected for development as safer islands should be subjected to detailed feasibility studies to ensure that they are appropriate for development.

- Ensure that public awareness and participation are key components of the SIP development process. Consultation undertaken as a part of this study consistently reported that the SIP process to date has been poorly understood by the public, and that much greater transparency and awareness raising needs to be conducted to gain buy-in.

- Establish capacity and financing for climate monitoring and research. There is a clear need for better data on potential climate impacts, and monitoring, to make effective decisions. A climate research body (government, research or both) needs to be established with a specific mandate to gather weather data, and model climate impacts for the Maldives, particularly downscaling of climate impacts for the region.

- Conduct a more detailed CBA study on the basis of the evidence gathered from the above recommendations. This CBA is heavily reliant on assumptions and estimations based on limited data, for hazard return periods and associated climate impacts, as well as feasibility and associated benefits of appropriate risk management measures. The CBA should be refined and revised for specific islands as selected through a systematic process. Furthermore, the CBA should be based on proper feasibility and environmental assessments for the specific risk management measures available on those islands, using more rigorous analyses of the return periods and climate impacts on hazard probabilities. Also, the studies will need to be refined on the basis that works are ongoing on these islands, particularly in Viligili where significant land reclamation has taken place recently, and thus was not factored into the CBA.

- Ensure early warning is implemented in full with adequate capacity for implementation at all levels. Effective "people-centred" early warning will be an essential preparedness measure against less frequent but high impact events such as tsunami and severe storm surges.

- Develop guidelines for settlement planning (inclusive of disaster risk reduction principles), which are integrated into development processes. Guidelines will be required for, inter alia, building codes, land reclamation, harbour development, and land use, to ensure that any development is sustainable and resilient to climate change, reducing rather than increasing risk. The EIA process needs to be more systematic, with clear guidelines for implementation of EIAs, and the process should be transparent and monitored to ensure that recommendations are incorporated into any projects.

- Conduct further research into viable alternative protection measures. To date the focus has been on more structural measures, and the analysis clearly indicates that this focus needs to be balanced with a greater understanding of more cost effective softer measures. For example, the SEEDS bio-defence project should be followed up to gather information on its effectiveness and possibilities for replication.

- Introduce a more holistic approach to risk mitigation, which puts much greater weight on societal and economic adaptation rather than the current focus on physical mitigation.

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# Annex

## ANNEX A

# MEETINGS WITH STAKEHOLDERS

| Name | Title/Organisation | Date | Reason for Meeting | Contact Info |
|---|---|---|---|---|
| First Field Mission | | | | |
| Maria Gemma, Azlifa Yoosuf, Aminath Shaliny, Ryo Hamaguchi | UNDP DRM team | April 29 | Initial briefing with UNDP team responsible for consultancy | Azu: azlifa.yoosuf@undp.org<br>+960 779 4220 |
| Mohamed Inaz | Assistant Resident Representative, Environment and Energy | April 29 | Discussion of Safer Islands Programme | Mohamed.inaz@undp.org<br>765 6516 |
| Residents on Thulusdhoo | | April 30 | A tour of the island included discussions with staff at the health facility, teachers, and residents to understand more about life on the island | |
| Patrice Coeur-Bizot | UNDP Resident Representative | May 3 | Briefing on the project | |
| Amjad Abdulla/ Aishath Shafina | Director General, Ministry of Housing, Transport and Environment/Assistant | May 3 | Briefing on project, discussion on review and CBA, data needs, agreement on scope, clarifications on work programme | Amjad.abdulla@environment.gov.mv<br>332 4861<br>aishath.shafina@environment.gov.mv<br>332 4861/ 793 8584 |
| Daniel Curtiss | Head of Office, American Red Cross | May 4 | Discussion on ARC work in Maldives, views on SIP | dcurtiss@amcrossasia.org<br>334 1994/ 790 2492 |
| Hudha Ahmed (Hudhu) | Independent Consultant | May 4 | Hudhu is an Environmental Expert, who has worked in the UNDP as ARR heading Environment portfolio. She was involved in developing and carrying out Risk Assessment, and DIRAM | Hudha_ahmed@hotmail.com |
| Per Jensnaes (Head of IFRC delegation), Kevin Guignan (IFRC), Alastair Burnett (Head of Mission, BRC) | Red Cross (BRC, IFRC) | May 5 | Discussion of construction activities, views on DRR, Safer Islands concept. | Per.jensnaes@ifrc.org<br>332 1987/ 779 1435<br>alastair@brcs.org.mv<br>334 0852/ 779 1409<br>Kevin.duignan@ifrc.org<br>779 4144 |
| Ahmed Shaig | Director, CDE consulting | May 5 | Author of Socio-economic DIRAM reports. Discussion around DIRAM, data limitations, approach to CBA | shaig@cde.com.mv<br>331 2514 |
| Natalia Pascual | NDMC, UNDP Consultant | May 5 | Discussion around her consultancy work on IDPs, Vilifushi, suggested contacts | npgavalda@gmail.com<br>763 8091 |
| Ahmed Saleem | Permanent Secretary, Ministry of Environment, Energy and Water | May 6 | Touching base on project, help with contacts within government | saleem@meew.gov.mv<br>334 1793/ 7906107 |
| Zaha Waheed | Ministry of Environment | May 6 | Formerly NDMC, so working on a lot of related issues | zahawaheed@gmail.com<br>790 4730 |
| Brett Campbell | Senior Project Manager, NDMC | May 6 | Has been working on Tsunami recovery, DRR issues, Vilifushi reconstruction | brett@tsunamimaldives.mv<br>333 3454/ 788 2296 |

| Name | Title/Organisation | Date | Reason for Meeting | Contact Info |
|---|---|---|---|---|
| Ibrahim Naufal | Engineer, Ministry of Housing, Transport and Environment | May 6 | Gathering data on potential mitigation measures and costs | naufal@construction.gov.mv<br>332 3234/ 765 3688 |
| Ali Amir | Department of Public Works | May 7 | Gathering data on the types of measures that are considered for mitigation | Ali.amir@publicworks.gov.mv<br>777 4775 |
| | Met Office | May 7 | Gathering information on hazards and weather related that is collected in the islands | |
| Mohamed Yoosuf | Ex-Ministry of Atolls, now home affairs | May 7 | Discussion on his perspective on the SIP, particularly at the Atoll level | 777 7588 |
| Second Field Mission | | | | |
| Hussain Naeem | Deputy Director, Ministry of Housing, Transport and Environment | May 17 | Briefing on project. Discussion on the progression of SIP to date. | hussain.naeem@environment.gov.mv |
| Patrice Coeur-Bizot | UNDP Resident Representative | May 18 | Discussion on island selection, and progression of project since the first mission / gaps to be filled during second mission | |
| Amjad Abdulla | Director General, Ministry of Housing, Transport and Environment | May 18 | Discussion on various components of the SIP and the interaction between the SIP and other agendas such as relocation | See above |
| | Island Councillor | May 19 | Discussion on land use planning, specific mitigation measures, social concerns regarding relocation | |
| Mohamed Hassan | Assistant Island Chief | May 19 | As above | moasan17@hotmail.com<br>Office: 960 6820027<br>Mobile: 960 7724857 |
| Haleem | Island Council Assistant | May 19 | Viligili transect walk | |
| | Viligili focus group meeting participants:<br>Adam Mohamed, Assistant Island Chief<br>Faisal, Power House<br>Shakeeb, Jungle Sport (NGO)<br>Naseer, Viligili Office<br>Niyaz, Capital City (NGO)<br>Azeema, National Women's Development Society (NGO)<br>Iqbaal, Community<br>Ali Didi, Community<br>Hassan, Boat Owner<br>Ali Rasheed, Fisherman<br>Shameel, Viligili Sports Club | May 20 | Focus group meeting - The target group for this meeting was vulnerable groups, development committees, NGOs, different type of income generating groups which include boat owners, fisherman, etc | |

| Name | Title/Organisation | Date | Reason for Meeting | Contact Info |
|---|---|---|---|---|
| | Viligili focus group meeting participants:<br>Majeed, Island Chief<br>Ibrahim Ali, Health Centre<br>Ibrahim Haneed, School Principal<br>Abdullah Zubair, Island Chief<br>Thamheen Hassan, Youth Centre<br>Ibrahim Hashim, Island Chief<br>Ibrahim Jameel, Atoll Office<br>Hassan Najeeb, Magistrate (Island Court)<br>Ali Shameem, Atoll Education Centre<br>Bagir, Viligili Office<br>Mohamed, Viligili Office | May 20 | | |
| | Island Chief | May 20 | Thinadhoo transect walk | |
| | Thinadhoo focus group meeting with approx. 50 participants | May 20 | Participants who came to the meeting were from Island Office, Atoll Office, Health Sector, Public Works, Education (School), Post Office, Fisherman, Contractors, Island Development Committee (IDC), Women's Development Committee (WDC) and NGOs. | |
| Ahmed Fathuhy | Public Works | May 21 | Tour of island | |
| | Thinadhoo focus group meeting | May 21 | Follow up to previous days' meeting for those interested in providing more further information (predominantly fishermen) | |
| Ahmed Saleem | Permanent Secretary, Ministry of Housing, Transport and Environment | May 25 | Briefing on progression of project | |
| | Deputy Minister, Ministry of Housing, Transport and Environment<br>+ UNDP DRM Team (Azlifa Yoosuf, Mohamed Inaz)<br>+ Hussain Naeem | May 25 | Presentation of draft SIP review and concept for SIP framework with discussion and feedback | |

## ANNEX B

# SIP REVIEW QUESTIONS

## General approach

Focus on softer side of DRR
What are going to be the issues at the local level?

- Awareness
- Capacity
- Participation in government proposed land-use plans?
- Relocation issues

Attention to be given to questions that will help to identify issues affecting the implementation of the SIP and environmental issues

### Consultations with local stakeholders:

- Key government officials, health and education sector, people involved with maintaining infrastructure and anyone engaged in land-use planning
- Island chiefs (and Atoll chiefs)
- Teachers, Religious leaders, Boat owners (those with influence)
- Vulnerable groups (e.g. women-headed households, households engaged in specific livelihoods)
- Development committees (e.g. Island Women Development Committee (IWDC) and Island Development Committee (IDC))
- Transect walk aof islands to understand lay of the land, any man-made interventions, impact of disasters, etc.
- Some of these people it may be appropriate to meet with in focus groups (e.g. vulnerable groups)

## HFA Priority 1 - Ensure that disaster risk reduction is a national and local priority with a strong institutional basis for implementation

### Multi-stakeholder dialogue

Key question:

- Who should be involved in the development of SIP?
- Who has responsibility for sustaining SIP at island level?

Sub-questions:

- How should the proposed risk mitigation measures be adapted to suit specific islands? What is the process?
- What capacity needs will there be?
- How well is it being received among different stakeholders (ministries, public, NGOs, UN agencies etc.)?
- What are the most important positive aspects of SIP, and what are the top key concerns?
- Are there lessons learnt /things SIP can do to ease the tensions over relocating families?

### Coordination

Key question:

- Who should have oversight for the development and implementation of SIP, and what powers/authority will they need (how high level) to integrate with other development issues?
- What are the competing development concerns?

Sub-questions:

- How does SIP link with national development strategy for consolidation of population?
- What mechanisms exist to aid coordination among stakeholders?

### Capacity

Key question:

- What will be the major areas where capacity development is required (national and local)?

Sub-questions:

- Where does capacity currently exist to drive the SIP process?
- How will appropriate resources for SIP be acquired and allocated?

## HFA Priority 2 - Identify, assess and monitor [climate and related] disaster risks and enhance early warning

Key question:
- How will warnings be disseminated (and will people trust / respond to warnings)?

Sub-question:
- How can SIP support risk awareness, particularly at local level?
- How can SIP monitor hazards (i.e. windstorm, tsunami etc)?
- How can SIP enhance response capability?

## HFA Priority 3 - Use knowledge, innovation and education to build a culture of safety and resilience at all levels

Key question:
- Where are the priorities for training on DRR/SIP (which sectors, levels)?
- How can the links between environmental management, livelihoods and DRR be strengthened (especially at the local level)?

Sub-questions:
- How is the SIP concept shared among the population to raise awareness of the need for enhanced DRR? Is there a dissemination of information programme?
- Is DRR /disaster preparedness included in the education system, and if so how can SIP be included? [Titus' area of work]

## Priority 4 - Reduce the underlying risk factors

Key questions:
- What are the barriers preventing national level policy on environmental protection from being implemented on the ground?
- [Is it lack of awareness, lack of capacity, lack of options - for instance, pumping waste into deep water is expensive, solid waste management – huge issue. Why is this a dilemma when livelihoods are 100% dependent on good envr protection (fisheries, tourism (beaches and reefs), etc)?]
- Can man-made environments mimic existing natural defence, what examples? (determine interviewees views)
- Who is most vulnerable to hazards, and why? How can resilience be improved through the SIP?
- How will SIP ensure the continued functioning of critical facilities and how will other structures (homes etc) be protected?

## Priority 5 - Strengthen disaster preparedness for effective response at all levels

Key question:
- How will disaster preparedness plans (vertical evacuation, stockpiling of emergency needs, strong transportation/communications etc) be implemented and sustained over the long term (e.g. drills)?

Further questions:
- Problems with vertical evacuation due to comparisons between communities – if some islands have 'special' facilities then shouldn't they all?
- Island selection: Why haven't the risk assessment studies been used to identify potential safer islands?
- Through consultation with community members, what do they think would be the most effective mitigation measures?
- What sorts of disaster risk reduction activities have been undertaken on the island already? EWS system in place? Community disaster contingency plans? Alternative livelihoods?
- How do community members feel about becoming a "safer island" and possibly expanding their community?
- Are they aware of climate change and its potential impacts on the Maldives?
- What types of development activities would they most like to see on their islands? What is their 25-year vision for their island?

Final question:
- Who else should we be speaking with?

## ANNEX C

# RATES AND ASSUMPTIONS

| Protection Measure/ Parameter | Rate (USD) | Unit | Description | Source | Additional Calculations/ Assumptions |
|---|---|---|---|---|---|
| Coastal Protection | | | | | |
| - Boulder | 2,570 | Linear Metre | Design based on Boulders (new standard for key outer island ports). Turnkey market rate | MPND | Design is constant. Water depths and Highest High Sea Level assumed constant on reef. Mobilisation cost constant |
| Access Infrastructure | | | | | |
| - Dredging Cost | 3.89 | Cubic Metre | | MCPI, MPND | Large Harbour = 548 x 365 x 2.5 m (Sea wall, Quay wall, dredge depth), Small Harbour = 335 x 152 x 2.5m. Standard harbour sizes as used by MPND and allocated according to island population size |
| - Sea wall cost | 2,570.46 | Linear Metre | | MCPI, MPND | |
| - Quay wall cost | 3,346.30 | Linear Metre | | MCPI, MPND | |
| - New Large Harbour | 2,903,671.03 | Island | Based on the above individual values | | |
| - Large Harbour Upgrade | 2,713,889.32 | | New quay wall and sea wall with maintenance dredging | | Only about 3 islands have breakwaters and quay walls designed to the new standard adopted by MPND. All existing harbours need upgrades and islands with no harbour need new harbour. Maintenance dredging incurs approximately 30% cost of a new dredging activity. |
| - Maintenance dredging | 2 | | Number of Maintenance req in 20 years | | |
| Road construction | | | | | |
| - Compaction Only | 10.00 | Square Metre | Road development (unsealed) Formula: (Rate * Preliminaries) + (Road length * rate * preliminaries) | MCPI, NDMC | Compaction Only - Assumptions:<br>- 50% of total road area<br>- US $ 10 per sq. m<br>- 17.5% for preliminaries<br>- roads cover 20% of land area |
| - Compaction & curbs | 21.00 | Square Metre | As above | MCPI, NDMC | Compaction and Curbs - Assumptions:<br>- 80% of total road area<br>- US $ 21 per sq. m<br>- 17.5% for preliminaries<br>- roads cover 20% of land area |
| Environment Protection Zone (EPZ) | | | | | |
| EPZ wide option | 389.00 | Linear Metre | Contains revegetation and drainage | Contractors | Calculated based on the cost of planting trees and establishing a low cost drainage system. |
| EPZ narrow option | 195.00 | Linear Metre | Contains revegetation and drainage | Contractors | Calculated based on the cost of planting trees and establishing a low cost drainage system. |

| Protection Measure/ Parameter | Rate (USD) | Unit | Description | Source | Additional Calculations/ Assumptions |
|---|---|---|---|---|---|
| Evacuation Facilities | | | | | |
| Community hall | 300,000.00 | Per facility | A multipurpose community building developed on stilts. | NDMC | |
| Reinforcing Walls | | | | | |
| Public facility outer walls | 115.00 | Linear Metre | Raising and reinforcing public infrastructure walls, particularly powerhouse, schools, hospitals, waste sites and other administrative buildings | Contractors | |
| Retrofitting houses | | | | | |
| Range of retrofitting measures for high risk households | 15,500.00 | Per house | Retrofitting measures such as raising houses on stilts, reinforcing walls, raising entrances, windows etc… | Contractors | An average figure is provided here. Figures are likely to vary significantly depending on the hazard zone. |
| Artificial Drainage Systems | | | | | |
| Drains | 1150.00 | Per drain | | | |
| Road Levelling | | | See road compaction above. | | Road maintenance needs to be carried out at least every two years |
| Power | | | | | |
| Power plant | 62,2600.00 | Per facility | Costs vary depending on the number and capacity of generator. Price is average value for an island with 2000-3000 persons. | Island Offices; STELCO | Values have been adjusted based on reports from each island |
| Power generation and distribution | 272.37 | Per Person | Power generation and general distribution | MoEE, ADB | Assumptions:<br>- Rf 3,500.00 per person<br>-Based on consumer willingness to pay |
| Flood proofing power houses | 3800.00 | Per engine | Raising the plants only; for structural reinforcement see reinforcing wall above. | Contractors | Figures will vary depending on equipment. |
| Communications (flood proofing) | | | | | |
| Raising equipment | 3800.00 | Per facility | Raising the equipment only | Contractors | Figures will vary depending on equipment. |
| Reinforcing walls | | | See reinforcing walls above. | | |
| Disaster Awareness Activities | | | | | |

| Protection Measure/ Parameter | Rate (USD) | Unit | Description | Source | Additional Calculations/ Assumptions |
|---|---|---|---|---|---|
| Businesses | 11,500.00 | Per island activity | Disaster risk awareness among business establishments. | | |
| High risk investment | 15,500.00 | Per island activity | Disaster risk awareness among high risk establishments and key employers. | | |
| Public | 15,500.00 | Per island activity | Disaster risk awareness among households covering a wide range of issues. | | |
| | | | | | |
| Housing | 23,346.30 | Per Household | | | RF 300,000 per household based on 2005 prices; Prices in 2009 were at around Rf400,000 |
| Value of Statistical Life (VSL) | | | | | |
| SVL based on Income-over-life method | 139,754.24 | Per Person lifetime | Average Monthly Income $204.32; Average Yearly Income $2,451.83; retirement age 65. | VPAII; HIES | IPCC VSL for developing countries: US$150,000 per person; VSL based on willingness to pay method: 179,462.78 (based on costs for Male' sea wall project) |

## ANNEX D

# DETAILED LOSS CALCULATIONS FOR GDH THINADHOO

*Estimated local losses and economic implication: tsunami*

| Sector | Estimated losses | Economic implications | Estimated proportion of losses (%) | Estimated value of losses (Rufiyaa) |
|---|---|---|---|---|
| Infrastructure | | | | |
| Power | Damage to electricity generation plants; transmission lines and distribution grids.<br>Can only be made fully operational within a minimum of 3 days. | Disruption of some business activities reliant on electricity. Most affected will be personal service sectors, retail trade (particularly fresh food and temperature sensitive goods), pharmacies, hotels and restaurants and the service sector in general. This will involve loss of business in some sectors.<br>Additional costs (on the Government) to repair the facilities, and to meet the interim energy demand (10% of replacement value)<br>Loss of income or profits by the power company. | 20% businesses<br>-<br>- | 80,000<br>800,000<br>5,000 |
| Water and Sanitation | Damage to water storage tanks, sewage treatment site and sewage pipelines. | Water storage tanks may have to be replaced at a cost to the households or to the Government.<br>Disruption of service oriented businesses such as café s and hotels (1 week)<br>Additional costs (on the Government) to repair the facilities, and to meet the interim requirements for sewage management and water supply. | 2% households<br>30% Businesses<br>2% loss | 3,000<br>20,000<br>700,000 |
| Harbour | Damage to quay wall. | Island local harbour is the key business infrastructure to the basic sectors on the island. Damage to harbour will disrupt wholesale and import trade, which requires a quay wall or jetty to load and unload goods.<br>Export of manufacturing products will be affected.<br>Disruptions in transport operations<br>Impact on fisheries sector may be minimal unless if vessels are damaged. There will be disruptions to vessel movements, however.<br>Additional costs (on the Government) to repair the facilities and dredge the harbour.<br>Lost income from visitors. | 20% businesses<br>20% of manufacturing industry workers<br>20% of vessels<br>20% vessels<br>50 %<br>15% loss | Mostly intangible losses<br>Mostly intangible losses<br>Mostly intangible losses<br>Mostly intangible losses<br>19,000,000 (50 % replacement cost)<br>20,000 |
| Communications | Moderate damage to communications equipment of Dhiraagu antenna site.<br>Disruption of power to the communications equipment | Disruption of contact between nearby islands and Male', affecting business operations of almost all business establishments.<br>Introduction of uncertainty in the economy regarding the availability of goods leading to rapid demand on stocks and ultimately, inflation. | -<br>- | Mostly intangible losses |

| Sector | Estimated losses | Economic implications | Estimated proportion of losses (%) | Estimated value of losses (Rufiyaa) |
|---|---|---|---|---|
| Fuel supply | Damage to fuel storage and delivery systems; damage to fuel supply vessels and vehicles; oil spills (see hazardous waste management below) | Disruption of fishing and transport sector leading to loss of income in these sectors (2 weeks). | 50% fishing businesses | 2,100,000 |
| | | Loss of transport sector will have knock-on effects on wholesale and retail trade causing shortages in supply of essential items, leading to inflation (2 weeks). | 20% businesses | 400,000 |
| | | Disruption of power (if power house undamaged) – See 'power' above | - | |
| | | High cost of repair and for storage and fuel supply facilities. | - | 500,000 |
| Solid and hazardous waste management | Damage to waste management site | Redevelopment of waste site | | 500,000 |
| Hospital | Structural damage to hospital<br>Damage to equipment and machinery | Public costs incurred in repairing hospital structure and replacing equipment (5% of replacement value) | 5% loss | 2,000,000 |
| Fish Market | Structural damage | Replacement cost (50% of replacement value) | 50% loss | 300,000 |
| Households | Physical damage to houses<br>Damage to belongings (furniture, appliances, electronics, clothes etc..)<br>Loss of cash and valuables (stored in the house) | Financial losses from lost savings (cash and valuables) leading to reduced spending capacity. | 5% households | No data |
| | | This will affect all non-basic sectors of the economy, depending on the number of households damaged. | 15% businesses | Mostly intangible losses |
| | | Financial losses incurred for rebuilding the uninsured houses and repurchasing household items. A general decline in economy is inevitable as spending halts for non-essential items. | 3<br>% households | 654,000 |
| | | Damage to households may prevent affected working population to turn-up for work as they have to attend to the household and family. This will lead to the temporary halting of all major economic activities. Fisheries sector is particularly vulnerable as a minimum number of persons are required for any fishing trip. Other sectors vulnerable to staff shortage include manufacturing, civil service, transport and communications, and retail shops. | 5% businesses | Mostly intangible losses |
| | | Costs incurred by the Government to build and service temporary shelters. | | |
| | | Cost of demolition and debris removal may have to be borne by the household family members. | 2% households | 400,000 |
| | | | 1% households | 60,000 |
| Fisheries | Damage to fishing vessels (vessel inoperable) and fishing gear.<br>Damage to fuel supply and storage (see above).<br>Damage to fish processing centres | Loss of income from the main economic sector of the island. Fishing activity may be halted for weeks if vessels cannot be repaired or replaced. There will be unemployment amongst fishermen. Sector recovery and efficiency will depend on how many vessels were destroyed beyond repair. This will be among the biggest economic impacts on the island. | 10% vessels partially damaged | 2,350,000 |
| | | Knock-on effects of lost income in non-basic sectors: construction, transport, personal services, retail and restaurants. | 10% businesses | Mostly intangible losses |
| | | Sector production will decrease or halt if fuel supply is damaged or destroyed. Alternate sources of fuel may be sought from other islands (see fuel supply). | | |
| | | Replacement cost of fish processing centres. | | |
| | | Loss of income from fish processing centres (2 weeks) | 30% businesses | 300,000 |
| | | | 50% businesses | 250,000 |

| Sector | Estimated losses | Economic implications | Estimated proportion of losses (%) | Estimated value of losses (Rufiyaa) |
|---|---|---|---|---|
| Agriculture | Damage to farms, farm equipment, fertilisers, seeds, crops in production and stock.<br>Loss production till the next rain due to groundwater salinization<br>Damage to backyard crops and fruit trees<br>Damage to timber trees<br>Damage to hydroponics centres | Loss of income (6 months)<br>Unemployment in the agricultural sector (3 months)<br>Loss of equipment leading to further decline in production in the short term.<br>The amount of money spend by households on food may increase when subsistence backyard crops are damaged.<br>Food shortages may result due to high demand and limited supply; may lead to temporary rise in food prices.<br>Costs incurred in replacing hydroponics investments | 20% farms<br>10%<br>10% farms<br>-<br>-<br>- | 180,000<br>20,000<br>No data<br>Mostly intangible losses<br>Mostly intangible losses<br>150,000 |
| Wholesale and retail trade | Damage to stock in retail and wholesale shops and warehouses.<br>Physical damage to buildings<br>Physical damage to equipment, electronics and business records<br>Short –term loss of business due to road blockade (debris). | Loss of income from wholesale and retail trade to business owners<br>Unemployment for staff of businesses destroyed or severely damaged (2 months).<br>Loss of uninsured stock and buildings leading to liquidity problems for wholesalers<br>Loss of re-export income (wholesale to nearby islands)<br>Financial losses incurred for rebuilding the uninsured buildings.<br>A number of engineering workshops may be damaged reducing the capability to repair damaged machinery, vessels and vehicles quickly. Costs incurred to rebuild. | 15% businesses<br>3% (2 months)<br>5% businesses<br>-<br>2% businesses<br>10% of workshops | 600,000<br>25,000<br>800,000<br>No Data<br>600,000<br>300,000 |
| Manufacturing | Damage to existing production and stock (damage to raw material stocks, vessels under construction and repair, wood stocks in carpentries and fabrics)<br>Damage to buildings, tools and equipment.<br>Damage to households – See households above. | Loss of income from manufacturing activities (2 months).<br>Unemployment among those involved in boat building and food processing<br>Loss of productivity in carpentries and boat yards due to building, equipment and tool damage.<br>Short to medium term decline in export income from manufacturing sector.<br>Damage to investments | 15% of businesses<br>5% (2 months)<br>5% businesses<br>-<br>5% businesses | 129,000<br>26,000<br>Mostly intangible losses<br>Mostly intangible losses<br>105,000 |
| Transport, storage and communications | Damage to transport infrastructure (harbour) – see infrastructure above<br>Damage to marine transport vessels (cargo and passenger)<br>Damage to land vehicles<br>Damage to communication establishments (dhiraagu and wataniya) - see infrastructure above<br>Damage to warehouses and other storage buildings and their stock – wholesale and retail trade above. | Unemployment for persons employed in affected vessels or vehicles.<br>Loss of income from transport sector (2 months).<br>Partial damage to at least one cargo boat<br>Knock-on effects on wholesale and retail trade, construction, agriculture and personal service sectors if cargo vessels are damaged.<br>Loss of stock and affects on liquidity of major businesses (see wholesale and retail trade) | 5% (2 months)<br>10%<br>20% of businesses damaged<br>10% businesses | 34,000<br>500,000<br>1,500,000<br>Mostly intangible losses<br>- |

| Sector | Estimated losses | Economic implications | Estimated proportion of losses (%) | Estimated value of losses (Rufiyaa) |
|---|---|---|---|---|
| Construction | Partial damage to equipment and machinery<br>Disruption of construction work | Generally positive: demand for construction will increase following damage to houses and buildings. Construction industry will experience a boom and will be a major source of temporary employment and income for those unemployed from other sectors.<br>Costs incurred in repairing and replacing equipment<br>More migrant workers in the economy to meet the excess demand for labour, leading to 'leakages' in foreign currency.<br>Expenditure from migrant workers will be an income to the local retailers and personal services. | 2% businesses<br>- | 30,000<br>Mostly intangible losses |
| Hotels and restaurants | Damage to buildings, appliances, furniture and stocks | Loss of income from affected establishments (2 months).<br>Loss of uninsured investments<br>Costs incurred in repurchasing of appliances and furniture, rebuilding and repairing.<br>Unemployment in affected establishments if the owner is unable to rebuild and recover in the short-term. | 25% businesses<br>5%<br>5% businesses<br>2% businesses | 200,000<br>60,000<br>25,000<br>3,000 |
| Public Administration | Partial damage to buildings, equipment, furniture and records, and disruption of operations mostly in Island office, Atolhuge, police station, Island court, nursery school and media centre. | Income losses are expected to be negligible as Government is unlikely to lay off staff following a disaster. Hence, unemployment in this sector is also unlikely.<br>Costs incurred by the government to rebuild and re-establish damaged establishments | 2 % establishments | 2,000,000 |
| Other community, social and personal service activities | Damage to buildings, equipment, stock and other tools in small businesses engaged in personal service activities. | Loss of income and employment in small businesses involved in personal service activities (2 months).<br>Costs incurred in rebuilding and repairing the establishments<br>Reduced demand for personal services due to reduced spending at household level. | 5% businesses<br>3% businesses<br>15% businesses | 20,000<br>30,000<br>Mostly intangible losses |
| Real Estate, renting and business activities | Partial damage to buildings, equipment, furniture. | Loss of rental income<br>Costs incurred for repairing | 10% properties<br>3% properties | 8,000<br>300,000 |
| Tourism | No direct investment losses on the island.<br>Resorts where temporary migrants from Thinadhoo work may be damaged. | Remittances from resort employees may decline if resorts around Maldives are damaged (3 months).<br>Some resort employees may be unemployed due to resort closure | 50% of households with tourism remittance<br>5% of households | 480,000<br>No data |

**SOURCE:** UNDP, 2009b

*Estimated local losses and economic implications:  Swell waves and Storm surges*

| Sector | Estimated losses | Economic implications | Estimated proportion of losses (%) | Estimated value of losses (Rufiyaa) |
|---|---|---|---|---|
| Power | Damage to electricity generation plants; transmission lines and distribution grids for over 24 hours | Disruption of some business activities reliant on electricity for over 24 hours. Most affected will be personal service sectors, retail trade (particularly fresh food and temperature sensitive goods), pharmacies, hotels and restaurants and the service sector in general. This will involve loss of business in some sectors.<br>Additional costs (on the Government) to repair the facilities, and to meet the interim energy demand (10% of replacement value)<br>Loss of income or profits by the power company. | 5% businesses<br>-<br>- | 10,000<br>50,000<br>5,000 |
| Water and Sanitation | Damage to water storage tanks, sewage treatment site and sewage pipelines. | Water storage tanks may have to be replaced at a cost to the households or to the Government.<br>Disruption of service oriented businesses such as café s and hotels (1 week)<br>Additional costs (on the Government) to repair the facilities, and to meet the interim requirements for sewage management and water supply. | 2% households<br>10% Businesses<br>1% loss | 3,000<br>8,000<br>250,000 |
| Harbour | No direct losses | | - | - |
| Communications | Moderate damage to communications equipment of Wataniya antenna site.<br>Disruption of power to the communications equipment | Disruption of contact between nearby islands and Male', affecting business operations of almost all business establishments.<br>Introduction of uncertainty in the economy regarding the availability of goods leading to rapid demand on stocks and ultimately, inflation. | -<br>- | Mostly intangible losses |
| Fuel supply | No direct losses | | - | - |
| Solid and hazardous waste management | Damage to waste management site | Redevelopment of waste site | | 500,000 |
| Hospital | No direct losses | | - | - |
| Fish Market | Disruptions to market activities | Disruption to market activities | - | Mostly intangible losses |

| Sector | Estimated losses | Economic implications | Estimated proportion of losses (%) | Estimated value of losses (Rufiyaa) |
|---|---|---|---|---|
| Households | Physical damage to houses<br>Damage to belongings (furniture, appliances, electronics, clothes etc..)<br>Loss of cash and valuables (stored in the house) | Financial losses from lost savings (cash and valuables) leading to reduced spending capacity.<br>This will affect all non-basic sectors of the economy, depending on the number of households damaged.<br>Financial losses incurred for rebuilding the uninsured houses and repurchasing household items. A general decline in economy is inevitable as spending halts for non-essential items.<br>Damage to households may prevent affected working population to turn-up for work as they have to attend to the household and family. This will lead to the temporary halting of all major economic activities. Fisheries sector is particularly vulnerable as a minimum number of persons are required for any fishing trip. Other sectors vulnerable to staff shortage include manufacturing, civil service, transport and communications, and retail shops.<br>Cost of demolition and debris removal may have to be borne by the household family members. | 5% households<br>15% businesses<br>2<br>% households<br>5% businesses<br>1% households | No data<br>Mostly intangible losses<br>500,000<br>Mostly intangible losses<br>60,000 |
| Fisheries | Disruption to fishing activities<br>Damage to fish processing centres | Sector production will decrease or halt if fishermen's households are affected.<br>Replacement cost of fish processing centres.<br>Loss of income from fish processing centres (2 weeks) | 5% fishermen<br>10% businesses<br>20% businesses | Mostly intangible losses<br>100,000<br>125,000 |
| Agriculture | Damage to farms, farm equipment, fertilisers, seeds, crops in production and stock.<br>Loss production till the next rain due to groundwater salinization<br>Damage to backyard crops and fruit trees | Loss of income (3 months)<br>Unemployment in the agricultural sector (3 months)<br>Loss of equipment leading to further decline in production in the short term.<br>The amount of money spend by households on food may increase when subsistence backyard crops are damaged.<br>Food shortages may result due to high demand and limited supply; may lead to temporary rise in food prices. | 20% farms<br>10%<br>10% farms<br>-<br>- | 90,000<br>20,000<br>No data<br>Mostly intangible losses<br>Mostly intangible losses |
| Wholesale and retail trade | Damage to stock in retail and wholesale shops and warehouses.<br>Physical damage to buildings<br>Physical damage to equipment, electronics and business records<br>Short –term loss of business due to road blockade (debris). | Loss of income from wholesale and retail trade to business owners<br>Loss of uninsured stock and buildings leading to liquidity problems for wholesalers<br>Loss of re-export income (wholesale to nearby islands) | 5% businesses<br>2% businesses<br>- | 80,000<br>40,000<br>No Data |

| Sector | Estimated losses | Economic implications | Estimated proportion of losses (%) | Estimated value of losses (Rufiyaa) |
|---|---|---|---|---|
| Manufacturing | Damage to existing production and stock (damage to raw material stocks, wood stocks in carpentries and fabrics)<br>Damage to buildings, tools and equipment.<br>Damage to households – See households above. | Loss of income from manufacturing activities (1 months).<br>Loss of productivity in carpentries and boat yards due to building, equipment and tool damage.<br>Short to medium term decline in export income from manufacturing sector.<br>Damage to investments | 5% of businesses<br>5% businesses<br>-<br>2% businesses | 21,000<br>Mostly intangible losses<br>Mostly intangible losses<br>40,000 |
| Transport, storage and communications | Damage to land vehicles<br>Disruption to communication establishments (wataniya) - see infrastructure above<br>Disruption to transport operations<br>Damage to warehouses and other storage buildings and their stock – see wholesale and retail trade above. | Unemployment for persons employed in affected vehicles.<br>Loss of income from transport sector (1 month).<br>Knock-on effects on wholesale and retail trade, construction, agriculture and personal service sectors if cargo vessels are damaged.<br>Loss of stock and affects on liquidity of major businesses (see wholesale and retail trade) | 2% (2 months)<br>2% land transport businesses<br>5% of businesses damaged<br>10% businesses | 30,000<br>36,000<br>Mostly intangible losses<br>- |
| Construction | Partial damage to equipment and machinery<br>Disruption of construction work | Generally positive: demand for construction will increase following damage to houses and buildings. Construction industry will experience a boom and will be a major source of temporary employment and income for those unemployed from other sectors.<br>Costs incurred in repairing and replacing equipment<br>More migrant workers in the economy to meet the excess demand for labour, leading to 'leakages' in foreign currency.<br>Expenditure from migrant workers will be an income to the local retailers and personal services. | 1% businesses<br>- | 14,000<br>Mostly intangible losses |
| Hotels and restaurants | Damage to buildings, appliances, furniture and stocks | Loss of income from affected establishments (2 months).<br>Costs incurred in repurchasing of appliances and furniture, rebuilding and repairing. | 1% businesses<br>1% businesses | 8,000<br>5,000 |
| Public Administration | Partial damage to buildings, equipment, furniture and records, and disruption of operations mostly in schools. | Income losses are expected to be negligible as Government is unlikely to lay off staff following a disaster. Hence, unemployment in this sector is also unlikely.<br>Costs incurred by the government to rebuild and re-establish damaged establishments | 10% of schools | 50,000 |
| Other community, social and personal service activities | Damage to buildings, equipment, stock and other tools in small businesses engaged in personal service activities. | Loss of income and employment in small businesses involved in personal service activities (2 months).<br>Costs incurred in repairing the establishments<br>Reduced demand for personal services due to reduced spending at household level. | 2% businesses<br>1% businesses<br>3% businesses | 5,500<br>10,000<br>Mostly intangible losses |
| Real Estate, renting and business activities | Partial damage to buildings, equipment, furniture. | Loss of rental income<br>Costs incurred for repairing | 2% properties<br>1% properties | 2,000<br>10,000 |

| Sector | Estimated losses | Economic implications | Estimated proportion of losses (%) | Estimated value of losses (Rufiyaa) |
|---|---|---|---|---|
| Tourism | No direct investment losses on the island.<br>Resorts where temporary migrants from Thinadhoo work may be damaged. | Remittances from resort employees may decline if resorts around Maldives are damaged (3 months). | 15% of households with tourism remittance | 200,000 |
| | | | 5% of households | |
| | | Some resort employees may be unemployed due to resort closure | | No data |

**SOURCE:** UNDP, 2009b

*ed local losses and economic implications: Rainfall flooding*

| Sector | Estimated losses | Economic implications | Estimated proportion of losses (%) | Estimated value of losses (Rufiyaa) |
|---|---|---|---|---|
| Infrastructure | | | | |
| Roads | Flooded roads may reduce mobility | Disruption of economic activities located close to the harbour<br>Minor loss of business due to flood water on the streets<br>Costs incurred by the Government to repair flood prone roads | | Mostly intangible losses<br>No Data<br>No Data |
| Harbour | Disruption to harbour activities.<br>Potential long term damage to quaywall, given the current construction and design | Short-term disruption to harbour operations affecting cargo, passenger and fishing operations.<br>Public costs incurred in repairing quay wall | 20% businesses affected<br>15% loss | Mostly intangible losses<br>100,000 |
| Water and Sanitation | Damage to sewerage network. | Disruption of service oriented businesses such as café s and hotels (1 week).<br>Additional costs incurred by households to manage sewerage.<br>Additional costs (on the Government) to repair the facilities, and to meet the interim requirements for sewage management. | 10% Businesses<br>3% households<br>1% loss | 10,000<br>50,000<br>500,000 |
| Retail and wholesale trade | Disruption of business activity.<br>Damage to stock. | Business activity may be slow during the event (3 days)<br>Damage to stock | 10% businesses<br>3% businesses | 40,000<br>160,000 |
| Households | Damage to household goods;<br>Disruption to daily life | Damage to household goods | 7% households | 250,000 |
| Public Administration | Partial damage to buildings, equipment, furniture and records, and disruption of operations mostly in schools.<br>Disruption to operations around hospital and power house | Income losses are expected to be negligible as Government is unlikely to lay off staff following a disaster. Hence, unemployment in this sector is also unlikely.<br>Costs incurred by the government to repair and replace damaged establishments and equipment | 3% of establishments | 50,000 |
| Hotels and restaurants | Disruption of business activity. | Business activity may be slow during the event | 5% businesses | No Data |

**SOURCE:** UNDP, 2009b

## ANNEX E

# DETAILED COST ESTIMATES FOR RISK MANAGEMENT MEASURES ON GDH THINADHOO

*Cost Estimates: Full SIP Protection on GDh Thinadhoo*

| Protection Measure | Specifications | | | | | | Fixed costs (RF) | Variable Cost notes |
|---|---|---|---|---|---|---|---|---|
| | Length (m) | Height (m) | Material | Qty | Lifetime (years) | Rate (RF) | | |
| Adopting the safe island mitigation measures | | | | | | | | |
| - Coastal protection (northern and eastern coastline) | 2,000 | 2 | Boulders | 1 | 50-75 | 33,025 | 66,049,000.00 | Maintenance free |
| - Coastal protection (western and southern coastline) | 2,000 | 2 | Boulders | 1 | 50-75 | 33,025 | 66,049,000.00 | Maintenance free |
| - Environment protection zone | 4,000 | | Boulders | 1 | 15 | 5,000 | 20,000,000.00 | |
| - Resilient harbour | | | | | 15-25 | | 37,312,172.76 | Maintenance dredging every 10 years up to 0.5m. Cost: 5,000,500 |
| - Evacuation facilities | | | | | 15-20 | | 3,855,000.00 | Multipurpose facility so variable costs should be covered in daily operations |
| Flood proofing the hospital | 400 | 2.5 | Reinforced concrete | 1 | 10 | 1,500 | 600,000.00 | None - one off development; possible hospital extension not covered. |
| Flood proofing warehouses and stock | | | | 4 | | 50,000 | 200,000.00 | |
| Protecting the fuel storage and supply | 110 | 2.5 | Reinforced concrete | 3 | 10-15 | 1,500 | 165,000.00 | None - one off development; possible expansion not covered. |
| Flood proofing the power house | | | | | | | | |
| - Reinforcing the walls | 345 | 2.5 | Reinforced concrete | | 10 | 1,500 | 517,500.00 | |
| - Raising the plants | | | | 4 | 15-20 | 50,000 | 200,000.00 | None - one off development; possible expansion not covered. |
| Flood proofing communications infrastructure | | | | | | | | |
| - Reinforcing the walls | 150 | 2.5 | Reinforced concrete | 2 | 10 | 1,500 | 225,000.00 | |
| - Raising the equipment | | | | 4 | 10 | 50,000 | 200,000.00 | None - one off development; possible expansion not covered. |
| Flood proofing waste management sites | 150 | 2.5 | Reinforced concrete | 1 | 10 | 1,500 | 225,000.00 | |

| Protection Measure | Specifications | | | | | Fixed costs (RF) | Variable Cost notes |
|---|---|---|---|---|---|---|---|
| Retrofitting to reduce flood risks in high risk houses and buildings | | | 38 | 15-25 | 200,000 | 7,600,000.00 | |
| Constructing artificial drainage systems in low-lying areas and main roads. | | | | | | | |
| - Drains | | Reinforced concrete | 150 | 10-15 | 15,000 | 2,250,000.00 | Maintenance cost; 2 persons per year Cost: 72,000 |
| - Road Levelling | 7500 | Compact & level | | 2 | | 354,225.35 | Maintenance every 2 years. Cost: 354,225.35 |
| Creating disaster risk awareness among businesses | | | | 2 | | | Cost of 150,000. May have to be repeated every 2-3 years |
| Creating insurance awareness among high risk investments | | | | 2 | | | Cost of 200,000. May have to be repeated every 2-3 years |
| Create awareness among the population to use banking facilities to store cash | | | | 2 | | | Cost of 200,000. May have to be repeated every 2-3 years |
| Sub-total: Flood Proofing | | | | | | 2,332,500 | |
| TOTAL | | | | | | 205,801,898.11 | |

## *Cost Estimates: Selected SIP Protection on GDh Thinadhoo*

| Protection Measure | Specifications | | | | | | Fixed costs (RF) | Variable Cost notes |
|---|---|---|---|---|---|---|---|---|
| | Length (m) | Height (m) | Material | Qty | Lifetime (years) | Rate (RF) | | |
| Adopting the safe island mitigation measures | | | | | | | | |
| - Coastal protection (northern, eastern and southern coastline) | 2,200 | 2 | Boulders | 1 | 50-75 | 33,025 | 72,653,900.00 | Maintenance free |
| - Environment protection zone | 2,200 | | Boulders | 1 | 15 | 5,000 | 11,000,000.00 | |
| - Resilient harbour | | | | | 15-25 | | 37,312,172.76 | Maintenance dredging every 10 years up to 0.5m. Cost: 5,000,500 |
| - Evacuation facilities | | | | | 15-20 | | 3,855,000.00 | Multipurpose facility so variable costs should be covered in daily operations |
| Flood proofing the hospital | 400 | 2.5 | Reinforced concrete | 1 | 10 | 1,500 | 600,000.00 | None - one off development; possible hospital extension not covered. |
| Flood proofing warehouses and stock | | | | 4 | | 50,000 | 200,000.00 | |
| Protecting the fuel storage and supply | 110 | 2.5 | Reinforced concrete | 3 | 10-15 | 1,500 | 165,000.00 | None - one off development; possible expansion not covered. |
| Flood proofing the power house | | | | | | | | |
| - Reinforcing the walls | 345 | 2.5 | Reinforced concrete | | 10 | 1,500 | 517,500.00 | |
| - Raising the plants | | | | 4 | 15-20 | 50,000 | 200,000.00 | None - one off development; possible expansion not covered. |
| Flood proofing communications infrastructure | | | | | | | | |
| - Reinforcing the walls | 150 | 2.5 | Reinforced concrete | 2 | 10 | 1,500 | 225,000.00 | |
| - Raising the equipment | | | | 4 | 10 | 50,000 | 200,000.00 | None - one off development; possible expansion not covered. |
| Flood proofing waste management sites | 150 | 2.5 | Reinforced concrete | 1 | 10 | 1,500 | 225,000.00 | |
| Retrofitting to reduce flood risks in high risk houses and buildings | | | | 38 | 15-25 | 200,000 | 7,600,000.00 | |
| Constructing artificial drainage systems in low-lying areas and main roads. | | | | | | | | |
| - Drains | | | Reinforced concrete | 150 | 10-15 | 15,000 | 2,250,000.00 | Maintenance cost; 2 persons per year Cost: 72,000 |

| Protection Measure | Specifications | | | Fixed costs (RF) | Variable Cost notes |
|---|---|---|---|---|---|
| - Road Levelling | 7500 | Compact & level | 2 | 354,225.35 | Maintenance every 2 years. Cost: 354,225.35 |
| Creating disaster risk awareness among businesses | | | 2 | | Cost of 150,000. May have to be repeated every 2-3 years |
| Creating insurance awareness among high risk investments | | | 2 | | Cost of 200,000. May have to be repeated every 2-3 years |
| Create awareness among the population to use banking facilities to store cash | | | 2 | | Cost of 200,000. May have to be repeated every 2-3 years |
| Sub-total: Flood Proofing | | | | 2,332,500.00 | |
| TOTAL | | | | 137,357,798.11 | |

## *Cost Estimates: Limited SIP Protection on GDh Thinadhoo*

| Protection Measure | Specifications | | | | | | Fixed costs (RF) | Variable Cost notes |
|---|---|---|---|---|---|---|---|---|
| | Length (m) | Height (m) | Material | Qty | Lifetime (years) | Rate (RF) | | |
| Adopting the safe island mitigation measures | | | | | | | | |
| - Coastal protection (eastern coastline) | 1,500 | 2.5 | Boulders | 1 | 50-75 | 33,025 | 49,536,750.00 | Maintenance free |
| - Environment protection zone | 1,500 | | Trees and drainage | 1 | 15 | 5,000 | 7,500,000.00 | |
| Flood proofing warehouses and stock | | | | 4 | | 50,000 | 200,000.00 | |
| Flood proofing the power house | | | | | | | | |
| - Reinforcing the walls | 300 | 2.5 | Reinforced concrete | | 10 | 1,500 | 450,000.00 | |
| Flood proofing waste management sites | 150 | 2.5 | Reinforced concrete | 1 | 10 | 1,500 | 225,000.00 | |
| Constructing artificial drainage systems in low-lying areas and main roads. | | | | | | | | |
| - Drains | | | Reinforced concrete | 150 | 10-15 | 15,000 | 2,250,000.00 | Maintenance cost; 2 persons per year Cost: 72,000 |
| - Road Levelling | 7,500 | | Compact & level | | 2 | | 354,225.35 | Maintenance every 2 years. Cost: 354,225.35 |
| Creating disaster risk awareness among businesses | | | | | 2 | | | Cost of 150,000. May have to be repeated every 2-3 years |
| Creating insurance awareness among high risk investments | | | | | 2 | | | Cost of 200,000. May have to be repeated every 2-3 years |
| Create awareness among the population to use banking facilities to store cash | | | | | 2 | | | Cost of 200,000. May have to be repeated every 2-3 years |
| Sub-total: Flood Proofing | | | | | | | 875,000.00 | |
| TOTAL | | | | | | | 60,515,975.35 | |

## ANNEX F

# DETAILED LOSS CALCULATIONS FOR GA VILIGILI

*Estimated local losses and economic implication: tsunami*

| Sector | Estimated losses | Economic implications | Estimated proportion of losses (%) | Estimated value of losses (Rufiyaa) |
|---|---|---|---|---|
| Infrastructure | | | | |
| Power | Damage to electricity generation plants; transmission lines and distribution grids.<br>Disruption over 48 hours; Can only be made fully operational within a minimum of 1 week. | Disruption of all major business activities reliant on electricity. Most affected will be personal service sectors, retail trade (particularly fresh food and temperature sensitive goods), pharmacies, hotels and restaurants and the service sector in general. This will involve loss of business in some sectors.<br>Disruption over 48 hours will damage stock in pharmacies and cold storage facilities.<br>Additional costs (on the Government) to repair the facilities, and to meet the interim energy demand (30% of replacement value)<br>Loss of income or profits by the power company. | 50% businesses<br>5% of stock<br>-<br>- | 200,000<br>7,000<br>2,400,000<br>80,000 |
| Water and Sanitation | Damage to water storage tanks, sewage treatment site and sewage pipelines. | Water storage tanks may have to be replaced at a cost to the households or to the Government.<br>Disruption of service oriented businesses such as cafés and hotels<br>Additional costs (on the Government) to repair the facilities, and to meet the interim requirements for sewage management and water supply. | 5% households<br>30% Businesses<br>20% loss | 10,000<br>50,000<br>1,400,000 |
| Harbour | Damage to breakwater; quay wall; and jetty.<br>Siltation of harbour basin making limiting harbour use by larger vessels | Island local harbour is the key business infrastructure to the basic sectors on the island. Damage to harbour will disrupt wholesale and import trade which requires a quay wall or jetty to load and unload goods.<br>Export of manufacturing products will be affected.<br>Potential secondary damage to vessels when breakwater is damaged for a prolonged period<br>Disruptions in transport operations<br>Impact on fisheries sector may be minimal unless if vessels are damaged. There will be disruptions to vessel movements, however.<br>Additional costs (on the Government) to repair the facilities and dredge the harbour.<br>Lost income from visitors. | 20% businesses<br>15% of manufacturing industry workers<br>5% vessels (half the replacement cost<br>20% of vessels<br>5% vessels<br>-<br>10% loss | Mostly intangible losses<br>Mostly intangible losses<br>1,000,000<br>Mostly intangible losses<br>Mostly intangible losses<br>38,000,000 (replacement cost)<br>7,000 |

| Sector | Estimated losses | Economic implications | Estimated proportion of losses (%) | Estimated value of losses (Rufiyaa) |
|---|---|---|---|---|
| Communications | Moderate damage to communications equipment of Dhiraagu and Wataniya antenna sites.<br>Disruption of power to the communications equipment | Disruption of contact between nearby islands and Male', affecting business operations of almost all business establishments.<br>Introduction of uncertainty in the economy regarding the availability of goods leading to rapid demand on stocks and ultimately, inflation. | 30% businesses<br>- | Mostly intangible losses |
| Fuel supply | Damage to fuel storage and delivery systems; damage to fuel supply vessels and vehicles; oil spills (see hazardous waste management below) | Disruption of fishing and transport sector leading to loss of income in these sectors (2 weeks).<br>Loss of transport sector will have knock-on effects on wholesale and retail trade causing shortages in supply of essential items, leading to inflation (2 weeks).<br>Disruption of power (if power house undamaged) – See 'power' above<br>High cost of repair and for storage and fuel supply facilities. | 50% fishing businesses<br>30% businesses<br>-<br>- | 1,650,000<br>180,000<br>500,000 |
| Solid and hazardous waste management | Damage to waste management site | Redevelopment of waste site | | 500,000 |
| Hospital | Structural damage to hospital<br>Damage to equipment and machinery | Public costs incurred in repairing hospital structure and replacing equipment (20% of replacement value) | 20% loss | 4,800,000 |
| Households | Physical damage to houses<br>Damage to belongings (furniture, appliances, electronics, clothes etc..)<br>Loss of cash and valuables (stored in the house) | Financial losses from lost savings (cash and valuables) leading to reduced spending capacity.<br>This will affect all non-basic sectors of the economy, depending on the number of households damaged.<br>Financial losses incurred for rebuilding the uninsured houses and repurchasing household items. A general decline in economy is inevitable as spending halts for non-essential items.<br>Damage to households may prevent affected working population to turn-up for work as they have to attend to the household and family. This will lead to the temporary halting of all major economic activities. Fisheries sector is particularly vulnerable as a minimum number of persons are required for any fishing trip. Other sectors vulnerable to staff shortage include manufacturing, civil service, transport and communications, and retail shops.<br>Costs incurred by the Government to build and service temporary shelters.<br>Cost of demolition and debris removal may have to be borne by the household family members. | 20% households<br>30% businesses<br>10% households<br>15% businesses<br>10% households<br>7% households | No data<br>Mostly intangible losses<br>10,320,000<br>Mostly intangible losses<br>1,200,000<br>500,000 |

| Sector | Estimated losses | Economic implications | Estimated proportion of losses (%) | Estimated value of losses (Rufiyaa) |
|---|---|---|---|---|
| Fisheries | Damage to fishing vessels (vessel inoperable) and fishing gear.<br>Damage to fuel supply and storage (see above). | Loss of income from the main economic sector of the island. Fishing activity may be halted for weeks if vessels cannot be repaired or replaced. There will be unemployment amongst fishermen. Sector recovery and efficiency will depend on how many vessels were destroyed beyond repair. This will be among the biggest economic impacts on the island.<br>Knock-on effects of lost income in non-basic sectors: construction, transport, personal services, retail and restaurants.<br>Sector production will decrease or halt if fuel supply is damaged or destroyed. Alternate sources of fuel may be sought from other islands (see fuel supply). | 5% vessels partially damaged<br>10% businesses | 700,000<br>Mostly intangible losses |
| Agriculture | Damage to farms, farm equipment, fertilisers, seeds, crops in production and stock.<br>Loss production till the next rain due to groundwater salinization<br>Damage to backyard crops and fruit trees<br>Damage to timber trees | Loss of income from farms and mango trees (12 months)<br>The amount of money spend by households on food may increase when subsistence backyard crops are damaged.<br>Food shortages may result due to high demand and limited supply; may lead to temporary rise in food prices. | 80% farms<br>20% farms<br>- | 500,000<br>Mostly intangible losses<br>Mostly intangible losses |
| Wholesale and retail trade | Damage to stock in retail and wholesale shops and warehouses.<br>Physical damage to buildings<br>Physical damage to equipment, electronics and business records<br>Short –term loss of business due to road blockade (debris). | Loss of income from wholesale and retail trade to business owners (2 months)<br>Unemployment for staff of businesses destroyed or severely damaged (2 months).<br>Loss of uninsured stock and buildings leading to liquidity problems for wholesalers<br>Loss of re-export income (wholesale to nearby islands)<br>Financial losses incurred for rebuilding the uninsured buildings.<br>Delays in rent payment for damaged buildings, affecting the flow of income to rental property owners.<br>A number of engineering workshops may be damaged reducing the capability to repair damaged machinery, vessels and vehicles quickly. Costs incurred to rebuild. | 20% businesses<br>10% (2 months)<br>20% businesses<br>-<br>5% businesses<br>5% businesses<br>15% of workshops | 300,000<br>25,000<br>1,600,000<br>No Data<br>600,000<br>No data<br>1,200,000 |
| Manufacturing | Damage to existing production and stock (damage to raw material stocks, vessels under construction and repair, wood stocks in carpentries and processed food)<br>Damage to buildings, tools and equipment.<br>Damage to households – See households above. | Loss of income from manufacturing activities (2 months).<br>Unemployment among those involved in boat building and food processing<br>Loss of productivity in carpentries and boat yards due to building, equipment and tool damage.<br>Short to medium term decline in export income from manufacturing sector.<br>Damage to investments | 15% of businesses<br>5% (2 months)<br>5% businesses<br>-<br>5% businesses | 650,000<br>30,000<br>Mostly intangible losses<br>Mostly intangible losses<br>150,000 |

| Sector | Estimated losses | Economic implications | Estimated proportion of losses (%) | Estimated value of losses (Rufiyaa) |
|---|---|---|---|---|
| Transport, storage and communications | Damage to transport infrastructure (harbour) – see infrastructure above<br>Damage to marine transport vessels (cargo and passenger)<br>Damage to land vehicles<br>Damage to communication establishments (dhiraagu and wataniya) - see infrastructure above<br>Damage to warehouses and other storage buildings and their stock – wholesale and retail trade above. | Unemployment for persons employed in affected vessels or vehicles.<br>Loss of income from transport sector (2 months).<br>Knock-on effects on wholesale and retail trade, construction, agriculture and personal service sectors if cargo vessels are damaged.<br>Loss of stock and affects on liquidity of major businesses (see wholesale and retail trade) | 5% (2 months)<br>10%<br>20% of businesses damaged<br>10% businesses | 21,000<br>80,000<br>Mostly intangible losses<br>- |
| Construction | Damage to equipment and machinery<br>Damage to buildings under construction<br>Damage to site office | Generally positive: demand for construction will increase following damage to houses and buildings. Construction industry will experience a boom and will be a major source of temporary employment and income for those unemployed from other sectors.<br>Costs incurred in repairing and replacing equipment<br>More migrant workers in the economy to meet the excess demand for labour, leading to 'leakages' in foreign currency.<br>Expenditure from migrant workers will be an income to the local retailers and personal services. | 5% businesses<br>- | 165,000<br>Mostly intangible losses |
| Hotels and restaurants | Damage to buildings, appliances, furniture and stocks | Loss of income from affected establishments (2 months).<br>Loss of uninsured investments<br>Costs incurred in repurchasing of appliances and furniture, rebuilding and repairing.<br>Unemployment in affected establishments if the owner is unable to rebuild and recover in the short-term. | 30% businesses<br>5%<br>5% businesses<br>2% businesses | 100,000<br>30,000<br>10,000<br>4,000 |
| Public Administration | Partial damage to buildings, equipment, furniture and records, mostly in ministry of Health office, customs office and Atholhuge. | Income losses are expected to be negligible as Government is unlikely to lay off staff following a disaster. Hence, unemployment in this sector is also unlikely.<br>Costs incurred by the government to rebuild and re-establish damaged establishments | 5 % establishments | 2,000,000 |
| Other community, social and personal service activities | Damage to buildings, equipment, stock and other tools in small businesses engaged in personal service activities. | Loss of income and employment in small businesses involved in personal service activities (2 months).<br>Costs incurred in rebuilding and repairing the establishments<br>Reduced demand for personal services due to reduced spending at household level. | 10% businesses<br>7% businesses<br>20% businesses | 80,000<br>150,000<br>Mostly intangible losses |
| Real Estate, renting and business activities | Partial damage to buildings, equipment, furniture. | Loss of rental income<br>Costs incurred for repairing | 2% properties<br>1% properties | 4,000<br>200,000 |

| Sector | Estimated losses | Economic implications | Estimated proportion of losses (%) | Estimated value of losses (Rufiyaa) |
|---|---|---|---|---|
| Tourism | No direct investment losses on the island.<br>Resorts where temporary migrants from Viligilli work may be damaged. | Remittances from resort employees may decline if resorts around Maldives are damaged (3 months).<br>Some resort employees may be unemployed due to resort closure | 50% of households with tourism remittance<br>5% of households | 400,000<br>No data |

**SOURCE:** UNDP, 2009b

*Estimated local losses and economic implications: Swell waves and Storm surges*

| Sector | Estimated losses | Economic implications | Estimated proportion of losses (%) | Estimated value of losses (Rufiyaa) |
|---|---|---|---|---|
| Infrastructure | | | | |
| Power | Damage to electricity generation plants; transmission lines and distribution grids.<br>Disruption over 48 hours; Can only be made fully operational within a minimum of 2 days. | Disruption of all major business activities reliant on electricity. Most affected will be personal service sectors, retail trade (particularly fresh food and temperature sensitive goods), pharmacies, hotels and restaurants and the service sector in general. This will involve loss of business in some sectors.<br>Disruption over 48 hours will damage stock in pharmacies and cold storage facilities.<br>Additional costs (on the Government) to repair the facilities, and to meet the interim energy demand (30% of replacement value)<br>Loss of income or profits by the power company. | 20% businesses<br>5% of stock<br>-<br>- | 70,000<br>7,000<br>1,400,000<br>40,000 |
| Water and Sanitation | Damage to water storage tanks, sewage treatment site and sewage pipelines. | Water storage tanks may have to be replaced at a cost to the households or to the Government.<br>Disruption of service oriented businesses such as café s and hotels<br>Additional costs (on the Government) to repair the facilities, and to meet the interim requirements for sewage management and water supply. | 2% households<br>20% Businesses<br>15% loss | 4,000<br>35,000<br>700,000 |
| Harbour | Damage to breakwater; quay wall; and jetty.<br>Disruption to transport operations | Island local harbour is the key business infrastructure to the basic sectors on the island. Damage to harbour will disrupt wholesale and import trade which requires a quay wall or jetty load and unload goods.<br>Disruptions in transport operations | 5% businesses<br>5% of vessels | Mostly intangible losses<br>Mostly intangible losses |
| Communications | Moderate damage to communications equipment of Dhiraagu and Wataniya antenna sites.<br>Disruption of power to the communications equipment | Disruption of contact between nearby islands and Male', affecting business operations of almost all business establishments.<br>Introduction of uncertainty in the economy regarding the availability of goods leading to rapid demand on stocks and ultimately, inflation. | 30% businesses<br>- | Mostly intangible losses |
| Fuel supply | Disruption to fuel delivery; | Disruption of fishing and transport sector leading to loss of income in these sectors (2 days).<br>Disruption of power (if power house undamaged) – See 'power' above | 50% fishing businesses<br>30% businesses | Mostly intangible losses<br>Mostly intangible losses |
| Solid and hazardous waste management | Damage to waste management site | Redevelopment of waste site | | 500,000 |

| Sector | Estimated losses | Economic implications | Estimated proportion of losses (%) | Estimated value of losses (Rufiyaa) |
|---|---|---|---|---|
| Hospital | Damage to equipment and machinery | Public costs incurred in repairing hospital structure and replacing equipment (5% of replacement value) | 1% loss | 200,000 |
| Households | Physical damage to houses<br>Damage to belongings (furniture, appliances, electronics, clothes etc..)<br>Loss of cash and valuables (stored in the house) | Financial losses from lost savings (cash and valuables) leading to reduced spending capacity.<br>This will affect all non-basic sectors of the economy, depending on the number of households damaged.<br>Financial losses incurred for rebuilding the uninsured houses and repurchasing household items. A general decline in economy is inevitable as spending halts for non essential items.<br>Damage to households may prevent affected working population to turn-up for work as they have to attend to the household and family. This will lead to the temporary halting of all major economic activities. Fisheries sector is particularly vulnerable as a minimum number of persons are required for any fishing trip. Other sectors vulnerable to staff shortage include manufacturing, civil service, transport and communications, and retail shops.<br>Costs incurred by the Government to service temporary shelters.<br>Cost of demolition and debris removal may have to be borne by the household family members. | 10% households<br>20% businesses<br>1% households<br>15% businesses<br>3% households<br>1% households | No data<br>Mostly intangible losses<br>800,000<br>Mostly intangible losses<br>300,000<br>90,000 |
| Fisheries | Damage to fishing vessels (vessel inoperable) and fishing gear.<br>Disruption to fuel supply and storage (see above). | Secondary damage to vessels.<br>Knock-on effects of lost income in non-basic sectors: construction, transport, personal services, retail and restaurants.<br>Sector production will decrease or halt if fuel supply is damaged or destroyed. Alternate sources of fuel may be sought from other islands (see fuel supply). | 1% vessels partially damaged<br>1% businesses | 60,000<br>Mostly intangible losses |
| Agriculture | Damage to farms, farm equipment, fertilisers, seeds, crops in production and stock.<br>Loss production till the next rain due to groundwater salinization<br>Damage to backyard crops and fruit trees<br>Damage to timber trees | Loss of income from farms and mango trees (12 months)<br>The amount of money spend by households on food may increase when subsistence backyard crops are damaged.<br>Food shortages may result due to high demand and limited supply; may lead to temporary rise in food prices. | 15% farms<br>-<br>- | 100,000<br>Mostly intangible losses<br>Mostly intangible losses |

| Sector | Estimated losses | Economic implications | Estimated proportion of losses (%) | Estimated value of losses (Rufiyaa) |
|---|---|---|---|---|
| Wholesale and retail trade | Damage to stock in retail and wholesale shops and warehouses.<br>Physical damage to buildings<br>Physical damage to equipment, electronics and business records<br>Short –term loss of business due to road blockade (debris). | Loss of income from wholesale and retail trade to business owners (2 months)<br>Unemployment for staff of businesses destroyed or severely damaged (2 months).<br>Loss of uninsured stock and buildings leading to liquidity problems for wholesalers<br>Loss of re-export income (wholesale to nearby islands)<br>Delays in rent payment for damaged buildings, affecting the flow of income to rental property owners.<br>A number of engineering workshops may be damaged reducing the capability to repair damaged machinery, vessels and vehicles quickly. Costs incurred to rebuild. | 10% businesses<br>7% (2 months)<br>5% businesses<br>-<br>4% businesses<br>3% of workshops | 150,000<br>20,000<br>300,000<br>No Data<br>No data<br>200,000 |
| Manufacturing | Damage to existing production and stock<br>Damage to buildings, tools and equipment.<br>Damage to households – See households above. | Loss of income from manufacturing activities (1 months).<br>Unemployment among those involved in boat building and food processing<br>Loss of productivity in carpentries and boat yards due to building, equipment and tool damage.<br>Short to medium term decline in export income from manufacturing sector. | 2% of businesses<br>3% (1 months)<br>5% businesses<br>- | 150,000<br>20,000<br>Mostly intangible losses<br>Mostly intangible losse |
| Transport, storage and communications | Damage to transport infrastructure (harbour) – see infrastructure above<br>Damage to marine transport vessels (cargo and passenger)<br>Damage to land vehicles<br>Damage to communication establishments (dhiraagu and wataniya) - see infrastructure above<br>Damage to warehouses and other storage buildings and their stock – wholesale and retail trade above. | Unemployment for persons employed in affected vessels or vehicles.<br>Loss of income from transport sector (2 months).<br>Knock-on effects on wholesale and retail trade, construction, agriculture and personal service sectors if cargo vessels are damaged.<br>Loss of stock and affects on liquidity of major businesses (see wholesale and retail trade) | 5% (2 months)<br>10%<br>20% of businesses damaged<br>10% businesses | 21,000<br>80,000<br>Mostly intangible losses<br>- |

| Sector | Estimated losses | Economic implications | Estimated proportion of losses (%) | Estimated value of losses (Rufiyaa) |
|---|---|---|---|---|
| Construction | Damage to equipment and machinery<br>Damage to buildings under construction<br>Damage to site office | Generally positive: demand for construction will increase following damage to houses and buildings. Construction industry will experience a boom and will be a major source of temporary employment and income for those unemployed from other sectors.<br>Costs incurred in repairing and replacing equipment<br>More migrant workers in the economy to meet the excess demand for labour, leading to 'leakages' in foreign currency.<br>Expenditure from migrant workers will be an income to the local retailers and personal services. | 5% businesses<br>- | 165,000<br>Mostly intangible losses |
| Hotels and restaurants | Damage to buildings, appliances, furniture and stocks | Loss of income from affected establishments (2 months).<br>Loss of uninsured investments<br>Costs incurred in repurchasing of appliances and furniture, rebuilding and repairing.<br>Unemployment in affected establishments if the owner is unable to rebuild and recover in the short-term. | 10% businesses<br>2%<br>5% businesses<br>2% businesses | 30,000<br>20,000<br>10,000<br>4,000 |
| Public Administration | Partial damage to buildings, equipment, furniture and records, mostly in ministry of Health office, customs office and Atholhuge. | Income losses are expected to be negligible as Government is unlikely to lay off staff following a disaster. Hence, unemployment in this sector is also unlikely.<br>Costs incurred by the government to rebuild and re-establish damaged establishments | 1 % establishments | 200,000 |
| Other community, social and personal service activities | Damage to buildings, equipment, stock and other tools in small businesses engaged in personal service activities. | Loss of income and employment in small businesses involved in personal service activities (1 month).<br>Costs incurred in rebuilding and repairing the establishments<br>Reduced demand for personal services due to reduced spending at household level. | 4% businesses<br>1% businesses<br>15% businesses | 35,000<br>60,000<br>Mostly intangible losses |
| Real Estate, renting and business activities | Disruption to operations | Loss of rental income | 2% properties | 4,000 |
| Tourism | No direct investment losses on the island.<br>Resorts where temporary migrants from Viligilli work may be damaged. | Remittances from resort employees may decline if resorts around Maldives are damaged (3 months).<br>Some resort employees may be unemployed due to resort closure | 25% of households with tourism remittance<br>5% of households | 200,000<br>No data |

**SOURCE:** UNDP, 2009b

*Estimated local losses and economic implications: Rainfall flooding*

| Sector | Estimated losses | Economic implications | Estimated proportion of losses (%) | Estimated value of losses (Rufiyaa) |
|---|---|---|---|---|
| Infrastructure | | | | |
| Roads | Flooded roads may reduce mobility | Disruption of economic activities located close to the harbour<br>Minor loss of business due to flood water on the streets<br>Costs incurred by the Government to repair flood prone roads | | Mostly intangible losses<br>No Data<br>No Data |
| Retail and wholesale trade | Disruption of business activity.<br>Damage to stock. | Business activity may be slow during the event<br>Damage to stock | 10% businesses<br>5% businesses | 10,000<br>120,000 |
| Households | Damage to household goods;<br>Disruption to daily life | Damage to household goods | 5% households | 80,000 |
| Hotels and restaurants | Disruption of business activity. | Business activity may be slow during the event | 5% businesses | No Data |

**SOURCE:** UNDP, 2009b

## ANNEX G

# DETAILED COST ESTIMATES FOR RISK MANAGEMENT MEASURES ON GA VILIGILI

*Cost Estimates: Full SIP Protection on GA Viligili*

| Protection Measure | Specifications | | | | | | Fixed costs (RF) | Variable Cost notes |
|---|---|---|---|---|---|---|---|---|
| | Length (m) | Height (m) | Material | Qty | Lifetime (years) | Rate (RF) | | |
| Adopting the safe island mitigation measures | | | | | | | | |
| - Coastal protection (eastern and southern coastline) | 2,800 | 2.5 | Boulders | 1 | 50-75 | 33,025 | 92,485,036.00 | Maintenance free |
| - Coastal protection (western coastline) | 1,000 | 2 | Boulders | 1 | 50-75 | 33,025 | 33,030,370.00 | Maintenance free |
| - Environment protection zone | 2,800 | | Boulders, wide option with drainage | 1 | 15 | 5,000 | 14,000,000.00 | |
| - Resilient harbour | | | | | 15-25 | | 37,312,172.76 | Maintenance dredging every 10 years up to 0.5m. Cost: 5,000,500 |
| - Evacuation facilities | | | | | 15-20 | | 3,855,000.00 | Multipurpose facility so variable costs should be covered in daily operations |
| Flood proofing the hospital | 176.4 | 2.5 | Reinforced concrete | 1 | 10 | 1,500 | 264,600.00 | None - one off development; possible hospital extension not covered. |
| Flood proofing warehouses and stock | | | | 5 | | 50,000 | 400,000.00 | |
| Protecting the fuel storage and supply | 170 | 2.5 | Reinforced concrete | 3 | 10-15 | 1,500 | 255,000.00 | None - one off development; possible expansion not covered. |
| Flood proofing the power house | | | | | | | | |
| - Reinforcing the walls | 243 | 2.5 | Reinforced concrete | | 10 | 1,500 | 364,500.00 | |
| - Raising the plants | | | | 4 | 15-20 | 50,000 | 200,000.00 | None - one off development; possible expansion not covered. |
| Flood proofing communications infrastructure | | | | | | | | |
| - Reinforcing the walls | 170 | 2.5 | Reinforced concrete | 2 | 10 | 1,500 | 225,000.00 | |
| - Raising the equipment | | | | 4 | 10 | 50,000 | 200,000.00 | None - one off development; possible expansion not covered. |
| Flood proofing waste management sites | 130 | 2.5 | Reinforced concrete | 1 | 10 | 1,500 | 195,000.00 | |

| Protection Measure | Specifications | | | | | Fixed costs (RF) | Variable Cost notes |
|---|---|---|---|---|---|---|---|
| Retrofitting to reduce flood risks in high risk houses and buildings | | | 51 | 15-25 | 200,000 | 10,200,000.00 | |
| Constructing artificial drainage systems in low-lying areas and main roads. | | | | | | | |
| - Drains | | Reinforced concrete | 100 | 10-15 | | 1,500,000.00 | Maintenance cost; 2 persons per year. Cost: 72,000 |
| - Road Levelling | 5000 | Compact & level | | 2 | | 236,165.97 | Maintenance every 2 years. Cost: 236,165.97 |
| Creating disaster risk awareness among businesses | | | | 2 | | | Cost of 150,000, may have to be repeated every 2-3 years |
| Creating insurance awareness among high risk investments | | | | 2 | | | Cost of 200,000, may have to be repeated every 2-3 years |
| Create awareness among the population to use banking facilities to store cash | | | | 2 | | | Cost of 200,000, may have to be repeated every 2-3 years |
| Sub-total: Flood Proofing | | | | | | 2,134,100 | |
| TOTAL | | | | | | 194,752,845 | |

## *Cost Estimates: Selected SIP Protection on GA Viligili*

| Protection Measure | Specifications | | | | | | Fixed costs (RF) | Variable Cost notes |
|---|---|---|---|---|---|---|---|---|
| | Length (m) | Height (m) | Material | Qty | Lifetime (years) | Rate (RF) | | |
| Adopting the safe island mitigation measures | | | | | | | | |
| - Coastal protection (eastern and southern coastline) | 2,800 | 2.5 | Boulders | 1 | 50-75 | 33,025 | 92,485,036.00 | Maintenance free |
| - Environment protection zone | 2,800 | | Boulders, wide option with drainage | 1 | 15 | 5,000 | 14,000,000.00 | |
| - Resilient harbour | | | | | 15-25 | | 37,312,172.76 | Maintenance dredging every 10 years up to 0.5m. Cost: 5,000,500 |
| - Evacuation facilities | | | | | 15-20 | | 3,855,000.00 | Multipurpose facility so variable costs should be covered in daily operations |
| Flood proofing the hospital | 176.4 | 2.5 | Reinforced concrete | 1 | 10 | 1,500 | 264,600.00 | None - one off development; possible hospital extension not covered. |
| Flood proofing warehouses and stock | | | | 5 | | | 400,000.00 | |
| Protecting the fuel storage and supply | 170 | 2.5 | Reinforced concrete | 3 | 10-15 | 1,500 | 255,000.00 | None - one off development; possible expansion not covered. |
| Flood proofing the power house | | | | | | | | |
| - Reinforcing the walls | 243 | 2.5 | Reinforced concrete | | 10 | 1,500 | 364,500.00 | |
| - Raising the plants | | | | 4 | 15-20 | 50,000 | 200,000.00 | None - one off development; possible expansion not covered. |
| Flood proofing communications infrastructure | | | | | | | | |
| - Reinforcing the walls | 170 | 2.5 | Reinforced concrete | 2 | 10 | 1,500 | 225,000.00 | |
| - Raising the equipment | | | | 4 | 10 | 50,000 | 200,000.00 | None - one off development; possible expansion not covered. |
| Flood proofing waste management sites | 130 | 2.5 | Reinforced concrete | 1 | 10 | 1,500 | 195,000.00 | |
| Retrofitting to reduce flood risks in high risk houses and buildings | | | | 51 | 15-25 | 200,000 | 10,200,000.00 | |
| Constructing artificial drainage systems in low-lying areas and main roads. | | | | | | | | |
| - Drains | | | Reinforced concrete | 100 | 10-15 | | 1,500,000.00 | Maintenance cost; 2 persons per year Cost: 72,000 |

| Protection Measure | Specifications | | | Fixed costs (RF) | Variable Cost notes |
|---|---|---|---|---|---|
| - Road Levelling | 5000 | Compact & level | 2 | 236,165.97 | Maintenance every 2 years. Cost: 236,165.97 |
| Creating disaster risk awareness among businesses | | | 2 | | Cost of 150,000, may have to be repeated every 2-3 years |
| Creating insurance awareness among high risk investments | | | 2 | | Cost of 200,000, may have to be repeated every 2-3 years |
| Create awareness among the population to use banking facilities to store cash | | | 2 | | Cost of 200,000, may have to be repeated every 2-3 years |
| Sub-total: Flood Proofing | | | | 2,134,100 | |
| TOTAL | | | | 161,722,475 | |

## *Cost Estimates: Limited Protection on GA Viligili*

| Protection Measure | Specifications | | | | | | Fixed costs (RF) | Variable Cost notes |
|---|---|---|---|---|---|---|---|---|
| | Length (m) | Height (m) | Material | Qty | Lifetime (years) | Rate (RF) | | |
| Adopting the safe island mitigation measures | | | | | | | | |
| - Coastal protection (eastern and southern coastline) | 2,800 | 2 | Sand cement bags | 1 | 50-75 | 3,000 | 8,400,000.00 | Maintenance cost every 2 years, 20% completely repaired |
| - Environment protection zone | 2,800 | | Boulders, narrow option without drainage | 1 | 15 | 2,500 | 7,000,000.00 | |
| - Resilient harbour | | | | | 15-25 | | 37,312,172.76 | Maintenance dredging every 10 years up to 0.5m. Cost: 5,000,500 |
| Retrofitting to reduce flood risks in high risk houses and buildings | | | Strong roofing and raised entrances | 150 | 10-15 | 50,000 | 7,500,000.00 | |
| Constructing artificial drainage systems in low-lying areas and main roads. | | | | | | | | |
| - Road Levelling | 5000 | | Compact & level | | 2 | | 236,165.97 | Maintenance every 2 years. Cost: 236,165.97 |
| Creating disaster risk awareness among businesses | | | | | 2 | | | Cost of 150,000, may have to be repeated every 2-3 years |
| Creating insurance awareness among high risk investments | | | | | 2 | | | Cost of 200,000, may have to be repeated every 2-3 years |
| Create awareness among the population to use banking facilities to store cash | | | | | 2 | | | Cost of 200,000, may have to be repeated every 2-3 years |
| TOTAL | | | | | | | 60,448,338.73 | |

## ANNEX H

# ASSUMPTIONS FOR SETTLEMENT PLANNING ANALYSIS

*Assumptions for Cost Estimates of Improved Settlement Planning for Thinadhoo*

| Costs for preparing guidelines | Assumptions | Cost (RF) |
|---|---|---|
| Consultancy costs – pro-rated for Thinadhoo | | |
| Developing Guideline for Hazard Resilient Land Use Planning | National cost: RF 1,734,750, prorated for Thinadhoo (1 of 200 inhabited islands). | 8,673.75 |
| Developing Guideline for High Impact Coastal Developments | National cost: RF 1,734,750, prorated for Thinadhoo (1 of 200 inhabited islands). | 8,673.75 |
| Updating building codes | National cost: RF 1,156,500, prorated for Thinadhoo (1 of 200 inhabited islands). | 5,782.50 |
| Recurrent Costs | | |
| High Impact Coastal and Terrestrial Developments | | |
| Increased costs of surveying and engineering | Cost of additional survey and engineer fees, RF 257k each. | 514,000.00 |
| Increased cost of environmental studies | Equivalent to USD 30k. | 385,500.00 |
| Increased cost of contracting - reclamation leveling and drainage | Additional cost of RF 12.5 per m3 (assume 25% increase in existing market rate at RF 50 per m3 of reclamation); 71 ha reclaimed on Thinadhoo. | 8,875,000.00 |
| Compulsory EPZ, natural ridge and re-vegetation | Assume natural ridge of 2.5m will require 17,250 m3 of additional sand at RF 50/m3. Assume 40% of reclaimed area will need to be re-vegetated (rest used for roads, housing) – equivalent to 28.4 ha – at a cost of RF 25/m2. | 7,962,500.00 |
| Capacity building to monitor and evaluate projects | 1 staff trained at Male' for 2 weeks; transport; accommodation; food and trainer cost. | 58,000.00 |
| Staffing costs | 1 technical staff at RF 18,000 per month for the project duration of 18 months. | 324,000.00 |
| Building Codes | | |
| Increased costs on surveying and engineering | Estimated at RF 10,000 per new household and RF 25,000 per industrial development; estimated 30 new households; 5 public establishments; 8 major economic establishments. | 625,000.00 |
| Capacity building to monitor and evaluate projects | 2 staff trained at Male' for 2 weeks; transport; accommodation; food and trainer costs. | 74,000.00 |
| Additional cost of contracting | Assume cost of contracting increases by 20% of the market rate, for 30 houses. | 1,800,000.00 |
| Staffing costs | 2 staff at RF 7,000 per month; for 10 years (time since reclamation). | 1,680,000.00 |

| Costs for preparing guidelines | Assumptions | Cost (RF) |
|---|---|---|
| Hazard Resilient Land Use | | |
| Increased costs of surveying and engineering | Most costs incorporated in building codes (above). | 10,000.00 |
| Increased cost on environmental studies | Increased cost for basic studies (not full EIAs); cost of study estimated at USD 4,000, or RF 51,400; 8-10 new major public and private developments. | 514,000.00 |
| Capacity building to evaluate and enforce development applications | 3 staff trained at Male' for 2 weeks; transport; accommodation; food and trainer costs. | 90,000.00 |
| Staffing costs | 3 staff at Rf7000 per month; for 10 years (time since reclamation). | 2,520,000.00 |
| | | 25,455,130.00 |

## MHTE

The Ministry of Housing, Transport and Environment (MHTE) is mandated to plan, oversee and execution of infrastructure developments within the country. MHTE has the overall mandate for the facilitation of the development and delivery of sustainable solutions for housing, infrastructure, transport, environment, climate change, energy and water and sewerage. Further the MHTE is also mandated to oversee and regulate the social infrastructures for the country as well as, for the creation and development of the necessary regulatory framework for the construction industry. MHTE is responsible for ensuring that the overall developments in the country are targeted towards achieving sustainability and environment conservation.

## UNDP

UNDP is the UN's global development network, advocating for change and connecting countries to knowledge, experience and resources to help people build a better life. We are on the ground in 166 countries, working with them on their own solutions to global and national development challenges. As they develop local capacity, they draw on the people of UNDP and our wide range of partners.

## ISDR

The United Nations International Strategy for Disaster Reduction Asia Pacific works through a growing network of regional partners, organizations and national platforms to mobilize governmental actions in disaster risk reduction. UNISDR aims at building and supporting disaster resilient communities by promoting an increased awareness for disaster risk reduction.

## EU

The European Union is made up of 27 Member States who have decided to gradually link together their know-how, resources and destinies. Together, during a period of enlargement of 50 years, they have built a zone of stability, democracy and sustainable development, while maintaining cultural diversity, tolerance and individual freedoms. The European Union is committed to sharing its achievement and its values with countries and people beyond its borders.