Potential Land Loss on Two Islands in Singapore with a Future Rising Sea

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Abstract

The Southern Islands comprises an urban planning area in the Central Region of Singapore and is made up of the islands of Kusu, Lazarus, Seringat, Tekukor, St. John, Sentosa and the Sister Islands. The islands had largely been expanded by land reclamation in the 1970s to create recreational space, beaches and swimming lagoons. The new coastlines are armoured by large quarry stones. Other than Sentosa, the rest of the islands are as yet undeveloped and remain as weekend destinations. As part of the Singapore Tourism Board's plan to develop the Southern Islands beyond Sentosa, a second phase of land reclamation was started in 2000 to link Seringat, Lazarus and St John. Recent suggestions include turning Lazarus Island into a getaway for the super-rich or housing a casino. The small Kusu is an important pilgrimage island for both the Chinese and Malays and will probably remain so in future. However, whatever development or non-development is planned for Lazarus or Kusu, the impacts of a future rising sea must be addressed regarding the sustainability of the two islands. Reclamation that took place in the 1970s as in Kusu was before concern about global warming. Consequently, the crest of sea walls and platform levels of reclaimed land are low and vulnerable to wave overtopping and inundation during extreme high tides. The newly-reclaimed Lazarus Island with higher platforms and sea walls tells a different story. Inundation analyses using Geographic Information System for different time frames carried out under A2 emission scenario for Lazarus and Kusu suggest that although the two islands tell different tales, nevertheless extra care must be taken in developing or sustaining both islands to avoid future problems.

1. Introduction

Planning without considering a possible rising sea may render some of the best conceived land use plan to fail. Global warming and a rising sea is a recent concern and the early plans did not have to address this issue. However, plans for coastal areas and islands are now expected to accommodate a rising sea. Unfortunately, there is much uncertainty regarding the quantum of rise and there are questions whether coastal structures and platform levels of reclaimed land are adequate to protect existing coastal settlements, and whether any proposed plan to encourage settlement along the coast and on islands is wise.

2. Objectives

This paper examines the potential loss of land for Lazarus and Kusu Island under the threat of a rising sea. Scenario for various time frames is examined.

3. Lazarus and Kusu Island

3.1 Tidal characteristics of Southern Islands

The nearest tide station for the Southern Islands is Tanjung Pagar on the main island of Singapore. According to the Singapore Tide Tables (MPA, 2010), the tides around the Southern islands are semidiurnal with a tidal range of 2.2 m. The mean high water spring is 2.8 m chart datum or 1.1 m above mean sea level. All months have tides of 3.0 m or higher during springs and the highest spring tides are expected during the months of January, February and March, where tides can reach 3.3-3.4 m above chart datum (1.6-1.7 m above mean sea level). Information on the highest astronomical tide (HAT) around Singapore is not given in recent tide tables, but is shown for selected stations including Tanjung Pagar in older tide tables. As a general practice the value of 1.7 m above mean sea level is used as HAT for the whole of Singapore. This value is in agreement with the predicted tides for Tanjung Pagar and is adopted as HAT in this study.

3.2 History of St John-Lazarus and Kusu Islands

Before the land reclamation of the 1960s, the area occupied by the present St John-Lazarus was a group of discrete islands dominated by St John and Lazarus, with islets of Kusu and Seringat and patchy reefs. The two larger islands, each with a school, were occupied by a decent sized population. Kusu

Island was formerly composed of two small outcrops surrounded by fringing reef, the 2.5 ha island was enlarged in 1975 and transformed into a recreational island of 8.5 ha. On the island is a temple, built in 1923 and during the ninth lunar month, devotees flock to the island to pray for good health, peace, happiness, good luck and prosperity. On top of the rugged hillock stands three *keramats* or holy shrines of Malay saints. Kusu is considered an island of religious and cultural importance. As part of the Singapore Tourism Board's plan to develop the Southern Islands beyond Sentosa, a second phase of land reclamation with sands imported from Indonesia was started in 2000 to link Seringat and Lazarus and create a wide sandy bay. The new island is linked to St. John by a causeway.

3.3 Lazarus Island after 2006 Reclamation

Lazarus Island at the end of the reclamation is dominated by the old hill towards the south and low-lying reclaimed land to the north targeted for residential and commercial development (Figure 1).

Figure 1: Coastal features of Lazarus Island

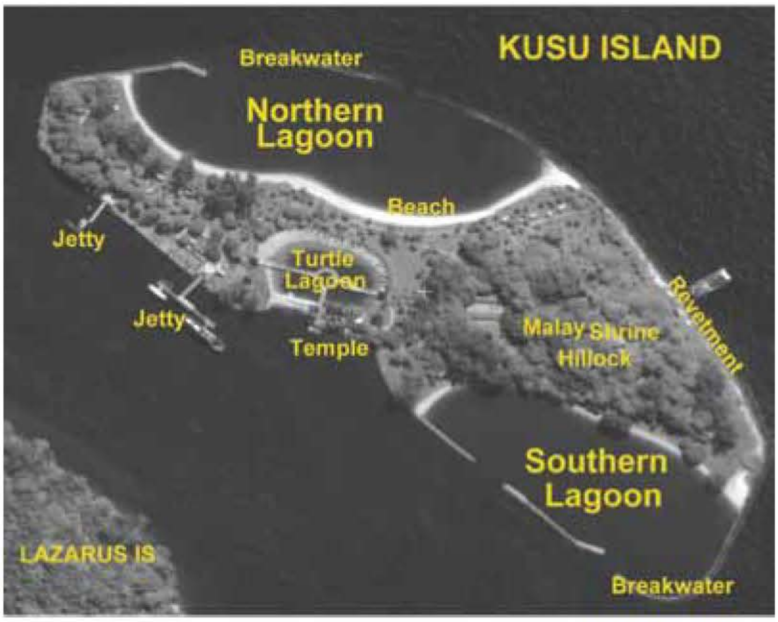


Figure 2: Coastal features of Kusu

The coastline of reclaimed land is protected by high seawalls and a short causeway and bridge connect the main Lazarus Island to two small artificial islands. A longer causeway connects Lazarus to St. John. A lagoon with narrow beaches has been created along the northern coast and a broad swimming bay with wide beaches backed by a sand terrace has been created along the eastern coast. The old narrow beaches below the bluff opposite Kusu island still remains.

3.4 Kusu Island after 1975 Reclamation

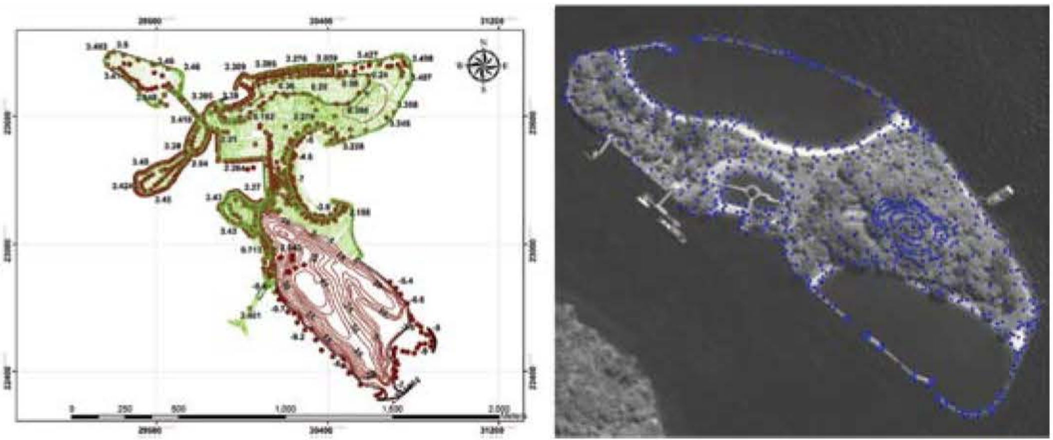
A pre-war photo of Kusu Island taken from Keramat Hill where the Malay shrine is located shows a small Chinese temple partially built into the sea on a small islet with several tall trees. Land reclamation in 1975 merged the islet to Keramat Hill to form the present day Kusu Island. Among the Southern islands, Kusu is the most exposed to swells entering the Straits of Singapore from the South China Sea. The whole island is protected by revetment/breakwater and there are two deeply-indented swimming lagoons and an enclosed turtle lagoon (Figure 2). The original plan of Kusu showed three swimming lagoons. The breakwaters are flexible in design and can be easily raised, lowered or reshaped. In places, erosion has breached the revetment and beaches have started to form behind the line of rocks. Wave over wash is common and strand materials are often deposited inland after storms. The island terrain, typically that of reclaimed land, is flat, cresting at less than three metres above mean sea level. The forested hillock and rock exposures within the Chinese temple complex form the topographic highs. The island, especially the reclaimed portion, is vulnerable to flooding and the coastline, exposed to waves bigger than that arriving on the main island of Singapore, is prone to erosion.

4. Method

Only the SRES scenarios of A2 (high) for different time frames (2020, 2030, 2050 and 2100) were used to assess land loss of future sea level rise on Lazarus and Kusu Island. SRES refers to the scenarios described in the IPCC Special Report on Emissions Scenarios (Nakicenovic and Stewart, 2000). The SRES scenarios are grouped into four scenario families (A1, A2, B1 and B2) that explore alternative development pathways, covering a wide range of demographic, economic and technological driving forces and resulting GHG emissions. The A1 storyline assumes a world of very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies. A1 is divided into three groups that describe alternative directions of technological change: fossil intensive (A1FI), non-fossil energy resources (A1T) and a balance across all sources (A1B). B1 describes a convergent world, with the same global population as A1, but with more rapid changes in economic structures toward a service and information economy. B2 describes a world with intermediate population and economic growth, emphasizing local solutions to economic, social, and environmental sustainability. A2 describes a very heterogeneous world with high population growth, slow economic development and slow technological change. No likelihood has been attached to any of the SRES scenarios. Under the A2 emission scenario, the projected global mean sea level rise by IPCC at the end of the 21st century varies from 23 to 51 cm (Pachauri and Reisinger, 2007). For the study, the projected sea level rise of the regional sea for different time frames is used to predict future coastline positions. These levels are higher than the IPCC projected levels. The projected future sea levels, shown in table 1, follow that of Tkalich and Gulev, (2009). This assumes a contribution of 20 cm by ice melt in 100 years. In order to assess extent of land loss, DEM of the islands were created by collecting a network of elevation point data using different survey techniques, as described by Santosh et al., (2009). This data set was supplemented by digital elevation information provided by Sentosa Development Corporation (SDC) for Lazarus Island. Remote sensing techniques were also used to collect elevation data on the steep, inaccessible hill on Kusu Island.

Table 1: Projected sea level of regional seas for 2020, 2030, 2050 and 2100

Time scale	Regional msl projection	Ice melt (m)	Coastline (m)
2010			0.863
2020	0.27	0.04	1.174
2030	0.30	0.06	1.179
2050	0.38	0.10	1.191
2100	0.65	0.20	1.713



Lazarus Island

Kusu Island

Figure 3: Elevation data of Lazarus and Kusu

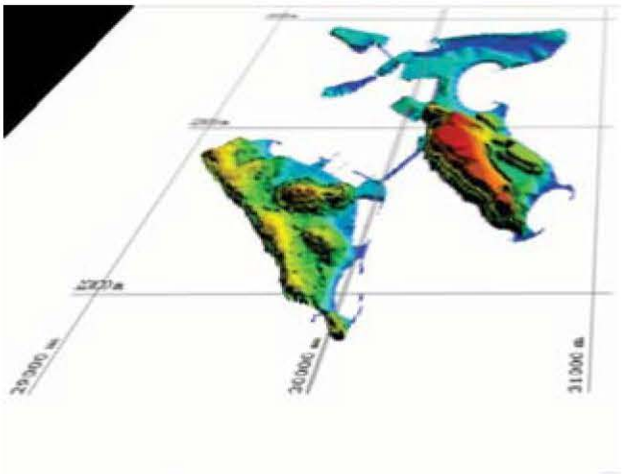


Figure 4: 3-D perspective map of Lazarus and St. John

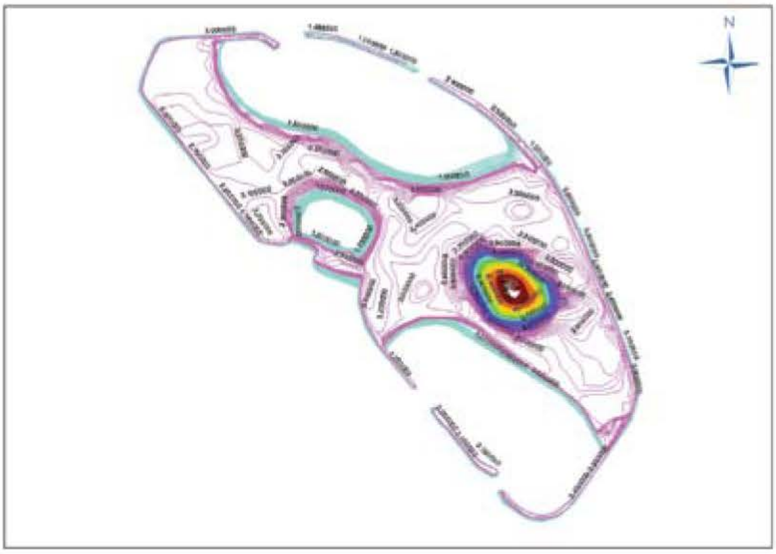


Figure 5: Contour map of 20cm interval of Kusu

4.1 Collecting Elevation Data in the Field

During visits to the islands in 2008 to collect elevation data, we did the following:

1. Set up a baseline consisting of two temporary bench marks (TBMs) using Trimble-R8 Real Time Kinematic (RTK) GPS on the islands.
2. Collected a network of elevation data using Nikon Total Station DTM-332 and two prisms- we selected points randomly or where changes in slope occurred.
3. Collected elevation data using mobile mapping with the RTK mounted on a truck on Lazarus Island.

4.2 Generating Digital Elevation Model (DEM)

The elevation data collected for the two islands was combined with data provided by SDC in a Microstation CAD platform (Figure 3). We imported the merged dataset in ArcGIS as elevation layer and then using the 3D analyst tools in ArcGIS, generated a Triangulated Irregular Network (TIN). We further processed the TIN in ArcGIS to generate a DEM. This was done for both Lazarus and Kusu Island. The DEM is imported into 3D modelling software (Global Mapper) and processed to generate a 3D perspective view (Figure 4) and contour map (Figure 5). The 3D view toolbar in Global Mapper further allows land loss modelling for various sea level rise scenarios. The output is taken into ArcGIS for land loss area calculation.

5. Result

To calculate the areas of land loss, a GIS analysis was carried out to obtain the total area of each island and areas lost from the present coastline to the projected future coastline.

5.1Land Loss under A2 Emission Scenarios on Lazarus and Kusu

For calculating land loss caused by a rising sea, the area above the legally defined coastline of 0.863 m reduced level is considered land and only the projected sea level rise and ice melt component are used. The area considered as land loss is from the old coastline (0.863 m) to the new coastline. For example, for the year 2020, the new coastline would be at about 1.173 m (0.863 m plus 0.27 m regional sea level rise plus 0.04 m ice melt)

5.1.1 Lazarus

The land loss statistics for Lazarus under A2 scenario is shown in Table 2. By the year 2020, loss of land with a rising sea totals 0.952 ha, increasing slightly to 0.97 ha by the year 2030 and to 1.53 ha by the year 2050. By the end of the century, a rising sea would cause land loss of 3.14 ha or 4.181% of Lazarus Island. The areas of land loss for selected sea level scenarios are shown in Figures 6, 7 and 8.The main areas of land loss will be along the beaches of the main bay and lagoon edge. Minor land loss will occur along the rocky coast. The breakwaters along the southeast coast will have to be raised to remain as land. There claimed land protected by seawalls will remain intact by the end of the century. Although little land will be lost by the end of the century, the future scenario is completely different with inundation under an extreme event of a one metre storm surge coinciding with HAT during which nearly all the reclaimed land on Lazarus Island will be temporarily inundated (Figure 9). However, it must be emphasized that it is highly unlikely for such an extreme event, a worst case scenario, to take place.

5.1.2 Kusu Island

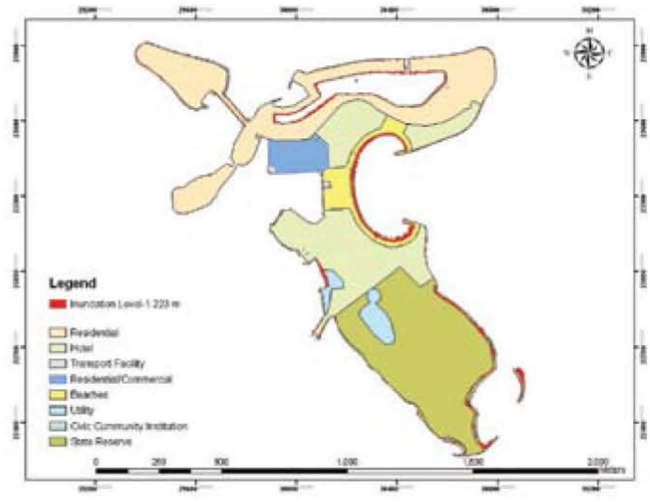
The land loss statistics for Kusu under A2 scenario is shown in Table 3. By the year 2020, land loss with a rising sea totals 0.272 ha, increasing to 0.309 ha by 2030 and to 0.39 ha by 2050. By the end of the century, a rising sea will cause land loss of 0.684 ha or 8.05% of Kusu Island.

Table 2: Land loss resulting from inundation: Lazarus-A2 scenario

Year	Position of new coastline (m)	Land loss (ha)	% land loss
2020	1.173	0.952	1.267
2030	1.223	0.97	1.291
2050	1.343	1.53	2.037
2100	1.713	3.14	4.181

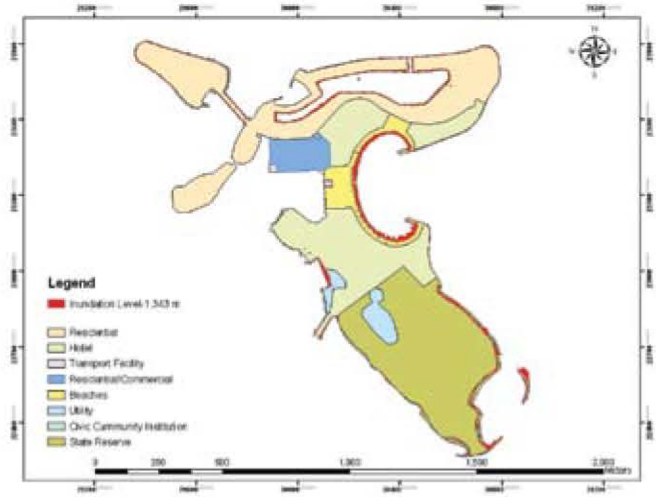
Table 3: Kusu land loss from a rising sea, A2 emission scenario

Year	Position, new coastline	Land loss (ha)	% land loss
2020	1.173	0.272	3.20
2030	1.223	0.309	3.64
2050	1.343	0.390	4.59
2100	1.713	0.684	8.05



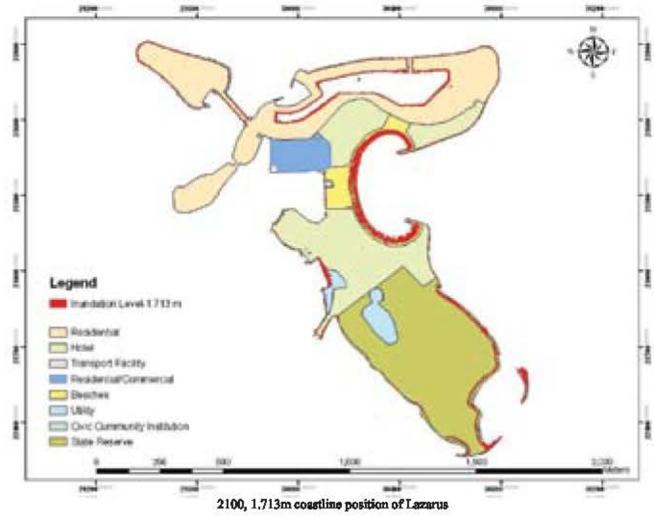
2030, 1.223m coastline of Lazarus

Figure 6: Land loss of Lazarus in 2030



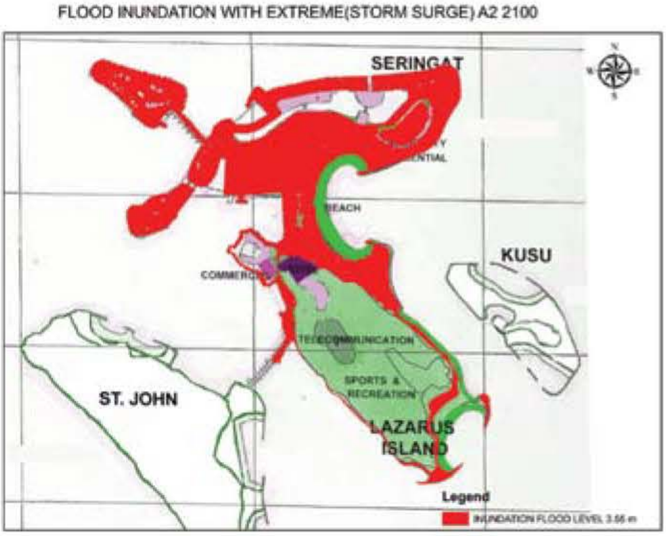
2050, 1.343m coastline of Lazarus

Figure 7: Land loss of Lazarus in 2050



2100, 1.713m coastline position of Lazarus

Figure 8: Land loss of Lazarus in 2100

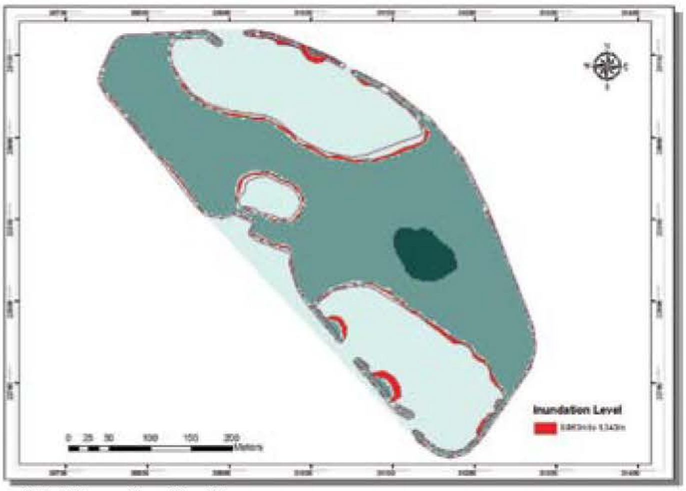


2100, 3.55m inundation level

Figure 9: Lazarus inundation during HAT with 1m storm surge in 2100 under A2 scenario

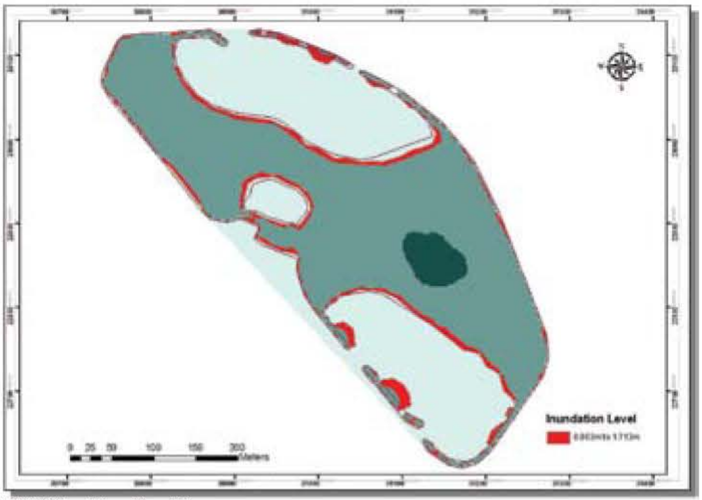
2030, 1.223m coastline position of Kusu

Figure 10: Land loss of Kusu in 2030



2050, 1.343m coastline position of Kusu

Figure 11: Land loss of Kusu in 2050



2100, 1.713 coastline position of Kusu

Figure 12: Land loss of Kusu in 2100

2100. 3.55 inundation level

Figure 13: 2100 under A2 emission scenario: Kusuinundation during HAT with 1m storm surge

The areas of land loss of Kusu for selected sea level scenarios are shown in Figures 10, 11 and 12. For all scenarios, the main areas of land loss will be along the beaches of the lagoon and along the lagoon edge of the breakwaters where sand had accumulated to form land. Minor land loss will occur along the revetted coastline where structures are failing and the coastline had retreat behind the line of rocks. Similar to Lazarus, little land will be lost by the end of the century but the future scenario is completely different with inundation under an extreme event of a one metre storm surge coinciding with HAT during which nearly all the reclaimed land on Kusu Island will be temporarily inundated, except for the hillock. (Figure 13).

6. Discussion and Conclusion

In the 2000 Initial National Communication to the United Nation Framework Convention on Climate Change (UNFCCC) Singapore recognizes that being a small island state with low-lying coastal areas, it is vulnerable to rises in sea level (Ministry of Environment, Singapore, 2000). Hence it is naturally concerned about the effects of a warming sea and what impact a future rising sea will have on Singapore. In the Initial National Communication, a key feature of Singapore's environmental protection programme is the policy of 'prevention is better than cure'. Careful land use planning and extensive infrastructural development is used to support the policy.

Land use planning has yet to be fully employed to address the prospect of loss of land and habitation in the coastal zone. In fact, high end sea- front residential properties are being encouraged and engineering solution is seen as the answer. In the 2008 National Climate Change Strategy for Singapore (MEWR, 2008), an important aspect of the strategy is continuous review by government agencies to assess the impacts, examine the adequacy of existing adaptation measures, identify new measures as necessary and establish national systems to monitor and manage the impacts. As a result of Singapore's planning in the past, some of the issues of climate change are already addressed. An area that needs close attention in future is how coastal land should be utilized. Currently, most land along the coast is public land and should remain so. Any change in land use policy for coastal land should be in line with one of the guiding principle of the strategy, that on sustainability. Although there is minimal land loss by the end of the century on reclaimed land of various platform levels and whatever loss can be easily mitigated by beach nourishment and strengthening of seawalls and other protective structures, reclaimed land along the coast or on islands is especially sensitive to inundation during extreme events. Properly-designed sea walls and a high platform level will help to prevent land loss. In land-starved Singapore, coastal land reclamation is seen as the favoured option to create additional land for living and development space. Land reclamation has increased the land area of Singapore from 581.5km^2 in 1960 to about 700km^2 in 2001, an increase of about 20%. It is planned to increase the island state by another 15% in the near future. Land is reclaimed under stringent conditions to ensure sustainability. In response to concerns about a rising sea, new sea wall heights and platform levels have been raised in Singapore. For example the platform level for reclaimed land is now 3.0m for the north coast and 3.5m for the south coast. Despite these efforts by policy makers, there is always the nagging question whether a rapidly warming world may render current standards inadequate (Teh et al., 2010).In addition there is the expected shoreline retreat with a rising sea which is expected to be much greater than that of land loss. According to controversial Bruun Rule, the sea level rise of one metre will result in the coastline retreating by about 100m (Bruun, 1962). There is also much uncertainty about the magnitude of future rise in sea level. In the 2013 AR5 report, the future sea level for A1B has been revised upward to a global mean sea level of 63cm and an upper range of 82cm under Representative Concentrated Pathway (RCP) 8.5 (IPCC, 2013). Under RCP8.5 the emission will continue to rise throughout the 21st century. The new projected sea levels are higher than those used in this paper. Although the loss of land with a rising sea is relatively minor on Lazarus and Kusu islands with the present projected sea level rise, it is always wise to adopt a precautionary approach for reclaiming land on small islands as these are more fragile and do not enjoy the resilience of most mainland ecosystems. On small islands, nature allows little room for error. Therefore, understanding island vulnerabilities, processes, and choosing proper strategies for sustainable development become critical for island development (Teh, 2000).

Acknowledgement

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