Valuation of Coastal Protection near Paramaribo, Suriname

by

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Photo by Sofie Ruysschaert (WWF-G)

NOTE:

This report reflects an analysis conducted by the authors for World Wildlife Fund Guianas (WWF-G). The report has not gone through an institutional review at the World Resources Institute (WRI) and should not be regarded as reflecting the views of WRI.

Collaboration:

This analysis benefited greatly from the reports and area descriptions provided by Edward Anthony (consultant contracted by WWF-G) and Sofie Ruysschaert (WWF-G, based in Suriname). In addition, this analysis relied heavily on spatial and socio-economic data assembled by Gregg Verutes (under contract with WWF-G). Gregg also provided expert input on modeling approaches and reviewed draft results. The report also benefitted from review by Daniel Sanbeg and Carmen Lacambra Segura.

Results of the analysis will be integrated in an online mapping platform developed by Gregg: http://www.geointerest.frih.org/Suriname.

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1. Executive Summary

This analysis was commissioned by WWF-Guianas (WWF-G) in response to the government of Suriname looking into the construction of coastal defense structures (dykes) to protect the shoreline near the capital city, Paramaribo. The government is considering such action in response to irregular flooding in some coastal areas in and near Paramaribo. WWF-G is particularly interested in the potential for mangrove ecosystems to serve as "natural infrastructure" to protect the shoreline and reduce the risk of flooding, while also providing other valuable "ecosystem services", such as supporting fisheries and sequestering carbon. WWF-G reached out to staff at World Resources Institute to apply their "Coastal Capital" valuation framework to explore the economic tradeoffs associated with either construction of "hard infrastructure" along the coast as compared with "natural infrastructure" options using mangroves. The analysis had a very short time-line (under two months) and did not include a site visit. The study did benefit from data collected by other consultants also contracted by WWF-G (Edward Anthony and Gregg Verutes).

Under this analysis, the authors worked with WWF-G and the consultants mentioned above to:

a) Develop a better understanding of the situation on the ground – hydrodynamics and storm regime of the area; extent and frequency of past flooding; socio-economic context and urban development trends; current mangrove extent and trends; and hard infrastructure options under consideration (and their costs);
b) Develop scenarios of possible futures to evaluate – for both hard and natural infrastructure solutions;
c) Agree upon an analysis approach.

The analysis approach used involves two stages – the first stage involves spatial analysis and quantification of the shoreline protection and flood reduction effect in both physical and economic terms (the latter is called "benefits") for each scenario, for a given year. The second stage of the analysis is to evaluate and compare which shoreline protection scenario results in higher net benefits through a benefit-cost analysis (BCA). Here, the benefits estimated in the spatial analysis are compared with the costs of implementing the option defined in the scenario (such as building and maintaining a dyke, or establishing a coastal setback to allow mangroves to expand or regenerate in new areas). The BCA framework is implemented for a 25-year time period.

Regarding the spatial analysis of shoreline protection – two approaches were explored. The first is an update of WRI's Coastal Capital framework to include additional detail on mangrove characteristics and to allow evaluation of hard infrastructure in a muddy coastal setting, where eroding and accreting mud bank systems have a major influence on coastal dynamics. This is an index-based approach, which integrates nine characteristics of the coastal system (including extent, width, density and diversity of mangroves, as well as presence and nature of built coastal defense) to arrive at estimates of the relative stability of the coastline (which is roughly the inverse of coastal vulnerability). This index allows comparison of different coastal protection options, as well as comparison of the level of protection over time (as mangroves grow, or as a coastal area erodes, for example.) This method was applied to three coastal areas near Paramaribo – from west to east, these are referred to as the Western zone (Weg Naar Zee), Middle zone and Eastern Zone. A second, more-nuanced analysis method was developed and applied only to the Western Zone area. This approach, called the "water height" method uses functions developed and based on observed relationships between different stands of mangrove and the attenuation (reduction) in wave height and storm surge they cause. This second approach allows examination of flooding by water depth behind the mangroves or behind the coastal defense. This approach was only applied to the Western Zone due to time constraints. All results were tested for sensitivity to discount rates – using 3% and 7% rates to reflect the social preferences of the value attached to avoided damages over time

Results. Our results suggest that investment in protection and enhancement of mangroves in the Western Zone and Middle Zone make economic sense, while investing in river dyke construction in the Eastern Zone is likely to be the more sensible option for protecting low-lying areas from flooding from the river (although this analysis does not fully consider other benefits that mangrove protection might bring). Full details of the scenarios over time are in the body of this report, but in summary:

- In the **Western Zone:**
    - The proposed dyke would not protect the Hindu Temple, as the Temple is on the seaward side of the dyke), and would likely not protect agricultural land against flooding for more than a couple of years (due to inadequate maintenance, coupled with a highly dynamic muddy coast).
    - Using the Coastal Capital method (and a 3 percent discount rate), mangrove regeneration appears to be the more cost-effective solution as it generates a higher net-present value (NPV) of US$ 290 million for a period of 25 years, in comparison to the earthen dyke protection scenario which generates a NPV of US$ 104 million. This solution was robust to sensitivity analysis with different choices of discount rate.
    - Using the water height method of analysis (and a 3% discount rate), mangrove enhancement is again more appropriate, with a NPV of $103 million, as compared with $51 million for the dyke. But, this analysis did prove to be sensitive to the choice of discount rate. When a 7% discount rate is used (reflecting much greater emphasis on short-term benefits), the dyke option appears more cost effective. Evidence on the ground and expert opinion suggest, however, that the dyke would only protect the shoreline for a couple years.
    - It is worth noting that the results are very sensitive to assumptions about the costs of both the hard and natural infrastructure options. Costs of establishing coastal setbacks for mangroves are likely overestimated, as this analysis used the full purchase price of land. (See results and limitations sections.)

- In the **Middle Zone**, the mangroves are currently healthy and expanding naturally. Building a dyke behind the mangroves would make little sense in either physical or economic terms. At a 3% discount rate, mangrove enhancement is again more appropriate as it generate a NPV of US$ 154 million that is roughly three times of those of an earthen dyke. This solution was also most favorable when using different discount rates.

- In the **Eastern Zone**, which lies along the Suriname River and not along the ocean coast, construction of a seawall (river dyke) was the only option considered to protect the area against flooding <u>from the river side</u>. (Dense, high value commercial and residential development along the coast prohibit consideration of a wide mangrove stand.) Additional flooding might occur from the land side during storms due to inadequate or clogged drainage. Due to the high commercial value of the property in this area, the total avoided damages due to the presence of the river dyke is substantial. The NPV of shoreline protection benefits is assessed to be around US$1.2 billion for a period of 25 years using a 3% discount rate, and US$870 million using a 7% discount rate.

It is important to note that the total economic benefits of the mangrove protection scenarios are likely to be much higher than reflected in this analysis, as we only evaluated shoreline protection benefits and not the value of other goods and services (such as support of fisheries or carbon storage). In addition, the cost of implementing the mangrove enhancement scenarios might be overestimated, as these assumed purchasing all land needed at full market prices. And finally, the costs of dyke construction and maintenance are likely underestimated in this study, as only minimum maintenance costs have been included, and construction costs were uncertain, but likely to be underestimated.

This analysis should be regarded as a rough-cut starting point for consideration of different coastal defense options near Paramaribo, not a definitive assessment. It made sensible use of the best data available to us at this time, but has many limitations. The accuracy of the analysis would improve with better information on past flooding and associated damage; refined estimates of land and property values; better information on costs of hard infrastructure construction and maintenance; and more realistic estimates of the cost of establishing a coastal development setback. In addition, including estimates of the value of other mangrove-related ecosystem services, such as fisheries habitat and carbon storage, would provide a more realistic picture of the overall value of investment in mangrove conservation and enhancement.

Results of the analysis will be integrated in an online mapping platform developed by Gregg Verutes: http://www.geointerest.frih.org/Suriname.

2. Introduction and Study Purpose

In Suriname, north and northwest of the capital city of Paramaribo, recent flooding in coastal areas has caused the government to consider building a dyke, or a series of dykes to fortify the coast. Such “hard infrastructure” radically alters coastal dynamics, inhibits mangrove regeneration, and impact the goods and services mangroves provide in untold ways. Several options are open to the government and local stakeholders for reducing flood risk, which offer alternatives to building a permanent or semi-permanent dyke. These include reducing pressure on existing mangroves and creating conditions favourable for mangrove regeneration, such as by establishing “coastal setbacks” – no development areas.

World Wildlife Fund Guianas (WWF-G) is interested in having better information on the costs and benefits of different coastal protection options in order to better inform discussion and decision-making on this subject. WWF-G has contracted researchers from the World Resources Institute (WRI) to evaluate different coastal protection options for the coast near Paramaribo – in terms of physical protection, ecosystem services, and the economic implications of these options.

The specific policy questions to be evaluated are: ***How do the costs and benefits of different shoreline protection options compare? Which shoreline protection option can generate greater net benefits?***

Comparing the costs and benefits of different shoreline protection options involves several steps in problem definition and several stages of modeling. These include:

a) Working with project partners (and, ideally local stakeholders) to clearly define the policy question;
b) Clearly defining the geographic extent of the study;
c) Clearly defining the scenarios to be evaluated;
d) Determining an appropriate time frame for the analysis;
e) Collecting data and developing a solid understanding of the dynamics of the study area;
f) Identifying and applying appropriate models, production functions or other analysis methods to evaluate the likely physical change in levels of erosion and damage due to flooding;
g) Applying benefit-cost analysis as a decision-making tool to highlight how the benefits and costs for each scenario compare and which scenario generates the highest net benefits for the study period.

This paper summarizes the analytical approach taken and presents the results, striving to make the results accessible, while still providing sufficient technical detail to support the analysis and make clear the sources of uncertainty.

WRI's past work on economic valuation of coastal ecosystems, including the report, *Coastal Capital: Economic Valuation for Decision-making in the Caribbean (*Waite et al., 2014) highlights the importance of stakeholder engagement throughout the valuation process and development of a clear communication strategy as being essential to achieving influence with an economic valuation. In the case of this valuation study, the analysis was constrained by a short timeline (November through December, 2015), and the contract did not allow for a site visit. As such, all stakeholder engagement was conducted by WWF-G, the contracting agency. They are also responsible for outreach and use of results.

• Collaborators and Data Sources

This analysis benefitted greatly from the reports and area descriptions provided by Edward Anthony (consultant contracted by WWF-G) and Sofie Ruysschaert (WWF-G, based in Suriname). Anthony's role involved doing desktop analysis and a site visit to document and provide background information on (1) the importance of mangroves as 'soft' ecosystem engineers in coastal protection; (2) the Suriname coastal system and the role of mangroves in this system; (3) the impacts of mangrove removal and the short to long-term costs of coastal protection options (mangrove conservation; mangrove replanting; dykes; mangroves and dykes); (4) meetings and displays aimed at convincing the Suriname Government and Public on the utility of mangrove conservation.

In addition, this analysis relied heavily on spatial and socio-economic data assembled by Gregg Verutes (under contract with WWF-G). Verutes also provided expert input on modeling approaches and reviewed draft results. Results of the analysis will be integrated in an online mapping platform developed by Gregg: http://www.geointerest.frih.org/Suriname.

This analysis relies on the best data available for the area, in light of the constraints of a short project timeline (two months) and lack of a site visit.

3. Study Area

• Physical setting

The coast of the Guianas is one of the most dynamic mangrove coasts in the world due to the alongshore migration of mud banks, which results in highly variable coastal expansion and contraction (Anthony, 2015). The onshore and alongshore transport of mud by waves can create accreting intertidal mudflats of several sq. km in short periods (within weeks), with very dense mangrove development in under three years (Anthony, 2015). Many sections of the coast of Suriname have been in an erosive phase for nearly a century (Nijbroek, 2014). (See Text Box on Coastal Dynamics in Suriname at end of this section.) Close to Paramaribo, Edward Anthony has suggested that this might, in part, be the result of increased water flow from the Suriname River due to land cover change in the watershed, which results in a sediment plume moving further offshore.

Mangroves occur naturally along much of the coast of the Paramaribo-Wanica districts, though mangroves have been removed in many areas, especially near the Weg Naar Zee, in the Western Zone. The coastal fringe is dominated by stands of Black Mangrove (*Avicennia germinans*), sometimes backed by *Rhizophora* spp. Natural mangrove stands are typically dense and mature. In areas where mangroves are removed, shoreline retreat can be rapid.

• Socio-economics

The city of Paramaribo has a population of about 240,000 people, according to the 2012 census. This is roughly half of the population of Suriname.

Using a land use data set developed by Gregg Verutes (based on Open Street Map, mangrove data from UNEP-WCMC, and forest, deforestation and ecosystem data provided by WWF-Suriname) we were able to examine land use within the study area. We defined three "protection sheds" which reflect the extent of the land potentially protected by the built infrastructure or mangroves in the three areas (Western, Middle and Eastern zones. (See map 2 for the protection shed boundaries.) Current and abandoned agricultural land is the most extensive land cover category, followed by forest / woodland, residential and grassland. See **Table 3-1**)

Table 3-1 - Land Use within the study area (sum for the three "protection sheds")

Land Use Category	Area (ha)
Agriculture and abandoned ag	2049
Forest or woodland	1428
Grassland	1048
Mangrove	531
Wetland / swamp	735
Residential	1318
Other developed	62
Mixed use / undefined	1241

- ## Storm and wave environment

We gathered information on wind, waves, storm surge and tidal range for several sources, and used this as input to guide the selection of storm conditions (and associated water height) to evaluate in the shoreline protection analysis and valuation. We used data from the DIVA spatial coastal database (provided by Gregg Verutes), as well as input from Edward Anthony. We also compared (limited) information on areas prone to flooding to inform the decision of what wave and storm surge environments to evaluate.

The DIVA database suggests these coastal characteristics:

Variable	Description	Value from DIVA
S1	Surge height for 1 year event (above mean sea level)	2.0 m
S10	Surge ht. for 10 yr. storm event	2.2 m
S100	Surge ht. for 100 yr. storm event	2.4 m
SLOPECST	Average slope along the coast (in degrees)	.03 to .04 degree
WAVECLIM	LOICZ Wave class	3.5-5.0 meter
TIDALRNG	Tidal range (m)	2-4 m
UPLIFT	uplift in mm / year	-0.43 subsidence
CPC	Coastal Plain characteristic	Destructive plain
WMP	Wetland Migratory potential	A retreat of coastline, combined with inland migration of ecosystems.

We reviewed the DIVA characteristics with Edward Anthony and Sofie Ruysschaert, to refine the characteristics likely for a 25-year storm event. We arrived at the following ranges:

Tide, storm and sea level rise environment for Paramaribo (In meters)

	Low	Mid	High
Storm Surge	1.5	1.9	2.3
Waves	1.5	2.25	3
Tidal range	2.2	2.85	3.5
SLR (over 25 years)	0.08	0.1	0.12
Sum	**5.3**	**7.1**	**8.9**

We used elevation data (30m resolution Shuttle Radar Topography Mission (SRTM) data provided to WRI by Deltares (2009) to evaluate vulnerability to flooding. Communication with WWF-G suggests that although there is some minor flooding every year, there is only extensive flooding every couple of years. In comparing the SRTM elevation data to the different components of water height from the above table, we would project regular flooding due to the tidal range alone. But, there is not such routine flooding, so coastal elevations must be above the tidal range. To bring water levels down to a level more consistent with the elevation data and observations of flooding, we excluded the tidal range from the above tally, to arrive at the following potential water levels:

Storm and sea level rise environment for Paramaribo (In meters)

	Low	**Mid**	**High**
Storm Surge	1.5	1.9	2.3
Waves	1.5	2.25	3
SLR (over 25 years)	0.08	0.1	0.12
Sum	**3.08**	**4.25**	**5.42**

In the analysis approaches described later, we use 5m of water height as our benchmark. In the application of the first method (the Coastal Capital method), we examine coastal land under 5m in elevation, within 5 km of the coast. In the second method (the "Water height" analysis), we look at a combined storm surge and wave height of 5m (2.2 m from storm surge and 2.8 m from waves).

Text Box - Coastal Dynamics of the Suriname Coast

- **By Edward Anthony** (Aix-Marseille Univ. Aix en Provence, France)

The 350 km long coast of Suriname is part of a unique system in the world characterized by large-scale muddy sedimentation in spite of the exposure of the coast to waves from the Atlantic. The coastal deposits form the Young (5-6000 years old) and Old Coastal Plains. The growth of this plain has been assured by mud supplied by the Amazon River in Brazil and transported westwards towards the Orinoco. The mud is organized into a series of banks that migrate along the coast under the influence of waves and currents. In 2012, there were 9 mud banks identified on the Suriname coast. The mud banks are separated by 'inter-bank' zones that also change in position as the banks migrate. In this unique system, mangroves play an important role by stabilizing the inner part of each mud bank and ensuring plant 'continuity' with the older muddy shoreline, from which subsequent mangrove regeneration is supported by propagule dispersal. This mangroves help the inner part of mud banks to become welded to the coast, thus creating new land (a process called progradation) that is added to the growing Young Coastal Plain. Much of the urban development of Paramaribo and other coastal towns is on the Young Coastal Plain. The relationship between mud banks, mangroves and the growth of the coastal plain is, thus, important in understanding the past, present and future state-of-health of the coast, as in the Paramaribo-Wanica area.

Mangroves in Suriname cover an estimated 100.000 ha, which is about 1.6-2% of the world's mangroves. They form large, variably wide (up to several km) stands of 'fringe' mangroves of *Avicennia germinans* throughout the coast of Suriname and are associated, in places, where erosion prevails, with sandy beach deposits called cheniers or 'rits'. In addition to their role in building the Young Coastal Plain in Suriname, mangroves provide several major ecological functions and services in Suriname. These include, notably, protection of the shoreline from erosion, provision of spawning zones and nurseries for coastal fisheries, and a habitat for millions of migratory shorebirds, breeding water birds and other wildlife.

Mangrove efficiency in coastal protection has been demonstrated in numerous scientific studies, especially following the 2004 Indian Ocean tsunami. The protection role is assured even by dead and dying mangroves through their foliage, trunks and roots. Efficiency has been demonstrated to increase with wider, thicker (healthy) mangroves. Recent observations of inter-bank erosion in an area of shoreline formerly occupied by rice fields in French Guiana (Mana rice fields) following large-scale mangrove and backswamp clearing, has shown that shoreline retreat rates are extremely high (up to 180 m a year) in the absence of mangroves. Such retreat rates exceed usually observed retreat rates in the presence of mangroves (up to 40 m a year).

Removal of mangroves has been carried out in a number of areas along the Suriname coast, notably north of Paramaribo, where this practice is now going on at a very large scale under the impetus of building societies, thus leading to increasing urbanization at the expense of mangroves. This removal also goes with an increasing call for the building of dykes for coastal protection, echoing a move that has, unfortunately, not been a viable solution in coastal protection in neighboring Guyana where dykes have largely replaced mangroves on the coast, and where mangroves are now being replanted.

4. Options for Mitigation

Within the coastal areas near Paramaribo, such as in the Western Zone area, residents and land owners are frustrated by the periodic flooding which occurs every couple of years on a larger scale (Sofie Ruysschaert, personal communication). A major concern is the flooding of the Hindu Temple complex. Residents favor the construction of a dyke. However, the currently proposed dyke would not protect the Hindu Temple because it is on the landward side of the temple. In addition, dykes are not very effective along a dynamic mud-bank-dominated coastline (Anthony, 2015). (See text box on existing dyke at Weg Naar Zee in the Western Zone.) This section lays out some key considerations.

Text Box: Existing Dyke at Weg Naar Zee in the Western Zone.

A 300 m-long concrete dyke constructed as recently as 2013 west of the Indian Temple in the Western Zone is now largely destroyed. It was poorly designed and poorly maintained (Anthony, 2015).

Hard solutions - "Hard" engineering solutions, such as dykes and seawalls, are a common coastal defense in the Guianas. They are often built to prevent saline intrusion in areas of shrimp farming or agriculture, and are commonly used in response to large-scale degradation of the mangrove fringe. Dykes are static engineering structures in highly dynamic environments, and need to be designed appropriately. The environmental problems associated with these structures are well known and are described in the literature. Common problems include increasing erosion and scouring (due to wave energy refraction off of hard structure) and that dykes sometimes sink in mud environments. In addition, dykes may act as barriers that impede mangrove propagule exchange between mature forests behind the dyke and a new mud bank which could be colonized, and also may impede freshwater supply to the young mangroves.

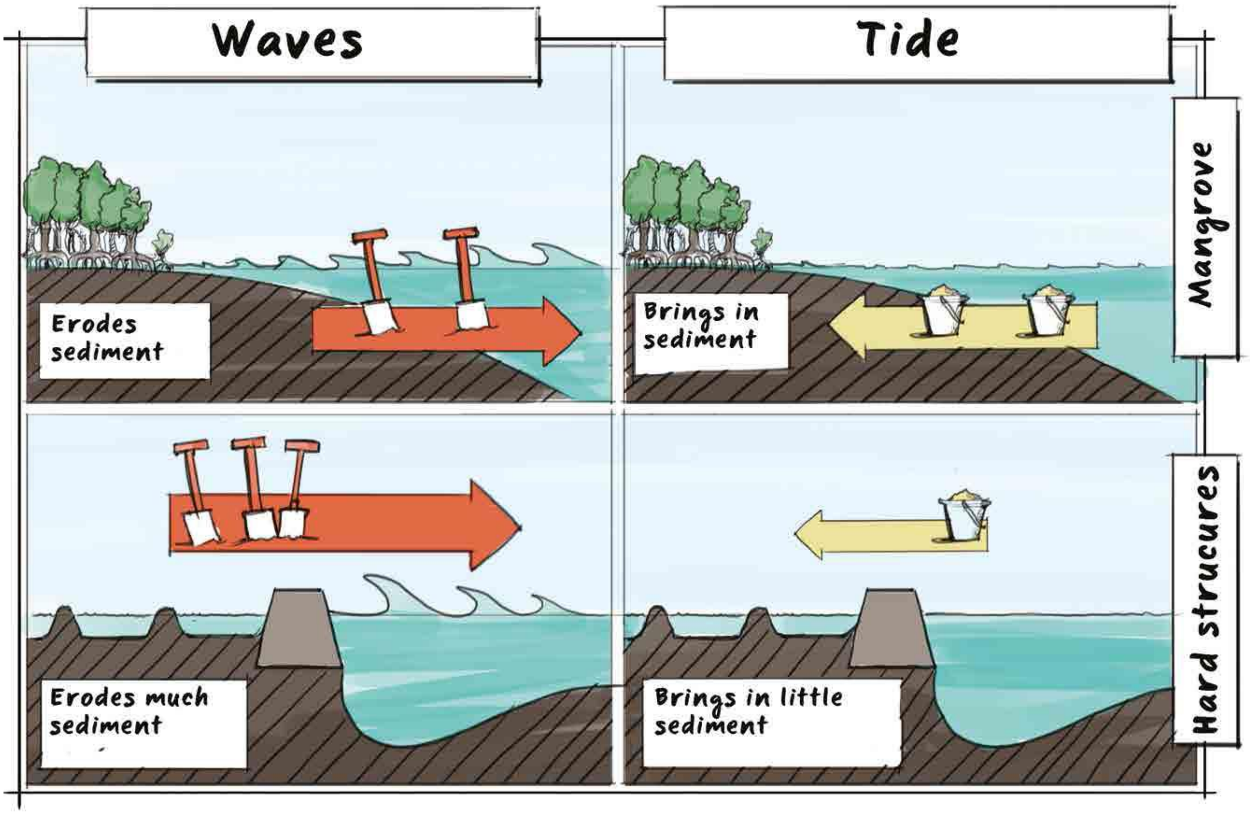
The effectiveness of hard solutions varies, but generally increases with cost. Dykes need to be appropriately designed for the setting and for future conditions, and need to be well-maintained. Inadequate maintenance of dykes is a common problem in the Guianas, including in Suriname. In wave-dominated environments (such as this study area), mud dykes are generally not efficient and can be easily destroyed if they are not reinforced by rock revetments. Costs vary considerably depending on the nature of construction and whether they are maintained (Anthony, 2015).

Natural infrastructure – mangroves offer natural protection of the shoreline and respond organically to changes in environmental conditions. The dense roots of mangroves help to bind and build soils. The above-ground roots slow down water flows, reduce erosion and encourage the deposition of sediments. Over time mangroves can actively build up soils, increasing the thickness of the mangrove soil, which may be critical as sea level rise accelerates (Spalding et. al, 2014).

It is most cost effective to protect existing stands of mangroves – not cutting them down, and not blocking the natural flow of water and propagules. Mangrove restoration (active planting) is difficult, expensive, and results are unreliable. The success of mangrove propagule or seedling planting depends strongly on topography and exposure to waves. A better, and more cost-effective solution is to establish conditions favorable for mangrove recolonization and allow nature to take its course, sometimes called ecological restoration. Restoring the natural patterns of water flow, preventing human disturbance and perhaps removing choking weed species may be enough to allow natural regeneration (Spalding et. al, 2014). Successful recolonization requires intermittent flooding and drying, as well as a source of mangrove propagules. Mangrove regeneration is most likely to be effective when the coastline is in an accreting bank period, rather than in an eroding inter-bank period (Anthony, 2015). Where there is small scale erosion it may be possible to reduce erosive impacts through protecting individual seedlings until they become more established (Spalding et. al, 2014).

Mangroves can be an important defense against sea level rise. Mangroves may be able to colonize landward areas if space is available, and thus continue to provide coastal defense services against waves and storms (Spalding, 2014). Anthony (2015) suggests that "it is likely that mangroves in the Guianas will keep pace with future sea-level rise because of the high mud supply from the Amazon. The active ecosystem renewal evinced by the coexistence of dead and dying mangroves, and by rapid mangrove colonization and thriving on new substrates is a feature unique to the coast of the Guianas."

Figure 1 - Why hard engineering structures can fail in muddy coasts (From Spalding et. al, 2014)



In a healthy mangrove ecosystem, waves take sediment away and tides bring sediment in. The mangroves' aerial root systems help to dissipate the waves and to capture and stabilize the sediment. By contrast, hard structures, such as breakwaters and earthen or concrete dykes, only protect against wave impacts in the short term, and may need rebuilding frequently as they are undercut by erosion. This occurs because waves can get 2 – 4 times bigger when they reflect off a hard structure. These bigger waves increase erosion in front of the structure, and can eventually lead to its collapse. Such collapsed sea walls are then useless in reducing waves or preventing erosion. Moreover, hard structures disturb the balance of incoming and outgoing sediment because they block the flow of water and sediment into areas that were previously flooded by the tides. (From Spalding et. al, 2014)

Hybrid solutions – mangroves planted in front of a dyke can lessen erosion of the dyke and reduce maintenance costs. But, if mangroves regenerate well, the dyke is often not necessary. In addition, dykes are fixed and inflexible and cannot keep pace with sea level rise. Mangroves maintain themselves (if the freshwater flow and coastal mud flow are not interrupted). Dykes require regular maintenance and often have limited lifespans. (See text box on Weg Naar Zee Dyke, earlier in this section). In addition, dykes can interrupt freshwater flow (needed by mangroves) and mangrove propagule exchange, thereby impeding mangrove stability and regeneration. For these reasons, hybrid solutions were not evaluated in this study.

Other solutions. Sediment Trapping Units (STUs), which could be considered as a type of ecological restoration, are an additional option being explored, to create conditions favorable to mangrove regeneration. STUs use relatively permeable (bamboo) enclosures, and have been deployed in recent years in eroding mangrove-fronted areas of the Mekong delta shoreline in Vietnam (Albers and Schmitt, 2015). Their lifespan in Vietnam is about 6-7 years. They are, however, labor-intensive in construction and maintenance phases. A factor that needs to be taken into account when implementing them is whether the application zone is in an eroding zone (e.g. inter-bank area) in which case, erosion is likely to continue during the high wave season (Anthony, 2015). STUs are being experimented in a pilot project by the Anton de Kom Universiteit van Suriname (ADEK University), near the Hindu Temple along the Weg Naar Zee coastline.

Comparison of options. Generally speaking it is still more cost-effective to prevent mangrove loss than to allow loss and then have to invest in rehabilitation or restoration, but this is not always an option. (Spalding et al, 2014.) Overall, Edward Anthony found that the effect of mangrove removal and an increasing resort to "hard" engineering structures such as dykes, have had a negative feedback loop on the Suriname coast – by concentrating and reflecting wave energy at the shoreline. This pushes mud offshore, reducing accretion at the coast and often causing a concave shoreline profile. (See **Figure *1***.) Anthony adds: "it is highly unlikely that dykes, static structures in a highly dynamic environment, will represent a sustainable means of coastal defense instead of mangroves." He adds, 'considering the scale of the muddy coastal system, the soundest approach, both in terms of ecology and costs, is to simply maintain the natural zones of (mangrove) colonization, avoid further urbanization in these areas, impose setback lines, and avoid alongshore fragmentation. It is also important to ensure that the connection between mangrove propagules and the muddy shoreline is not impeded.

(See Anthony, 2015 for additional details on options and local conditions.)

5. Scenarios to be evaluated

The set of scenarios to be evaluated was developed through a collaborative process – working closely with WWF-G and Edward Anthony, and based on review of several reports on coastal planning and coastal defense in the study area (ESIA, ESMP, 2015; Deltares, 2009). Through an iterative, collaborative process we arrived at a set of scenarios to be evaluated along three contiguous segments of the coast near Paramaribo. From west to east these areas are referred to as the Western Zone Middle Zone and Eastern Zone (along the SurinameRiver). (See map 1 below.) The coastal setting, situation and options (scenarios to be evaluated) are as follows:

A) **Western Zone.** The western-most part of this study area is along the Weg Naar Zee coast. This coastal extent was originally mangrove, but has mostly been cleared due to a large-scale destruction by coastal residents for agriculture and smoking fish (Nijbroek 2014). It is now dominated by agriculture, abandoned agriculture, grassland, or mixed land use. A few small pockets of mangrove remain and there are a few houses in the area. There is a Hindu temple complex on a triangular promontory along this coast. Both the Hindu temple complex and some of the coastal lands experience periodic flooding. Land owners and members of the temple community are not happy about the flooding and are vocal in their support of the building of a dyke. Two options will be explored for the Western Zone– one is the building of an earthen dyke along the coast, based largely on details provided in the ESIA report. The second is the establishment of a coastal development setback to allow for recolonization of mangroves to protect the shoreline. Mangrove recolonization is a slow process, and this is reflected in the progression of scenarios. Both options will be evaluated for a 25 year period.

A1. Western Zone 1 – Mangrove regeneration. Under this scenario:

- A 1.5km development setback from the coast is established, and the land is left to return to a natural state. (Although a narrower mangrove belt could be effective in reducing wave height, a belt of this width is needed to have an influence on storm surge heights.)
- The area is sometimes dry and sometimes flooded, which allows cracks to form. The area receives a flow of mangrove propagules, both from small remnant patches as well as from neighboring areas. During high water periods, some propagules take hold and begin colonization. One risk of this assumption is that storm severity or mud bank erosion could hamper rapid colonization. This is, however, the natural progression over time, and could possible be aided by the presence of STUs, though these were not explicitly included in the analysis.
- Colonization and growth are assumed to be slow over the first three years, but the mangrove becomes more established – wider, denser and taller, from year 5 on. The mangrove is tall, dense and mature at the end of the 25 year period. The amount of progression provided increases with growth of the mangroves.
- The main costs for this scenario are for purchase of land in the setback.

A2. Western Zone 2 – Construction of an earthen dyke.

- The ESIA and ESMP (2015) reports proposed a design and evaluation of building a 9km earthen dyke on the coast at WNZ. We have evaluated their proposed design, have digitized the dyke location, and used the available design parameters to evaluate cost and effectiveness. It is important to note that **the design builds a dyke BEHIND the Hindu Temple promontory, so will not protect the Hindu Temple complex**.
- This earthen dyke, covered with rocks, is built during year 1 and provides good protection of the area initially. But, there are two problems which can hinder the protection provided over time. The hard surface of the earthen dyke can result in increased scouring and erosion, which reduces the stability of the dyke over time. Such dykes must be well maintained (annually), else they fail within a few years due to erosion. Funds for dyke maintenance are rarely established.
- In this implementation, the dyke provides good protection in year 1; after that, age and increasing erosion take their toll (as the dyke is not well-maintained). By year 10 the dyke is no longer providing protection and by year 25 no longer exists.

B) Middle Zone. This central section of the coastline is near the mouth of the SurinameRiver. Land bulges northward toward a headland on the far side of the river. Land is accreting and mangroves are mature, healthy and expanding on the coastline. The main threat to the stability of this situation is coastal development moving northward from Paramaribo toward the mangroves. The coastal development options under consideration focus on urban development encroaching on mangrove areas. The scenarios to be evaluated are– 1) establishment of a coastal development setback which protects existing mangroves, but also allows mangroves to thrive and expand or 2) build a dyke along the back of the mangroves (through some less dense mangrove areas), to encourage further development to the south of this line of defense.

B1. Middle Zone 1 – Protection and expansion of Mangroves. This scenario involves:

- A setback line (a no development zone) is proposed. It runs a length of 6.8 km and ranges from about 2 to 2.5 km inland from the coast. This proposed setback was digitized from a map in Deltares, 2009. Much of the land inside this setback is mangrove.
- The current level of flood mitigation / flood protection is very good.
- Due to limiting encroachment on mangroves in this area, the mangroves are able to expand, become denser, thrive and fill in an existing gap.
- The stability of the shore increases over time, as this scenario benefits from the reduction of the coastal development threat.
- In later years, coastal stability further increases due to mangrove expansion and growth.

B2. Middle Zone 2 – Construction of an earthen dyke behind the mangroves. The concept of a dyke in this area is to connect the dyke in the Western Zone with a dyke (rock sea wall) on the Suriname River, providing continuity of armor along the coast. But, the mangroves along this shoreline are healthy and are expanding naturally. They are already provide effective defense and are an adaptable defense as sea levels rise under a warming climate. The proposed dyke might be intended to entice development behind the dyke, providing a sense of security against flooding. But, building a dyke behind a healthy, functioning mangrove has the risk of altering the coastal dynamics – the freshwater flow to the mangroves, and limits the ability of mangroves to shift landward as sea levels rise. The scenario evaluated is:

- A dyke of length 6.8 km is built (as shown on ***Map 1***). It is about 1.5 to 2 km inland from the coast. It does not cut through the thick of the mangroves, but is in some less dense mangroves, at the back of the stand. In year 1, this dyke provides added protection – a second defense against high water.
- But, this protection option peaks at the start. The dyke alters water flows to the mangroves, resulting in reduced density and width of mangroves over time. Also, some minor erosion results from the hard structure, and this increases over time as the protection provided by mangroves diminishes. As is common in this region, the dyke is not well maintained. By year 25 the protection is back to "current level", though in reality would likely be lower.

C) Eastern Zone – Further east, moving upstream along the river, this section of coast begins with a narrow fringe of mangroves, and then shifts to a more developed, commercial and residential land cover. There is periodic flooding of this area, some of which comes from problems with inadequate and clogged drainage during storm events, and some flooding from swells on the river. Property values are higher here, and there is dense commercial and residential development along the coast. There is insufficient land available for establishing a coastal setback for mangrove recolonization – the option is cost prohibitive. As such, we do not explore any option involving mangroves providing natural infrastructure protection. Rather, the only option evaluated is the construction of a 2.75 km concrete river dyke.

C1. Eastern Zone 1 – Construction of a concrete river dyke along the river.

- A concrete river dyke is built along the river from the Middle Zone area in the north (meshing with either the dyke or the protected mangroves), to a drainage outlet near Pommerakstraat, with a length of 2.75 km.
- The river dyke is effective in protecting this area at the start, and maintains that ability pretty well over time. It is reasonably well (but not perfectly) maintained, the incentive being the high property values at risk in this area. Age takes some toll. The Coastal stability is very high in year 1, and declines some by year 25, but still provides reasonably good protection.

Map 1- Mangroves, proposed dykes and coastal setbacks in the study area

6. Goods and services to be evaluated

Mangroves provide a wide range of ecosystem goods and services in coastal areas. They protect the shoreline by mitigating wave energy – reducing erosion and lessening water levels and flooding. They store carbon, cleanse water, form soil, provide habitat for fisheries, are a source of fuel, fiber, and building materials, and offer compounds useful for development of medicine. They also provide inspiration, support cultural traditions, and attract tourists – for birding, boating and fishing. But, this wide range of values too often goes unaccounted for in decision-making. For full consideration, it is worth noting that a negative aspect of mangroves is that this nutrient rich, moist environment can serve as a breeding ground for mosquitos.

A. Shoreline protection

As defined in the ToR, the primary interest of this project is to compare alternative shoreline protection scenarios that protect the north of Paramaribo against storms and coastal floods by identifying benefits and costs of these options. In particular, this study has focused on comparing shoreline protective benefits to the costs directly incurred in each shoreline protection option, i.e. green vs. gray shoreline protection infrastructures. Either natural mangroves, or manmade dykes and sea walls can protect shoreline against Sea Level Rise (SLR) and coastal flooding and therefore provide essential benefit savings to the local communities through the avoided damages on property and human life. The shoreline protection values can therefore be valued using replacement cost method, i.e. by assessing the total expenses necessary for replacing and/or repairing the damaged structures and the economic losses due to interruptions of economic activities (e.g. agricultural productivity) after the flooding events, which could have been avoided if effective shoreline protection was in place; or by assessing the people's willingness-to-pay to avoid these economic losses (e.g. the coastal damage insurance). The disadvantage is that these approaches are often very time and resources intensive.

Time and funding constraints often prompt a need for streamlined analysis, as is the case in this project. Here, the shoreline protection value is approximated by assessing the value of properties that potentially have less damage (experience reduced erosion or flooding) as a result of the shoreline protection infrastructure in place.

Furthermore, studies have shown that the relative shoreline stability provided by mangroves and dyke protection may vary greatly over time (Anthony and Gratitot, 2012). Mangroves can provide vital protection in the fairly localized areas where they are present. They protect the shoreline by mitigating wave energy – reducing erosion and lessening water levels and flooding. In addition, they provide protection against the effects of extreme weather events, such as tropical cyclones, by dispersing the energy of floodwaters as they spill out of water channels. The natural mangrove protection rises naturally as sea level rises and gets strengthened over time if sufficient space is allowed for landward retreat (Deltares, 2009).

On the contrary, manmade infrastructures such as dykes and seawalls can provide strong flood protection from the sea at the very beginning, but the shoreline stability will decrease over time due to the wave energy reflection and continued coastal erosion - unless the structures well-maintained or rebuilt. Moreover, hard infrastructure is fixed and does not adapt to changes in the environment, e.g. sea level rise.

B. Other services remain unvalued

Mangroves are rich ecosystems, capable of providing a range of ecosystem goods and services in coastal areas that similar manmade shoreline protection infrastructures cannot. In addition to coastal protection, mangroves store carbon, cleanse water, form soil, provide habitat for fisheries, are a source of fuel, fiber, and building materials, and offer compounds useful for development of medicine. They also provide inspiration, support cultural traditions, and attract tourists – for birding, boating and fishing. These products and services can benefit people either because they are directly or indirectly used by humans. The direct-use value of mangroves includes uses such as timber provision, whereas the indirect-use values include, for example, providing habitat for fisheries that can contribute to local income generation and food security, as well as the climate regulating services through carbon sequestration in both below- and above- ground biomasses. In addition, mangroves can provide economic benefits to humans without necessarily being used, but simply because of the existence value of mangroves, i.e. the satisfactions an individual derives from knowing that mangroves continue to exist; or because of the desire to preserve mangrove ecosystems for future generations.

Economists tend to apply different valuation methods to assessing these different values, including demand/supply analysis, market prices and production function approaches for use values and surrogate market prices for non-use values. For instance, Barbier and Strand (1998), Barbier (2003) and Blaber (2007) have empirically demonstrated a positive relationship between fishery productivity and mangrove areas, among other determinant factors to be examined. As for non-use values of mangroves, surrogate market approaches such as the Contingent Valuation Method and the Travel Cost Method may be used to assess individual's willingness to pay for traveling to enjoy the coastal ambient provided by healthy mangrove ecosystems. These research questions require time and resources to investigate. Within this analysis, we focused on an ecosystem service which is at the heart of the policy question – shoreline protection services. Other goods and services were not evaluated in this study. However, it should be noted that quantifying the monetary value of these ecosystem services will help improve the understanding of the true value of mangroves ecosystems to the local livelihoods of Paramaribo district, and can better inform policy decision-making.

7. Valuation Approach

The valuation approach proposed in this analysis consists of two phases of evaluation:

A. Spatial evaluation of the shoreline protection services provided by hard (built) infrastructure and natural infrastructure in physical terms.
B. Evaluating these shoreline protection services in monetary terms and conducting a cost and benefit analysis of alternative shoreline protection options

A. Spatial evaluation of shoreline protection services

There are several approaches available to evaluate the shoreline protection services provided by built infrastructure and natural infrastructure. These options are sometimes called hard vs. soft infrastructure or gray vs. green solutions. In our approach, we examine the location, elevation, and value of property which is low-lying and is potentially exposed to wave-induced storm damage and erosion. We estimate the flood and erosion damages likely to be avoided (damage which does not occur) due to the presence of the coastal protection features – either mangroves or built infrastructure. Such analysis is complex, and needs to take a wide range of contextual factors into account – the coastal profile; local elevation; wind, wave and storm regime; the nature of the mangrove stand (width, length, height, density, age, and complexity of root system); the nature of the built infrastructure (width, length, materials, maintenance); and the local hydrology and mud bank dynamics, among other factors.

We explored two different approaches to this evaluation. The first is an index-based approach developed by WRI and the Institute of Marine Affairs (IMA) in Trinidad and Tobago (Cooper et al., 2009). This approach highlights the relative stability of different coastal segments based on a range of physical factors and isolates the contribution of mangroves or built infrastructure within the overall coastal configuration. The valuation method published in Cooper et al, 2009 was extended for this analysis in Suriname– to allow more nuanced consideration of mangrove characteristics and of shoreline defense structures. The second approach focuses on the ability of different types and extents of mangroves to attenuate wave heights and storm surge, based on a review of literature conducted for this and other projects. Assumptions are made about the combined height of waves and storm surge reaching the coast; the degree to which these heights are reduced; and the resulting height of water over land. Unlike the index approach, this "water height" method allows estimation of the flood level across the landscape, and the associated extent of damage from a given water depth. This method was only applied in the Western Zone due to both time and data constraints.

There are significant uncertainties associated with both of these approaches, as well as with the estimation of the costs and benefits of each option.

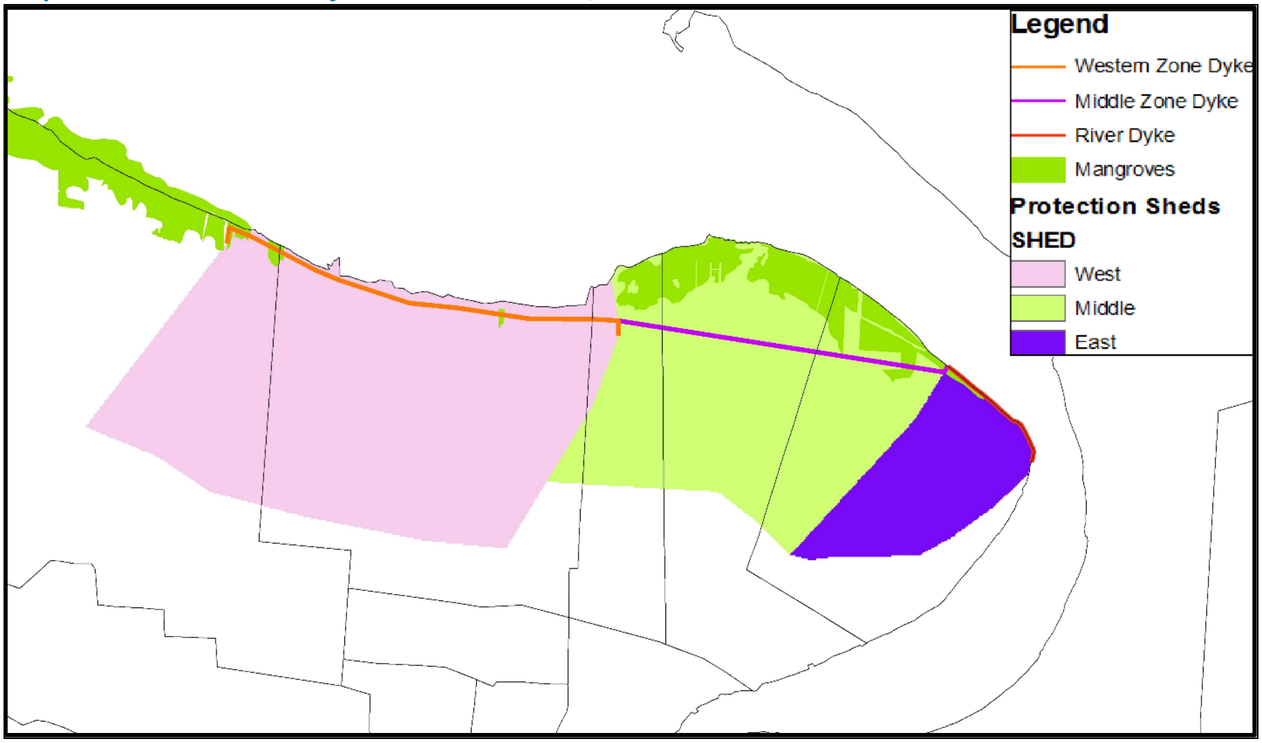
Spatial analysis option 1: Adapt and apply the index-based Coastal Capital model to evaluate relative protection of the coast (for three coastal segments)

WRI's Coastal Capital project developed a model for evaluating the shoreline protection services provided by coral reefs and mangroves (See Cooper et al, 2009). This method has been extended to provide additional detail on the role and characteristics of mangroves, dykes and sea walls in protecting a muddy coast. The steps involved are:

1) **Identify land which is vulnerable** to wave-induced erosion and storm damage (low-lying land within 5 km of the coast.) We are using a maximum inland distance of 5km, and a flood height of 5m. Vulnerability is highest close to the coast, and diminishes with distance inland. We are considering this range as being representative of a 5-year return period storm event.

2) **Identify coastline which is protected by mangroves or by a dyke/ seawall,** as well as land behind the protected coast in an area we call the "protect shed"**.** These areas were digitized based on the location of proposed built infrastructure, predominant storm tracks, elevation and proximity to the coast. The three protect sheds are shown in **Map 2**.

Map 2- "Protection Sheds" for the Western Zone, Middle Zone and Eastern Zone



3) **Estimate the relative stability of the shoreline based on a range of physical factors** (See table of factors in Appendix 1.) Coastal segments are evaluated across nine categories with scores ranging from 0 (no protection / low stability) to 4 (very high protection / stability). The nine categories (factors) are coastal geology; degree of exposure to open ocean; protection by coral reefs; wave energy; storm / hurricane regime; coastal elevation; anthropogenic threats (such as sand mining and coastal development); protection by mangroves (an index); and protection by built infrastructure (an index). The indexes on mangroves and coastal defense have been added to this version of the framework for application on the muddy coast of Surinam. The mangrove index includes sub-categories covering mangrove width; density and complexity; age and height; and continuity along the coast. The coastal defense index includes sub-categories on type; age; maintenance / condition of the infrastructure, and the status of erosion in front of the infrastructure. The mangrove and coastal defense indexes are each calculated by taking the average of the four sub-categories. To arrive at a score for relative stability of the shoreline (which is roughly the inverse of vulnerability), the scores for the nine factors are averaged. (See Table 1 in Appendix 1 for details.) Some elements not appropriate for Suriname, such as the coral reef index, have been left in to make the framework more comprehensive for the Caribbean region.

4) **Evaluate how much protection each scenario is offering.** Two options will be evaluated:
    a. We compare these "relative stability" indicators across scenarios (current, mangrove conservation, built infrastructure) to see how protection compares.
    b. We calculate the relative stability of the shore both with and without the coastal defense feature to isolate its contribution. (In the Coastal Capital method this "share" of protection

was used to estimate the proportion of real estate value which should be assigned as "avoided damages.")

5) **Examine protection over a 25 year period:** This evaluation must be done for multiple time periods within each scenario, as the protection provided changes over time.
   a. In the mangrove conservation and regeneration scenario, there will be growth (and increased protection over time);
   b. In the dyke / sea wall scenario, there will be good protection at the beginning, but decreased protection as the hard surface begins to promote erosion and the built defense weakens, if inadequately maintained, which is commonly the case in this region. This progression is very dependent upon the level of investment in maintenance of the built feature.

The scenarios described in an earlier section are evaluated for years 1, 3, 5, 10 and 25. Evaluating protection for each of the 25 years was impractical, but the above intervals allow for capturing all key changes, such as the benefits of mangrove growth and the changes in protection provided by hard structures over time.

The matrix of index values for each scenario is included in appendix 1. The key summary statistics resulting from this application are:

- Relative stability of the shoreline
- Comparison of relative stability over time (and comparison to the current situation / status quo)
- Share of relative stability which can be attributed to the coastal defense feature – mangroves or built infrastructure

This information is then combined with data on areas which are low-lying and close to the coast (5m or lower and within 5km of the coast), including the land cover type and associated property value. This serves as input to the subsequent benefit cost analysis (BCA).

Spatial analysis option 2: Apply wave and storm surge attenuation functions to evaluate potential water level and flooding (for the Western Zone area only)

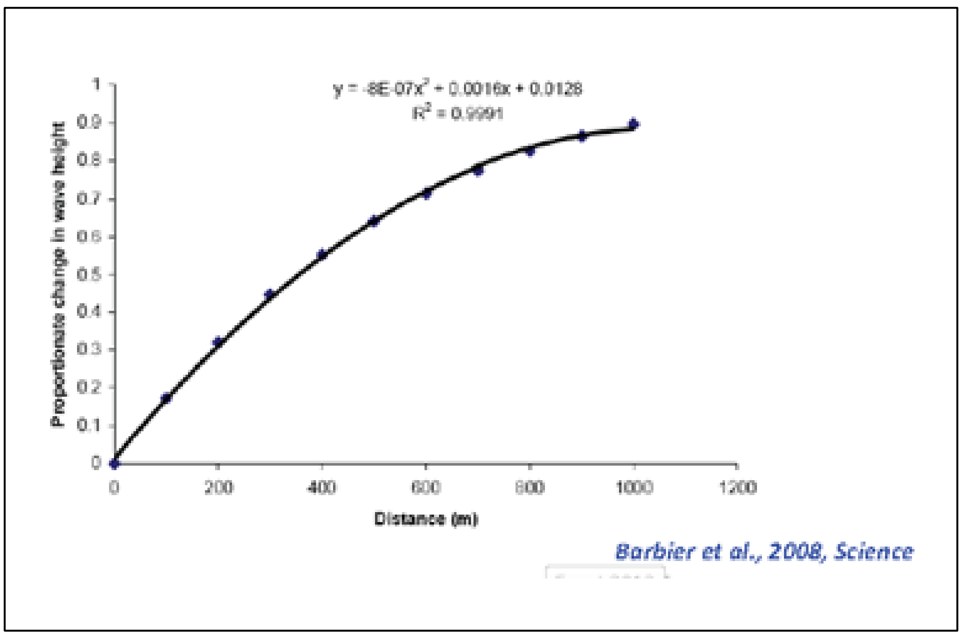
Although spatial analysis of shoreline protection is complex and time-consuming, we wanted to explore a second method to this assessment, which allows for more spatially detailed analysis of the likely extent of coastal flooding. This second approach is also reliant on detailed information on elevation of the land, as well as information on the factors which influence the degree of wave attenuation and storm surge reduction by mangroves. Below, we will discuss in detail how the wave height and storm surge reduction have been modeled to evaluate the impacts of shoreline protection alternatives in the Western Zone.

i. **Wave Height.**

In this analysis, we made use of several recent compilations of information on wave attenuation by mangroves compiled by Spalding et al. (2014), Carmen Lacambra (2009) and Barbier et al. (2008). They all find a strong relationship between mangrove width and wave attenuation, and point to the characteristics of both individual mangrove trees and of mangrove forests which influence the mangroves' effectiveness (forest width, density, diversity, complexity of aerial root structure, continuity and length along coastline, and tree age and height). Spalding et al., 2014 found that typically, "wave height is reduced 13-66% per 100m of mangrove." Other observations include that "50m of Avicennia reduced a small wave by 66% (1m to 0.3m)" and that "a dense mangrove forest can reduce wave height 0.5m per km of width" (Lacambra, 2009).

Barbier et al., 2008 published a function reflecting reduction in wave height based on width of mangrove stand (see **Figure 2** below), which serves as the basis for our analysis. This function reflects a regression based on a compilation of observations from the literature. It links the width of the mangrove forest (seaward to landward boundary) to the degree of wave height reduction a mangrove provided. For example, a mangrove with a width of 200 m reduces wave height by 30%, while a mangrove of 400 m width is projected to reduce wave height by 52%. We use this function as the foundation for estimating a reduction in wave height, but elaborate on the function by varying the percent reduction (up to 25% of the base – in either direction) based on the key factors affecting attenuation – mangrove density and complexity; age and height; length and continuity.

***Figure 2*- Proportionate change in wave height (at mid-tide) as a function of mangrove width**

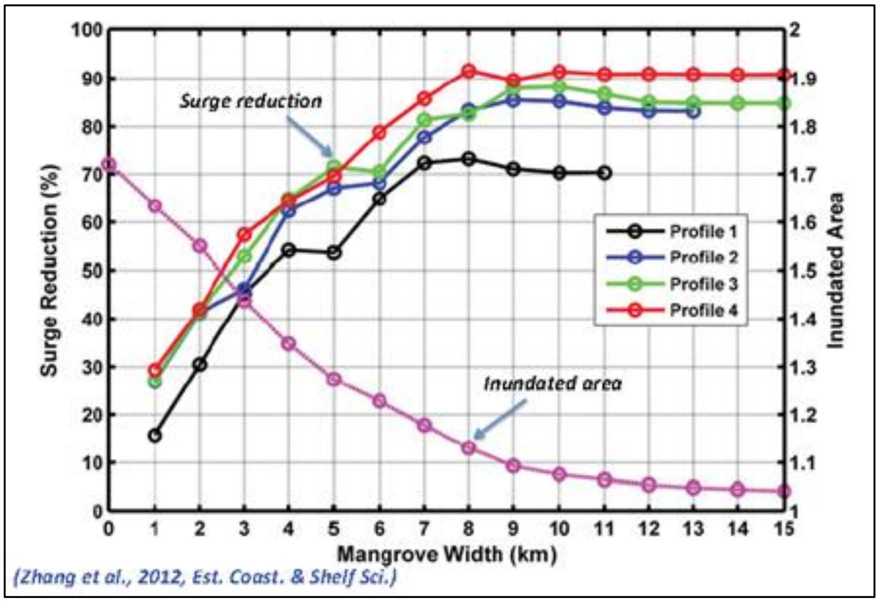


ii. Storm Surge Reduction.

Mangroves are less effective at reducing the height of storm surge than at reducing wave height. Storm surge has a much wider period than waves, and as such, requires a greater width of mangroves to reduce the surge height.

Spalding et al., 2014 found that "thousands of meters are needed to reduce flooding impact (storm surge height is reduced 5 – 50 cm / km). Zhang *et al.* (2012) plotted observations of storm surge reduction across different coastal profiles (see **Figure 3**). We use average values from this relationship as the basis for our estimation of degree of reduction in storm surge height.

***Figure 3* - Proportionate change in storm surge height as a function of mangrove width (km)**



In applying these functions, we again look at (a slightly conservative) 5m height for combined storm surge and wave height for the starting water level at the coast (with storm surge at 2.2 m and wave height at 2.8 m). The 5m height aligns with the design of the dykes. (If higher levels occur, there could be overtopping.)

This starting water level (5m) will be reduced based on the mangrove width and characteristics noted above. The water level on the inside of the mangroves will further dissipate as the water mass moves inland, decreasing at the rate of 1% of water height per 100m of land. Water level will be compared to elevation of the land, to arrive at depth of water (if flooded). This will be combined with land cover type and assumptions about the depth/damage relationship to arrive at the "avoided damages" due to the presence of the dyke or sea wall.

B. Cost Benefit Analysis of Shoreline Protection Services

Economic valuation method overview

The Cost-Benefit Analysis (CBA) is an economic decision-making approach, consisting a set of procedures for defining and comparing benefits and costs (Zerbe and Dively, 1994). In this analysis, CBA is used to compare the total expected costs of constructing (or protecting and promoting) the shoreline protection option against the total expected benefits for a period of 25 years. For each option, both benefits and costs are expressed in monetary terms, and are adjusted for the time value of money, so that all flows of benefits and flows of project costs over time (which tend to occur at different points in time) are expressed on a common basis in terms of their "present value." The results will be presented in the form of net present value (NPV) to allow users to easily compare options that provide benefits outweighing costs and to rank options by the highest NPV.

In order to compare economic effects that occur at different points in time, the practice of applying a discount rate to future effects is essential. However, the selection of the discount rate (or rates) may greatly alter the NPV and ultimately, influence decision-making. Discount rates reflect social or individual's preferences of the value attached to future resources, therefore two types of discount rates are often used in practice, i.e. social discount rates and individual discount rates. A social discount rate reflects the social rate of time preferences. Unlike individuals, societies must consider future generations to a greater extent and must also balance the benefits accruing to different sections of society in current and future periods. As a result, social discount rates are often much lower than individual discount rates as they place relatively more value on returns for future generations. In the case of shoreline protection in Paramaribo, whether a mangrove option or an engineering structure is used, the objective is to protect the societal value against flooding damages. Therefore, a social discount rate is considered to be appropriate in this study.

A large body of economics literature exists concerning which rate(s) best measures the social rate of time preference, but the discount rates used in natural disasters tend towards a low rate by assuming that society values heavily the long-term economic impacts of these disasters. For example, NOAA (1999) suggested the use of a 3 percent real discount rate for discounting interim service losses and restoration gains. Similarly, in a recent CBA for analyzing sea dikes to adapt to the sea level in the Vietnamese Mekong River Delta, Danh and Khai (2014) also applied a 3 percent social discount rate. Following the guidance of the literature, the present study also uses a 3 percent social discount rate, but also applies a higher discount rate of 7 percent as a sensitivity analysis to test the robustness of the results.

Costs and Benefits Categories

Depending on whether a manmade dyke or natural mangroves protection is considered in each scenario, a variety of different benefits and costs may be considered for valuing the true economic gains and losses associated with the alternative options.

The main cost categories include the following and are assessed wherever data are available:

(1). **Financial costs**, refer to actual expenditures for establishing the protection option, e.g. the costs of constructing and maintaining dykes and seawalls, or the costs of purchasing coastal lands to create buffer zones for mangroves to regenerate.

(2). **Costs of environmental damages**, are the economic costs of potential environmental damages (either monetarized or non-monetarized) as a result of the implementation of the shoreline protection option. This may include erosion and loss of mangroves propagule connectivity due to the construction of concrete dykes or seawalls.

(3). **Replacement costs of flooding**, refer to the money compensations to replace and repair the damages to manmade structures after flooding events.

As previously mentioned, the main benefit categories include the following and are assessed wherever data are available:

(1). **Shoreline protection benefits**, are approximated by assessing the value of property that potentially is not damaged or has reduced damage due to the shoreline protection infrastructure in place.

(2). **Ecosystem service benefits**, refer to a range of mangrove ecosystem goods and services in coastal areas that similar manmade shoreline protection infrastructures cannot provide.

In practice, the economic valuation is constrained by the limited data availability for the study area. For the same reason, many previously mentioned ecosystem service benefits should have been but could not be assessed during the course of the present study. Table 7-1 below provides an overview of the benefit and cost categories that are ideally to be included, and that have actually been included reflecting the available data. (Green checks reflect a yes; red crosses are a no.) In fact, it is clear that due to data limitations, many costs, especially the cost of environmental damages related to seawall and dyke are not valued and therefore not included in the CBA. Similarly, all ecosystem benefits associated with mangrove protection are not valued and included in this CBA as well. Therefore, it is reasonable to assume that the costs of dyke and seawall protection and the benefits of mangrove protection are largely underestimated in this study.

*Table 7-1. **Costs/Benefits to be considered when evaluating alternative shoreline protection options***

Costs/Benefits Categories	Natural mangrove shoreline defense		Seawall/ earth dyke shoreline protection	
	Ideally to be valued	Actually valued	Ideally to be valued	Actually valued
Costs				
1. Financial costs				
Cost of purchasing land for developing "setbacks"	√	√	x	X
Cost of dyke/sea wall construction	X	X	√	√
Cost of dyke/sea wall maintenance	X	X	√	√
Cost of purchasing land for building dykes	X	X	√	√

Cost of mangroves removal	X	X	√	X
Cost of household relocation due to establishing "setbacks" or building dykes	√	X	√	X
2. Cost of environmental damages				
Ecosystem degradation	X	X	√	X
Erosion	X	X	√	X
Loss of mangroves propagule connectivity	X	X	√	X
Loss of mangroves as fishery nursing ground	X	X	√	X
3. Replacement costs of coastal flooding				
Loss of agriculture productivity	√	X	√	X
Cost of replacing or repairing the damaged manmade structures	√	X	√	X
Benefits				
1. Shoreline protective benefits				
Avoided property damages	√	√	√	√
2. Ecosystem services benefits				
Potential reduction in further erosion	√	X	x	X
Improved fishery productivity through mangrove restoration	√	X	x	X
Increased carbon sequestration benefits	√	X	x	X
Legend: **√ : indicating where costs or benefits that are ideally to be valued, and actually valued in this study;** **X : indicating where costs or benefits that are not required to be valued, nor actually valued due to data limitations.**				

A. Data and assumptions

Two main data sources have been used in this study.

(1) Costs of earth dyke and concrete seawall construction are provided by Anthony's report, as a result of the previous phase of the project. Due to the limited data for Suriname, Anthony reported the estimates of costs of dyke construction in 2012 in neighboring Guyana without maintenance costs amount to US$16,000 for a km-long compacted earth dike and US$3million for a 1 km-long rock armor dike. Therefore we used these costs as a reference to calculate the costs of dyke and seawall construction in Paramaribo. Since in the Western Zone and Middle Zone of Paramaribo coast, building an earthen dyke with rocky side has been considered as a shoreline protection scenario alternative to the natural mangrove protection scenario, we therefore assume the costs of building 1 km of such a dyke will cost US$16,000 for the earth dyke and at least 1% of US$3 million for building the rocky side. Since the original costs were reported in 2012 US$, we adjust the value to 2014 US$ to get $47,380/km cost. In the Eastern Zone scenario, we use the US$3 million / km unit cost, after adjusting for inflation.

(2) Dyke maintenance costs are not currently budgeted by the government of Suriname, but they can be extremely high. Anthony reported that in Guyana, maintenance cost of a similar but much longer mud dyke (a 14km long mud dyke) in neighboring Guyana required the equivalent of 10% of the country's GDP (which is about US$204 million in 2012). In a different developing country context, Vietnam, maintenance costs of the Mekong delta dyke represent 48% of the total costs of dyke construction and maintenance (hence, maintenance costs are slightly lower than construction costs). In the present study, we assume some minimum dyke maintenance

will be performed annually in Surinam, which accumulated over the years is equivalent to 48% of the total construction costs to reduce the decay of earthen dyke.

(3) Land property values are derived from a property value survey conducted in Suriname in 2014: http://surinameonline.maps.arcgis.com/home/webmap/viewer.html?webmap=4570da63c5494514aa867bdf687f4b4d. In particular, we have assumed that these values do not include the values of built structures on the land; the higher end property value represent the value of more developed commercial and residential land uses; the average values are values of former and current agriculture land; and the lower end property values represent the value of underdeveloped areas, such as grassland, swaps and other. The original values were reported in 2014€ and have converted to 2014 US$. The unit land property values are presented in **Table 7-2**. These values have been used in this study to assess (i) Cost of purchasing land for developing "setbacks", (ii) Cost of purchasing land for building dykes, and (iii) Avoided property damages. The area of each land cover category at risk of flooding is estimated in the spatial analysis of shoreline protection described earlier in this section.

Table 7-2 - Property values of various land uses in different areas of Paramaribo and Wanica districts (Unit: $/m2, 2014 US$)

Resort	Commercial/residential	Agriculture land	Grassland/swap/other
Blauwgond	$253	$52	$19
Munder	$76	$23	$13
Rainville	$507	$53	$19
Weg naar Zee (Western Zone)	$76	$30	$13
Source: own assumption based on http://surinameonline.maps.arcgis.com/home/webmap/viewer.html?webmap=4570da63c5494514aa867bdf687f4b4d			

8. Results

We applied the Coastal Capital method and Cost Benefit Analysis to all three areas, but also applied the water height approach (with CBA) to the Western Zone area. We present the results grouped by method, beginning with the Coastal Capital approach.

The scenarios described in Section 5 served as input to the revised Coastal Capital framework, with all nine factors rated for each scenario. For each location, the framework was applied for “current”, where there is no change in coastal protection infrastructure; and for years 1, 3, 5, 10, and 25 for each coastal infrastructure option considered. The completed frameworks are included in Appendix 1. For each scenario, the nine factors are used to compute a Coastal Stability Score (the average of the nine factors), and then are used to compare the scores across scenarios and time periods, and finally – to derive an estimate of the proportion of coastal stability attributed to the coastal protection infrastructure.

A. Western Zone

Within the Western Zone "protection shed" over 75% of land is under 5m elevation – about 3,365 ha. Elevation data are from US NASA Shuttle Radar Topography Mission (SRTM), processed and provided by Deltares. The predominant land use categories in the area are grassland, agriculture, abandoned agriculture, "mixed", swamp and forest. Land cover data were provided by Gregg Verutes and are an integration of several data sets – Open Street Map, mangrove data from UNEP-WCMC, and forest, deforestation and ecosystem data for Suriname. See Appendix 1 for detailed results for all land cover types.

Application of the Coastal Capital method for the mangrove enhancement scenario suggests that mangrove recolonization produces only minor benefits during the first three years (while mangroves become established), but by year 25, the protection (as indicated by the coastal stability score) is 50% better than current, reflected by the 1.50 for the "score relative to current". Under this scenario, the "share of shoreline protection attributed to the mangrove" grows to 33% by year 25.

The Earthen Dyke scenario, on the other hand, provides relatively good protection once built (28% better than current in year 1), but this declines to comparable to the current situation by year 25.

Table 8-1 Comparison of Shoreline Protection Options for the Western Zone (using Coastal Capital method)

Scenario	Current	A1. Mangrove enhancement					A2. Earthen Dyke				
Time Period	CURRENT	Yr 1	YR 3	YR 5	YR 10	YR 25	Yr 1	YR 3	YR 5	YR 10	YR 25
Coastal Stability Score for Scenario (average of 9 factors)	**0.89**	**1.00**	**1.00**	**1.11**	**1.28**	**1.33**	**1.14**	**1.07**	**1.00**	**0.97**	**0.89**
Score relative to "Current"		**1.13**	**1.13**	**1.25**	**1.44**	**1.50**	**1.28**	**1.20**	**1.13**	**1.09**	**1.00**
Share of Coastal Stability attributed to mangrove or built infrastructure		**11%**	**11%**	**20%**	**30%**	**33%**	**22%**	**17%**	**11%**	**9%**	**0%**

The cost-benefit analysis of these results (see table below) suggest that although the cost of the mangrove enhancement scenario (A1) is much higher than the costs of constructing an earthen dyke instead (scenario A2) ($215 million vs. $28 million), the benefits over the 25-year time period more than make up for the difference in costs, and the mangrove enhancement scenario is preferable, at both 3% and 7% discount rates. The relatively high costs for the mangrove enhancement scenario are mainly driven by the costs of buying back coastal land for establishing setbacks to allow mangrove regeneration. However, this might be an overestimate if other, lower-cost options are available for supporting mangrove regeneration. Examples of such options include expropriation of land (with some compensation) and legal restrictions against the cutting of mangroves on one's property.

The high economic benefits for the mangrove enhancement scenario are mainly driven by the increasing shoreline stability (and thus increasing shoreline protection benefits) overtime, whereas in scenario A2, the shoreline protection benefits represented by the dyke protection show a decreasing trend over time. (See appendix 3 for details of CBA results by year.) Overall, this analysis suggests that the shoreline protection benefits of mangrove enhancement for a period of 25 years is significantly higher than those from constructing a dyke. The results are not sensitive to the choice of discount rate.

Table 8-2 Results of Cost-Benefit Analysis of different shoreline protection scenarios in Western Zone.

Shoreline protection scenarios	CBA results ($'000, US$2014, dr=3%)			CBA results ($'000, US$2014, dr=7%)		
	Cost	Benefit	NPV	Cost	Benefit	NPV
Scenario A1. Western Zone Mangroves	$215,458	$505,784	$290,326	$215,458	$325,262	$109,804
Scenario A2. Western Zone Earthen dyke	$28,079	$132,653	$104,574	$28,033	$116,808	$88,775

B. Middle Zone

In the Middle Zone protection shed, just under half of land area is under 5m (just under 1,500 ha). The predominant land cover categories are residential, swamp, and active and abandoned agricultural land. (See Appendix 1 for detailed results.)

Mangroves are healthy and are currently providing good protection in this area. In the mangrove enhancement scenario (B1), a coastal development setback allows mangrove colonization and expansion. By the end of 25 years, the mangroves provide 20% more Coastal Stability than at present. In the case of scenario B2, where an earthen dyke is built behind the mangrove, this (initially) provides increase protection from flooding, but this diminishes over time. The dyke alters water flow in the area, and remaining mangroves become less dense. Within the Coastal Capital framework, the protection only diminishes back to “current” level, but this probably understates the damage a dyke behind the mangroves could do.

Table 8-3 - Comparison of Shoreline Protection Options for the Middle Zone (using Coastal Capital method)

Scenario	Current	B1. Mangrove enhancement					B2. Earthen Dyke				
Time Period	CURRENT	Yr 1	YR 3	YR 5	YR 10	YR 25	Yr 1	YR 3	YR 5	YR 10	YR 25
Coastal Stability Score for Scenario (average of 9 factors)	**1.61**	**1.85**	**1.88**	**1.90**	**1.93**	**1.93**	**1.97**	**1.86**	**1.79**	**1.67**	**1.61**
Score relative to "Current"		**1.15**	**1.16**	**1.18**	**1.20**	**1.20**	**1.22**	**1.16**	**1.11**	**1.03**	**1.00**
Share of Coastal Stability atributed to mangrove or built infrastructure		**13%**	**14%**	**15%**	**17%**	**17%**	**18%**	**13%**	**10%**	**3%**	**0%**

Similar to the cost-benefit analysis for the Western Zone, in the Middle Zone the costs associated with establishing a coastal development setback for mangrove protection are estimated to be much higher than the costs associated with building a dyke. This is mainly because we have assumed a minimum annual maintenance cost of US$7000 for some basic dyke maintenance and a relatively high cost of establishing a coastal development setback (as we used property value rather than land value to calculate this cost. Similarly, the estimated cost for buying setback might have been overestimated if other lower-cost options are also available for supporting mangrove regenerations. However, as already mentioned above, the dyke loses protection function over time as a result of coastal erosion, and there is some evidence to suggest the annual maintenance costs may be more expensive than this. In comparison, mangrove protection increases over time as mangroves grow and become denser and more complex. Even with these assumptions, for a period of 25 years the overall benefits from mangrove enhancement are found in this analysis to eventually dwarf the benefits associated with building a dyke. The net present value of the mangrove enhancement option is higher under both the 3% and 7 % discount rates, suggesting that mangrove enhancement is a robust and sensible solution for the Middle Zone area.

Table 8-4 Results of Cost-Benefit Analysis of shoreline protection scenarios for the Middle Zone.

Shoreline protection scenarios	CBA results ($'000, US$2014, dr=3%)			CBA results ($'000, US$2014, dr=7%)		
	Cost	Benefit	NPV	Cost	Benefit	NPV
Scenario B1. Middle Zone Mangroves	$88,898	$243,219	$154,320	$88,898	$166,321	$77,423
Scenario B2. Middle Zone Earthen dyke	$19,056	$75,053	$55,997	$19,021	$67,694	$48,673

C. Eastern Zone

In the area potentially protected by the proposed river dyke in the Eastern Zone over 90% (880 ha) are under 5m elevation. The land use is predominantly residential, followed by a more commercially "developed" category. Some flooding in this area results from rainfall on land, coupled with poorly maintained drains. But, there is also significant risk due to the potential for additional surge near the channel into the river, where the surge can be funneled towards the river mouth area. The nature of hydrodynamics in this area should be considered, and serves as important context for interpretation of these results.

In the Eastern Zone, the only solution evaluated in this analysis was the building of a river dyke, as mangrove enhancement does not make sense in this area due to the dense, high value commercial and residential development along the coast. The river dyke is effective at reducing the risk of flooding from river swells in this area. After the river dyke is built, the coastal stability score is about 30% higher than current. Due to the river dyke aging, at year 25 this protection is only about 20% higher than current.

Table 8-5 - Evaluation of River Dyke option for the Eastern Zone (using Coastal Capital method)

Scenario	Current	Build River Dyke				
Time Period	Current	Yr 1	YR 3	YR 5	YR 10	YR 25
Coastal Stability Score for Scenario (average of 9 factors)	**1.33**	**1.75**	**1.69**	**1.64**	**1.58**	**1.58**
Score relative to "Current"		**1.31**	**1.27**	**1.23**	**1.19**	**1.19**
Share of Coastal Stability attributed to mangrove or built infrastructure		**24%**	**21%**	**19%**	**16%**	**16%**

The estimated benefits of construction of the river dyke are found under this analysis to vastly exceed the cost of construction – see **Table 8-6**. The estimated costs of construction and maintenance are $11.4 million (using a 3% discount rate) and $10.4 million (using a 7% discount rate). Again, the costs associated with dyke protection scenario are also likely to be underestimated as we only assumed some minimum maintenance efforts will be undertaken to maintenance the dykes over the course of years. The benefits of the protection provided by the river dyke (damages which do not occur over the 25 year period) are valued at $1.2 billion (using a 3% discount rate) and $0.9 billion (using a 7% discount rate). The analysis suggests that it makes sense to build a river dyke to protect the area if a significant amount of the flooding comes from elevated river levels (as opposed to clogged drains blocking runoff of streams and drainage areas.)

Table 8-6 Results of Cost-Benefit Analysis of different shoreline protection scenarios in Paramaribo.

Shoreline protection scenarios	**CBA results ($'000, US$2014, dr=3%)**			**CBA results ($'000, US$2014, dr=7%)**		
	Cost	**Benefit**	**NPV**	**Cost**	**Benefit**	**NPV**
Scenario C1. Eastern Zone – river dyke	$11,376	$1,223,459	1,212,084	$10,447	$877,992	$867,545

D. Water Height analysis results for the Western Zone

As described in the methodology section, a second spatial analysis approach – this one for estimating potential flood water heights – was applied for the Western Zone area only. This component goes beyond the terms of reference for analysis, but was done to test a new and more detailed method for evaluating the shoreline protection benefits provided by mangroves. It uses local topography in a more detailed manor and allows a more nuanced consideration of degree of damage in light of flood water height.

1) **Water height** – In this analysis, the initial water height at the shoreline is 5.0 m (2.8m waves on top of a 2.2m storm surge. We used the wave and surge attenuation functions described in section 7.A. Option 2 (see **Figure 2** and **Figure 3**) to estimate the reductions in water height in light of mangrove characteristics in a given year (based on the scenarios described in Section 5.)

   Under scenario A1, in year 1, mangroves have not grown enough to have an influence on water height, as establishment success and growth take time. By year 5, they reduce storm surge by 0.4m and wave height by 1.7 m, resulting in a water level inside the mangroves of 2.9m. By year 25 of scenario A1, the mangroves are wider and denser, reducing storm surge by 0.7 m and wave height by 2.6 m. The resulting water level inside the mangroves is 1.7m. (See **Table 8-7**)

   Under scenario A2, it is assumed that in year 1, the dyke is sufficient to deter flooding, so there are no flood damages behind the dyke. The Hindu Temple, however is outside of the dyke, so does experience some flooding. By year 5, the dyke has eroded substantially, but still provides minor protection. We assume a 0.5 m reduction in water height due to friction provided by the remaining structure. By year 25, the dyke is gone and provides no protection.

Table 8-7 - Water height reductions due to presence of mangroves

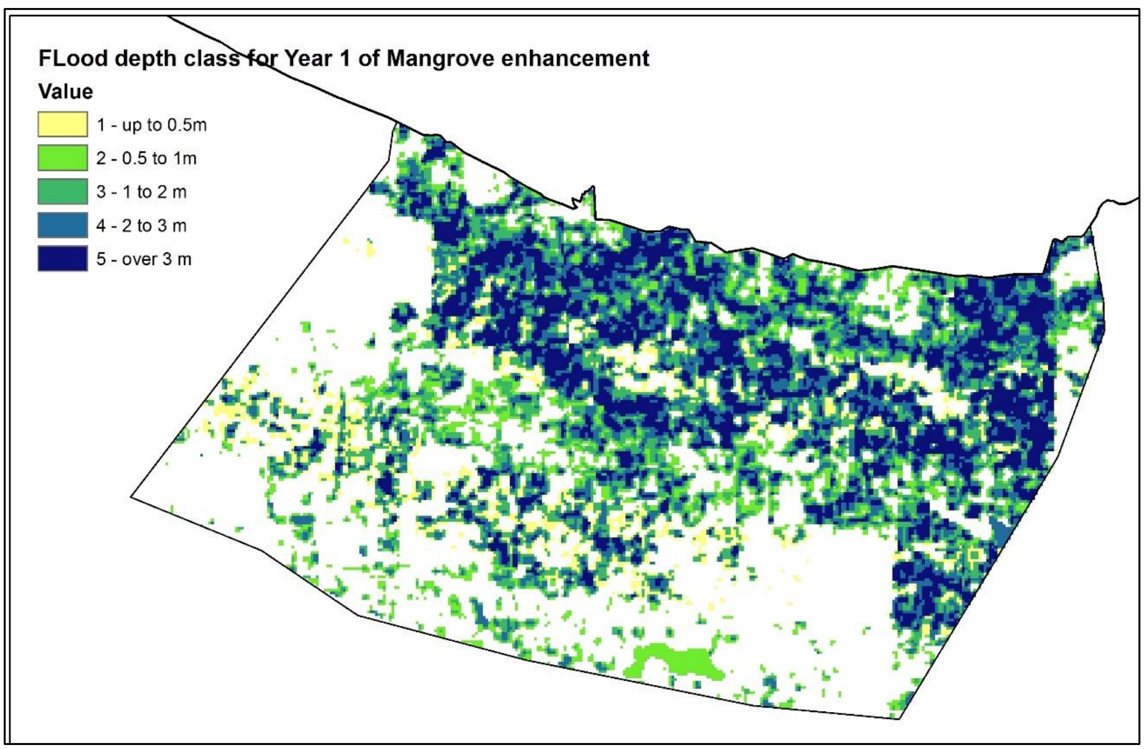
Component	Height in m	Height Reduction due to young mangroves (Year 5)	Water level inside mangroves (Year 5)	Height Reduction due to mature mangroves (Year 25)	Water level inside mangroves (Year 5)
Surge	**2.2**	0.4	1.8	0.7	1.5
Waves	**2.8**	1.7	1.1	2.6	0.2
Sum	**5.0**		**2.9**		**1.7**

2) **Flood height –** the water level coming inland from the mangroves (or from the shoreline) is run inland, with some reduction in water level due to friction and dissipation. This water level is compared with the local elevation (for each 30m resolution grid cell) to determine water height at that location. **Table 8-8** reflects the flooded area in the Western Zone protection shed by depth of water. Map 3, Map 4 and Map 5 depict these water depths for three time periods for scenario A1 – mangrove enhancement.

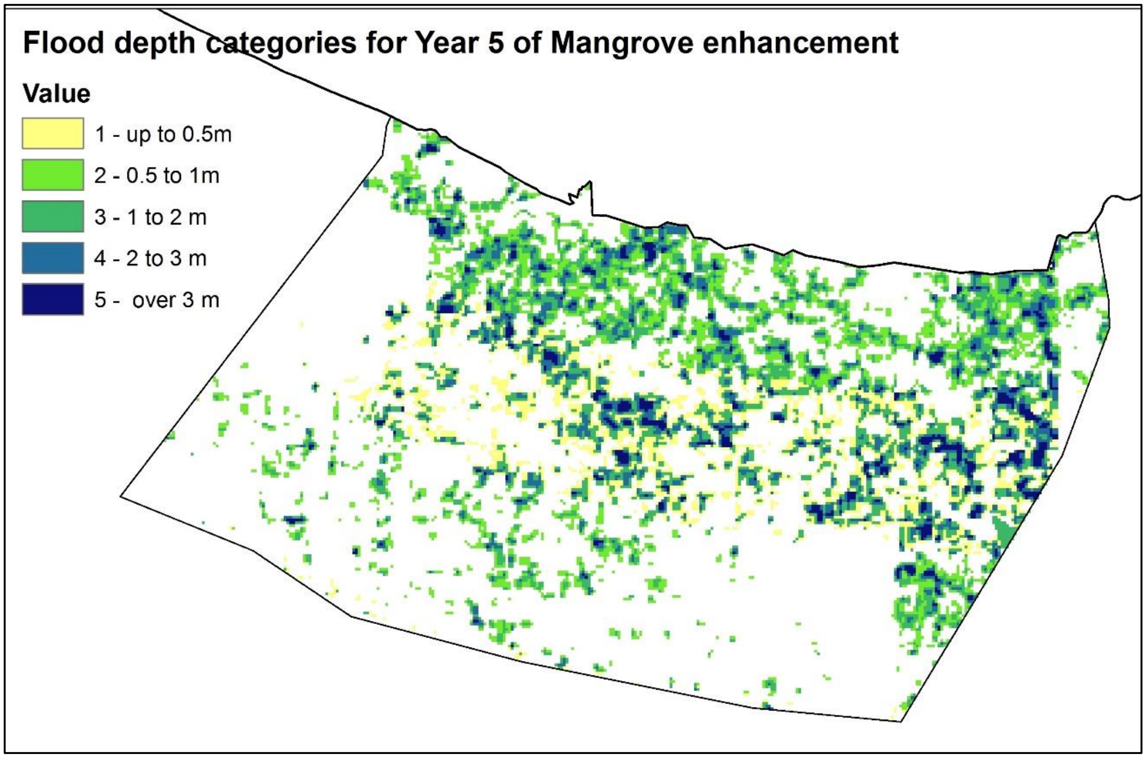
Table 8-8 Flood levels at Western Zone by Scenario and Year

	Land area under each water level (m2)					**total Flooded area**
Scenario \ Water level	Up to 0.5m	0.5 to 1m	1 to 2 m	2 to 3 m	over 3m	**(m2)**
A1 - Mangrove at 1 year	2,296,800	3,639,600	6,485,400	6,087,600	6,485,400	**24,994,800**
A1 - Mangroves at 5 years	2,763,000	3,853,800	4,793,400	2,309,400	953,100	**14,672,700**
A1 - Mangroves at 25 years	3,438,000	1,804,500	2,651,400	862,200	247,500	**9,003,600**
A2 - Dyke at 1 year	0	11,700	5,400	4,500	0	**21,600**
A2 - Dyke at 5 years	3,577,500	2,844,900	6,426,000	5,499,900	4,909,500	**23,257,800**
A2 - Dyke at 25 years	2,296,800	3,639,600	6,485,400	6,087,600	6,485,400	**24,994,800**

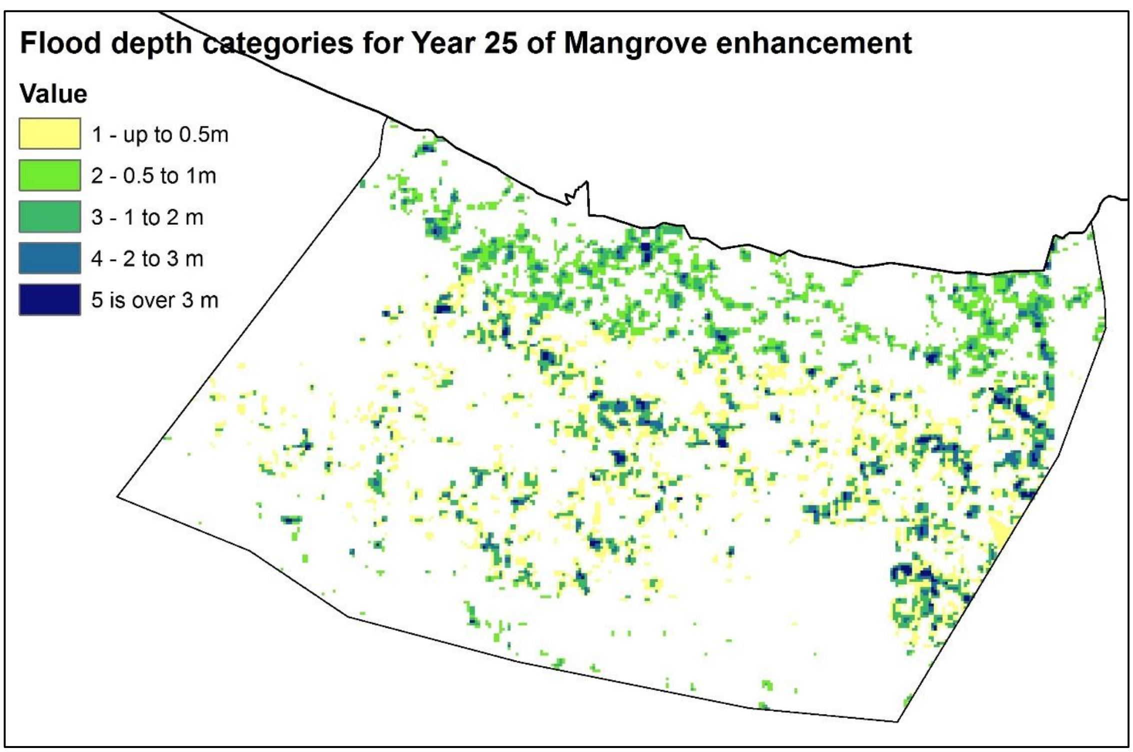
Map 3



Map 4


Flood depth categories for Year 5 of Mangrove enhancement
Value
1 - up to 0.5m
2 - 0.5 to 1m
3 - 1 to 2 m
4 - 2 to 3 m
5 - over 3 m

Map 5


Flood depth categories for Year 25 of Mangrove enhancement
Value
1 - up to 0.5m
2 - 0.5 to 1m
3 - 1 to 2 m
4 - 2 to 3 m
5 is over 3 m

3) **Damages and Damages Avoided.** The above flooded areas were combined with the land use map to arrive at
   a. Area flooded by land use category and depth and
   b. Value of the land under the different water depths.

   We applied a crude depth-to-damage relationship to arrive at an estimate of the potential amount of damage from the modeled storm event and water attenuation for each scenario (See Table 8-9). For example, in areas where flooding does not exceed 0.5m, we assume 5% of property value is damaged. In areas where flooding exceeds 3.0m, we assume 25% of property value is damaged.

Table 8-9 - Percent Damage by Flood Level

Flood level	Assumed Percent Damage
Up to 0.5m	5.0%
0.5 to 1m	10.0%
1 to 2 m	15.0%
2 to 3 m	20.0%
over 3m	25.0%

Using land areas, flood levels and property values, we estimated the likely amount of property damage for each scenario for the modeled storm event (which is regarded as a 2-year return period storm, in light of the average frequency of flood events in this area). These values are reflected in the "Damage" column in Table 8-10). The "Damages Avoided" are the reduction in damages relative to current. See Appendix 2 for more detailed results on these calculations.

Table 8-10 - Estimated Damages due to Flooding (and Damages Avoided as compared to Current)

Scenario \ Water level	Damage ($000)	Damage Avoided ($000) – Relative to Current
Current \ Status quo	70,479	
A1 - Mangrove at 1 year	70,479	0
A1 - Mangroves at 5 years	32,083	38,395
A1 - Mangroves at 25 years	16,139	54,339
A2 - Dyke at 1 year	288	70,191
A2 - Dyke at 5 years	62,045	8,434
A2 - Dyke at 25 years	70,479	0

4) **Comparison of Benefits and Costs of different scenarios.** "Damage Avoided" refers to benefits from shoreline protection (reflected in Table **Table 8-10**). The annual benefit of shoreline protection services under two scenarios was estimated by assuming a linear rate of changes in damage avoided between three points of estimates for Years 1, 5, and 25, when the water height modeling were implemented.

Results of the economic analysis are presented in ***Table 8-11***. It should be noted that this analysis uses the same assumptions related to the costs of implementing the dyke option or mangrove enhancement option as for the model presented earlier. The costs of the mangrove enhancement scenario refer to the costs of buying the land in "setbacks" to allow mangrove regeneration, which is likely an overestimate for the reasons described earlier. The costs of earthen dyke scenario consist of dyke construction cost, cost of purchasing land for building dykes, and some dyke maintenance cost.

The benefits (avoided damages) estimated using the water height method differ from the Coastal Capital method. In particular, under this new model, it is estimated that the avoided property damage for the mangrove enhancement scenario was $0 in year 1 and after a few years of recovery and regeneration, the mangrove protection started to be functional from the 4th year and the protection increased over the years, leading to a gradual increase in the avoided damages every year. Whereas in the dyke scenario (A2), the total avoided property damage was estimated much higher in year 1, however its protection function declines quickly (relative to the Coastal Capital results). As a consequence, the estimate of net benefits (estimated as NPV) for both scenarios are much lower than the Coastal Capital results. Despite the difference in magnitude, the CBA results of the new spatial model suggest again that the mangrove protection provides an overall higher net benefits than those of dyke protection, and thus should be recognized as a preferred policy solution.

However, the new results are found to be sensitive to changes in discount rate. The sensitivity analysis using a 7% discount rate shows an opposed result, where mangrove protection presents a negative NPV, whereas a dyke solution generates a positive NPV instead. This result suggests that in a decision-making context, it is very likely that the local policy-makers or stakeholders who pursue fast economic returns might favor a dyke protection solution. On the contrary, if the policy-makers or stakeholders acknowledge the importance of shoreline protection in the future (using the social discount rate of 3%), then the analysis suggests that mangrove shoreline protection should be selected as the net benefits will be double those of dyke protection ($103 million vs. $51 million.)

Table 8-11 Results of Cost-Benefit Analysis of different shoreline protection scenarios in the Western Zone (Water Height method).

Shoreline protection scenarios	CBA results ($'000, US$2014, dr=3%)			CBA results ($'000, US$2014, dr=7%)		
	Cost	Benefit	NPV	Cost	Benefit	NPV
Scenario A1. WNZ Mangroves	$215,458	$318,067	$102,609	$215,458	$194,858	-$20,601
Scenario A2. WNZ Earthen dyke	$28,079	$79,318	$51,239	$28,033	$76,028	$47,995

Finally, it should be noted that the benefits associated with the mangrove protection scenario are most likely underestimated as none of the essential ecosystem benefits has been accounted for in this study. Similarly, the costs associated with the dyke protection scenario are also likely to be underestimated as we only assumed some minimum maintenance efforts will be undertaken to maintain the dykes over the course of years.

9. Limitations of the Analysis

This analysis was conducted over a relatively short time period (under 2 months) and without the benefit of a site visit. Although some anecdotal information was communicated by WWF-G about the frequency of recent flood events, there was limited information on the actual extent or height of flooding and no information on the degree of damage due to the flooding. This information limitation makes calibration of results difficult.

Detailed information on elevation of the land is a critical input to the examination of flood extent and level. Although the elevation data used are moderately detailed (SRTM data are 30 m resolution), there are significant errors in the elevation values because the radar sensor detects the height of structures (including buildings and trees.) Hence, the elevation data reflect ground height in some locations, and tops of trees or tops of buildings in other locations. As such, we have most likely underestimated flood extent and depth in areas dense with trees or buildings.

With regard to wave heights, storm surge and tidal range, we made use of a global data source and adjusted it based on local observations and expert opinion. This was not a bad starting point. But, when these data were compared to the local elevation data (height above mean sea level), it appeared that tidal range alone would be sufficient to flood most areas. As it is not the case in reality that these areas in Paramaribo flood on a daily basis, something is amiss. As such, we evaluated a lower (and more realistic) storm event – with a combined water (wave and surge) of 5m above mean sea level. In our application of the Coastal Capital method, we mapped all areas under 5m as being "potentially vulnerable to flooding" and treated this as a "5 year-return-period storm event". The application of the "water height" method uses the 5m water height only as a starting point, with the water level dissipating based both on coastal protection features and because of dispersal across the landscape. This approach (and results) calibrate better with our understanding of the extent and frequency of (roughly bi-annual) flooding in the area. As such, we treated this as a 2 year-return-period storm event.

The land cover data used in the analysis (which were compiled from four sources by Gregg Verutes) seem good (in light of what is visible from other sources, such as Google Earth). The information on property values is less reliable – described below. An additional source of uncertainty is the amount of damage to property which might result from a given flood level and duration. We used very rough approximations of percent of property damaged (ranging from 5% to 25%), based on some published depth-damage tables. These tables, however, typically relate to damage to constructed structures and not to land-related damage, such as damage to crops. As such, we have probably exaggerated the amount of damage in some areas.

In addition, the economic analysis presented in this study is also strongly constrained by data limitations. As already mentioned, we could not assess the actual avoided damages due to the presence of shoreline protection by applying replacement cost method to assessing the total expenses necessary for replacing and/or repairing the damaged structures and the economic losses due to interruptions of economic activities (e.g. agricultural productivity) after the flooding events, nor by assessing the people's willingness-to-pay to avoid these economic losses (e.g. the coastal damage insurance). Instead, we could only use property value as a proxy of such damage, and used a varying proportion of the property value depending upon either the relative stability of the shoreline (in the Coastal Capital method) or the height of flood water (in the water height approach). We had summaries of property values by administrative units (resorts). The data, provided by WWF-G provided only an average, a maximum and a minimum property value found based on a survey conducted in the three resorts within our study area. Assumptions were needed for obtaining variable property values for different land use types, as the economic damages should differ depending on the type of land use involved. In particular, we assumed that the maximum property values found in a resort reflect the value of commercial and residential uses of the land in this resort, the average property values found in a resort reflect the value of agricultural land uses in the resort, and the minimum property values found in a resort reflect the value of grassland, swamp and other land uses in this resort.

In addition, the time and data constraints on this analysis precluded inclusion of valuation of other ecosystem services provided by mangroves. As a consequence, the benefits estimated for all mangrove protection scenarios underestimate the total benefits mangrove ecosystem goods and services in the long term. Finally, as far as costs are concerned, we were not able to account for the social costs associated with relocating farms from the coastal areas to inland areas in this analysis, as no similar studies as such have been found in either the study area or neighboring countries. Moreover, a lack of precise costs data on dyke and river dyke construction and maintenance in Suriname also forced us to apply data that could be found in the literature or have been reported by the neighboring countries.

10. Conclusion

We implemented the analysis with an emphasis of using the best available inputs and assumptions (but recognizing the limited data available), and tested the results for sensitivity to the discount rate applied. In general, the results were robust with regard to the choice of discount rate. Our results suggest that investment in protection and enhancement of mangroves in the Western Zone and Middle Zone areas are likely to make economic sense, while investing in river dyke construction in the Eastern Zone may be the more sensible option for protecting low-lying areas from flooding from the river. In particular:

- In the **Western Zone**, the currently proposed dyke will not protect the Hindu Temple, as it is on the wrong side), and will not protect agricultural land against flooding for more than a couple years (due to the wave refraction caused by dykes, the high risk of erosion in the interbank phase of the mud banks along this coast, and due to inadequate investment in maintenance, which is common in the region.) At a 3 percent discount rate (and using the Coastal Capital method), mangrove protection is more appropriate as it generates a higher NPV of US$ 290 million for a period of 25 years, in comparison to the earthen dyke protection scenario which generates a NPV of US$ 104 million. Also, using the water height method (and a 3% discount rate), mangrove enhancement is again more appropriate, with a NPV of $103 million, as compared with $51 million for the dyke. The only scenario in which this is not the preferred solution is under the water height method using a 7% discount rate.
- In the **Middle Zone**, the mangroves are currently healthy and expanding naturally. Building a dyke behind the mangroves would make little sense in either physical or economic terms. At a 3%

discount rate, mangrove enhancement is again found to be more cost-effective as it generate a NPV of US$ 154 million that is roughly three times of those of an earthen dyke.

- In the **Eastern Zone**, construction of a river dyke appears an appropriate option to protect the coastal area against flooding from the river side. Additional flooding might occur from the land side during storms due to inadequate or clogged drainage. Due to the high commercial value of the property in this area (as shown in **Table 7-2**), the total avoided damages due to the presence of shoreline protection is also significant. The NPV of shoreline protection benefits is assessed to be around US$1.2 billion for a period of 25 years (for a 3% discount rate) and US$870 million (for a 7% discount rate).

However, as already mentioned previously, it is important to note that the total economic benefits of the mangrove protection scenarios are likely to be much higher in reality if the value of other ecosystem goods and services provided by mangrove were included. In addition, the costs of dyke construction and maintenance are likely underestimated in this study, as only minimum efforts of dyke maintenance have been assumed for a 25-year analysis period, and there is considerable uncertainty regarding dyke construction costs.

This analysis should be regarded as a rough-cut starting point for consideration of different coastal defense options near Paramaribo. It made sensible use of the best data available to us at this time, but has many limitations, as described in the previous section. The accuracy of the analysis would improve with better information on past flooding and associated damage; refined estimates of land and property values; better information on costs of hard infrastructure construction and maintenance; and more realistic estimates of the cost of establishing a coastal development setback. In addition, including estimates of the value of other mangrove-related ecosystem services, such as fisheries habitat and carbon storage, would provide a more realistic picture of the overall value of investment in mangrove conservation and enhancement.

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Appendix 1 – Shoreline Protection Modeling – Using the Coastal Capital Approach

This appendix includes:

1) A table of factors used in the Coastal Capital Index-based approach to evaluating relative stability of the shoreline.
2) Three tables reflecting factors used for the three locations – both for current and future scenarios.
3) A table reflecting the area of land potentially at risk of flooding by land cover class for each of the three areas.

Table A- 1 - Coastal Protection Factors - Source: Adapted from Coastal Capital: Belize (WRI and Institute of Marine Affairs (IMA), 2008.)

Factor	***Level Of Coastal Protection***				
	Very High **4**	**High** **3**	**Medium** **2**	**Low** **1**	**None** **0**
Coastal Geology	Igneous and/or Volcanic	Metamorphic	Sedimentary	Unconsolidated Sediments	N/A
Coastal Exposure *(does the coast face open ocean?)*	Significantly protected by a large atoll or headlands	Protected by atoll, or by headlands	Slightly protected by atoll or headlands	--	No protection by atoll or headlands
Coral Reef Index *(average of the 3 scores)* *(not used in Suriname)* **Reef Type**	Emergent Reef (barrier or windward side of atoll)	Fringing and Leeward side of atoll	Patch	--	No reef present
Reef Distribution	---	---	Continuous	Discontinuous	No reef present
Reef Distance Offshore (m)	< 250 m 250 – 500m	.5 – 1 km 1 - 2 km	2 – 4 km 4 – 8 km	8 – 16 km > 16 km	No reef present
Wave Energy (~ Max. Wave Height)	< 25 cm	25 – 50 cm	50 – 100 cm	1 – 2 m	> 2 m
Storm/Hurricane Events	Not in hurricane belt	Affected by at least a category 1 every 25 years	Affected by at least a category 2 every 25 years	Affected by at least a category 3 every 25 years	2 or more category 3 or higher expected every 25 years
Coastal Elevation (m)	> 12	6 – 12	2 - 5	0 - 1	< 0 (N/A) **
Coastal Anthropogenic Activities	No sand mining, coastal development, etc.	Misc. Other Activities	Either sand mining or coastal development	Sand mining and coastal development	N/A
Mangrove Index (Average of the 4 scores) 1. Mangrove Width	➢ 1000 m width	500 – 1000m	100 – 500 m	< 100 m	No mangrove present
2. Mangrove Density and Complexity	Very dense mangrove with complex areal roots	Moderate density and complexity	Not very dense single species stand	Sparse mangrove / not dense	
3. Mangrove Age and Height	over 20 m height	10 – 20 m tall	5 – 10 m tall	< 5 m tall	
4. Continuity of Mangrove (along coast)	Thick, continuous for over 2 km	Thick and continuous for > 1 km or	Over 500 m length, with minor gaps	Patchy / with gaps	
Coastal Defense Index (Avg. of the 4 scores) 1. Type	Hard sea wall on accreting or stable coast	Earthen dyke on accreting or stable coast	Hard sea wall on eroding coast	Earthen dyke on eroding coast	No built defense present, or damaged and not providing defense.
2. Age	Newly built	Up to 2 years old	2-5 years old	5-10 years old	
3. Maintenance / Condition	Well maintained – annually	Periodically maintained	Poorly maintained	Not maintained	
4. Erosion status	No detectable erosion	Minor erosion	Moderate erosion	Significant erosion	

Table A- 2 - Coastal Capital Results for the Western Zone

Scenario	**Current**	Mangrove enhancement					Earthen Dyke				
Time Period	CURRENT	Yr 1	YR 3	YR 5	YR 10	YR 25	Yr 1	YR 3	YR 5	YR 10	YR 25
Factors											
Coastal Geology	1	1	1	1	1	1	1	1	1	1	1
Coastal Exposure	0	0	0	0	0	0	0	0	0	0	0
Coral Reef Index	0	0	0	0	0	0	0	0	0	0	0
Wave Energy	0	0	0	0	0	0	0	0	0	0	0
Storm/Hurricane Events	4	4	4	4	4	4	4	4	4	4	4
Coastal Elevation (m)	1	1	1	1	1	1	1	1	1	1	1
Coastal Anthropogenic Activities	2	2	2	2	2	2	2	2	2	2	2
Mangrove Index *(Average of 4 below)*	0	1	1	2	3.5	4	0	0	0	0	0
Mangrove Width	0	1	1	4	4	4	0	0	0	0	0
Mangrove Density and Complexity	0	1	1	1	3	4	0	0	0	0	0
Mangrove Age and Height	0	1	1	1	3	4	0	0	0	0	0
Continuity of Mangrove (along coast)	0	1	1	2	4	4	0	0	0	0	0
Coastal Defense Index *(Average of 4 below)*	0	0	0	0	0	0	2.25	1.63	1.00	0.75	0.00
Type							1	1	1	0	0
Age							4	2	1	1	0
Maintenance / condition							2	2	1	1	0
Erosion status							2	1.5	1	1	0
Score for Scenario *(average of 9 factors)*	**0.89**	**1.00**	**1.00**	**1.11**	**1.28**	**1.33**	**1.14**	**1.07**	**1.00**	**0.97**	**0.89**
Score relative to "Current"		**1.13**	**1.13**	**1.25**	**1.44**	**1.50**	**1.28**	**1.20**	**1.13**	**1.09**	**1.00**
Share of Coastal Stability attributed to mangrove or built infrastructure		**11%**	**11%**	**20%**	**30%**	**33%**	**22%**	**17%**	**11%**	**9%**	**0%**

Table A- 3 - Coastal Capital Results for the Middle Zone

Scenario	Current	Mangrove enhancement					Earthen Dyke				
Time Period	CURRENT	Yr 1	YR 3	YR 5	YR 10	YR 25	Yr 1	YR 3	YR 5	YR 10	YR 25
Factors											
Coastal Geology	2	2	2	2	2	2	2	2	2	2	2
Coastal Exposure	2	2	2	2	2	2	2	2	2	2	2
Coral Reef Index	0	0	0	0	0	0	0	0	0	0	0
Wave Energy	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Storm/Hurricane Events	4	4	4	4	4	4	4	4	4	4	4
Coastal Elevation (m)	1	1	1	1	1	1	1	1	1	1	1
Coastal Anthropogenic Activities	2	4	4	4	4	4	2	2	2	2	2
Mangrove Index *(Average of 4 below)*	3	3.125	3.375	3.625	3.875	3.875	3	2.75	2.625	2	2
Mangrove Width	3	3	3	3.5	4	4	3	3	2.5	2	2
Mangrove Density and Complexity	4	4	4	4	4	4	4	3	3	2	2
Mangrove Age and Height	3	3	3.5	3.5	3.5	3.5	3	3	3	3	3
Continuity of Mangrove (along coast)	2	2.5	3	3.5	4	4	2	2	2	1	1
Coastal Defense Index *(Average of 4 below)*	0	0	0	0	0	0	3.25	2.50	2.00	1.50	1.00
Type	0.00	0	0	0	0	0	3	3	3	3	1
Age	0	0	0	0	0	0	4	3	2	1	1
Maintenance / condition	0	0	0	0	0	0	2	1	1	1	1
Erosion status	0	0	0	0	0	0	4	3	2	1	1
Score for Scenario *(average of 9 factors)*	**1.61**	**1.85**	**1.88**	**1.90**	**1.93**	**1.93**	**1.97**	**1.86**	**1.79**	**1.67**	**1.61**
Score relative to "Current"		**1.15**	**1.16**	**1.18**	**1.20**	**1.20**	**1.22**	**1.16**	**1.11**	**1.03**	**1.00**
Share of Coastal Stability attributed to mangrove or built infrastructure		**13%**	**14%**	**15%**	**17%**	**17%**	**18%**	**13%**	**10%**	**3%**	**0%**

Table A- 4 - Coastal Capital Results for the Eastern Zone

Scenario	Current	Build River Dyke				
Time Period	Current	Yr 1	YR 3	YR 5	YR 10	YR 25
Factors						
Coastal Geology	1	1	1	1	1	1
Coastal Exposure	3	3	3	3	3	3
Coral Reef Index	0	0	0	0	0	0
Wave Energy	1	1	1	1	1	1
Storm/Hurricane Events	4	4	4	4	4	4
Coastal Elevation (m)	1	1	1	1	1	1
Coastal Anthropogenic Activities	2	2	2	2	2	2
Mangrove Index *(Average of 4 below)*	0	0	0	0	0	0
Mangrove Width	0	0	0	0	0	0
Mangrove Density and Complexity	0	0	0	0	0	0
Mangrove Age and Height	0	0	0	0	0	0
Continuity of Mangrove (along coast)	0	0	0	0	0	0
Coastal Defense Index *(Average of 4 below)*	0	3.75	3.25	2.75	2.25	2.25
Type	0.00	4	4	4	4	4
Age	0	4	3	2	1	1
Maintenance / condition	0	4	3	3	2	2
Erosion status	0	3	3	2	2	2
Score for Scenario *(average of 9 factors)*	**1.33**	**1.75**	**1.69**	**1.64**	**1.58**	**1.58**
Score relative to "Current"		**1.31**	**1.27**	**1.23**	**1.19**	**1.19**
Share of Coastal Stability attributed to mangrove or built infrastructure		**24%**	**21%**	**19%**	**16%**	**16%**

Table A- 5 - Summary of area under 5m elevation by land use category (in ha and as percent of the land use category) within the three "protection sheds"

Western Zone		
LU Category	Ha. under 5m	As pct of LU Category
grassland	877.8	94%
Ag land	636.4	91%
old ag land	490.5	71%
land	450.3	84%
mixed	349.3	92%
swamp	254.5	85%
forest	252.4	37%
woodland	27.6	25%
water	13.1	88%
mangrove	7.6	28%
Hindu Temple	3.1	63%
recreation	2.0	81%
residential	0.2	100%
Total	**3,365**	**77%**

Middle Zone		
LU Category	Ha. under 5m	As pct of LU Category
residential	354.2	74%
swamp	328.5	77%
old ag land	240.0	53%
land	145.4	54%
Ag land	134.6	68%
grassland	98.7	87%
woodland	85.6	57%
forest	51.4	11%
mangrove	23.7	5%
water	20.3	63%
landfill	5.9	68%
recreation	5.2	97%
Total	**1,494**	**48%**

Eastern Zone		
LU Category	Ha. under 5m	As pct of LU Category
residential	763.4	95%
land	49.6	89%
developed	36.9	97%
woodland	9.2	37%
swamp	8.8	99%
mangrove	4.9	72%
recreation	4.0	100%
Ag land	3.1	57%
grassland	0.2	100%
Total	**880**	**93%**

Appendix 2 – Shoreline Protection Modeling – Using the Water Level Approach

These results are for the Western Zone only.

1) The Current (no action) results serve as the mangrove enhancement scenario (A1) for year 1. (These also reflect the flood condition for scenario A2 for year 25.)

Current (no Action / Status Quo) scenario - Area flooded (m2) by flood depth and land use

Pct Damage Assumed	5.0%	10.0%	15.0%	20.0%	25.0%		
Flood depth	Up to 0.5m	0.5 to 1m	1 to 2 m	2 to 3 m	over 3m		
Land_use						Sum of Flooded area	Property Value ($/m2)
recreation	0	3,600	900	0	0	4,500	30
water	3,600	9,900	13,500	57,600	11,700	96,300	13
woodland	23,400	42,300	45,900	40,500	23,400	175,500	13
swamp	392,400	256,500	511,200	321,300	161,100	1,642,500	13
land	125,100	564,300	873,000	1,004,400	1,165,500	3,732,300	13
residential	0	0	1,800	0	0	1,800	76
grassland	549,900	707,400	1,834,200	1,960,200	2,600,100	7,651,800	13
agriculture	321,300	667,800	1,358,100	1,206,000	1,283,400	4,836,600	30
mangrove	0	22,500	11,700	11,700	4,500	50,400	13
forest	227,700	379,800	388,800	198,900	113,400	1,308,600	13
old ag land	342,000	751,500	642,600	388,800	153,000	2,277,900	13
mixed	311,400	222,300	798,300	893,700	969,300	3,195,000	13
Hindu Temple	0	11,700	5,400	4,500	0	21,600	100
Sum of Area (m2)	**2,296,800**	**3,639,600**	**6,485,400**	**6,087,600**	**6,485,400**	**24,994,800**	**Flooded area (m2)**
						70,479	**Potential damage ($000)**

2) Under Mangroves enhancement scenario (A1) for year 5, the water level just behind the mangroves is 2.9 m.

Mangroves at 5yr - Area flooded (m2) by flood depth and Land Use

Pct Damage Assumed	5.0%	10.0%	15.0%	20.0%	25.0%		
Flood Category	Up to 0.5m	0.5 to 1m	1 to 2 m	2 to 3 m	over 3m		
Land_use						Sum of Flooded area	Property Value ($/m2)
recreation	0	900	0	0	0	900	30
water	1,800	7,200	59,400	2,700	1,800	72,900	13
woodland	4,500	38,700	18,900	6,300	0	68,400	13

swamp	125,100	253,800	178,200	58,500	12,600	628,200	13
land	94,500	907,200	731,700	372,600	128,700	2,234,700	13
residential	0	1,800	0	0	0	1,800	76
grassland	1,161,000	903,600	1,788,300	988,200	504,000	5,345,100	13
agriculture	610,200	756,900	1,029,600	494,100	156,600	3,047,400	30
mangrove	0	11,700	4,500	0	0	16,200	13
forest	228,600	88,200	135,000	36,000	5,400	493,200	13
old ag land	216,900	299,700	270,000	71,100	16,200	873,900	13
mixed	320,400	579,600	577,800	279,900	127,800	1,885,500	13
Hindu Temple	0	4,500	0	0	0	4,500	100
Sum of Area (m2)	**2,763,000**	**3,853,800**	**4,793,400**	**2,309,400**	**953,100**	**14,672,700**	**Flooded area (m2)**
						32,083	**Potential damage ($000)**

3) Under Mangroves enhancement scenario (A1) for year 25, the water level just behind the mangroves is 1.7 m.

Mangroves at 25 years - Area flooded (m2) by flood depth and Land Use

Pct Damage Assumed	5.0%	10.0%	15.0%	20.0%	25.0%		
Flood Category	**Up to 0.5m**	**0.5 to 1m**	**1 to 2 m**	**2 to 3 m**	**over 3m**		
Land_use						**Sum of Flooded area**	**Property Value ($/m2)**
recreation	0	0	0	0	0	0	30
water	51,300	8,100	2,700	1,800	0	63,900	13
woodland	17,100	10,800	10,800	1,800	0	40,500	13
swamp	234,000	54,000	93,600	19,800	3,600	405,000	13
land	132,300	630,900	388,800	107,100	30,600	1,289,700	13
residential	1,800	0	0	0	0	1,800	76
grassland	1,622,700	293,400	1,154,700	431,100	152,100	3,654,000	13
agriculture	651,600	442,800	533,700	171,000	20,700	1,819,800	30
mangrove	0	4,500	0	0	0	4,500	13
forest	114,300	31,500	39,600	900	4,500	190,800	13
old ag land	303,300	60,300	147,600	28,800	8,100	548,100	13
mixed	309,600	268,200	279,900	99,900	27,900	985,500	13
Hindu Temple	0	0	0	0	0	0	100
Sum of Area (m2)	**3,438,000**	**1,804,500**	**2,651,400**	**862,200**	**247,500**	**9,003,600**	**Flooded area (m2)**
						16,139	**Potential damage ($000)**

4) Under the Hard Infrastructure scenario (A2) – Dyke constructed at the Western Zone for year 1, it is assumed that the dyke provides protection, so no damage behind the dyke. But, as the Hindu Temple is seaward of the dyke, flooding continues in that area.

Dyke at year 1 - Area flooded (m2) by flood depth and Land Use

Flood Category	Up to 0.5m	0.5 to 1m	1 to 2 m	2 to 3 m	over 3m		
Land_use						**Sum of Flooded area**	**Property Value ($/m2)**
Hindu Temple	0	11,700	5,400	4,500	0	21,600	100
Sum of Area (m2)	**0**	**11,700**	**5,400**	**4,500**	**0**	**21,600**	**Flooded area (m2)**
						288	**Potential damage ($000)**

5) By year 5 the dyke has eroded substantially, but still reduces water level by 0.5m.

Dyke at 5yrs -

Pct Damage Assumed	5.0%	10.0%	15.0%	20.0%	25.0%		
Flood Category	**Up to 0.5m**	**0.5 to 1m**	**1 to 2 m**	**2 to 3 m**	**over 3m**		
Land_use						**Sum of Flooded area**	**Property Value ($/m2)**
recreation	3,600	0	900	0	0	4,500	30
water	8,100	2,700	12,600	57,600	11,700	92,700	13
woodland	50,400	14,400	45,900	32,400	17,100	160,200	13
swamp	310,500	261,900	430,200	231,300	126,000	1,359,900	13
land	599,400	104,400	863,100	954,000	1,132,200	3,653,100	13
residential	0	0	1,800	0	0	1,800	76
grassland	657,000	919,800	2,011,500	1,924,200	1,731,600	7,244,100	13
agriculture	599,400	535,500	1,287,000	1,134,900	1,047,600	4,604,400	30
mangrove	22,500	0	11,700	11,700	4,500	50,400	13
forest	338,400	209,700	333,000	163,800	68,400	1,113,300	13
old ag land	747,900	319,500	571,500	288,900	117,900	2,045,700	13
mixed	228,600	477,000	851,400	696,600	652,500	2,906,100	13
Hindu Temple	11,700	0	5,400	4,500	0	21,600	100
Sum of Area (m2)	**3,577,500**	**2,844,900**	**6,426,000**	**5,499,900**	**4,909,500**	**23,257,800**	**Flooded area (m2)**
						62,045	**Potential damage ($000)**

6) By 25 years, the dyke no longer exists, so provides no protection. This flood situation is treated as the same as "current". (See entry 1 above.)

Appendix 3 –Shoreline Protection Costs and Benefits Analysis by Scenario

(1) Western Zone shoreline protection scenarios.

	WNZ (West)									
	Scenario A1. Mangroves enhancement ($'000)				Scenario A2. Earthen dyke with rock sides ($'000)					
	Benefits	Costs			Benefits	Costs				
Year (2016-2040)	Avoided property damage	buy back "setbacks"	Total	Net Benefit	Avoided property damage	Dyke construction	purchasing land for building	Dyke maintanence	Total	Net Benefit (lower restoration cost)
1	$ 12,214	$215,458	$215,458	$ (203,245)	$ 24,129	$ 426	$ 27,509	$ -	$27,935	$ (3,806)
2	$ 12,214	$ -	$ -	$ 12,214	$ 21,161	$ -	$ -	$ 9	$ 9	$ 21,153
3	$ 12,214	$ -	$ -	$ 12,214	$ 18,558	$ -	$ -	$ 9	$ 9	$ 18,550
4	$ 16,386	$ -	$ -	$ 16,386	$ 15,055	$ -	$ -	$ 9	$ 9	$ 15,047
5	$ 21,985	$ -	$ -	$ 21,985	$ 12,214	$ -	$ -	$ 9	$ 9	$ 12,205
6	$ 23,910	$ -	$ -	$ 23,910	$ 11,596	$ -	$ -	$ 9	$ 9	$ 11,587
7	$ 26,005	$ -	$ -	$ 26,005	$ 11,009	$ -	$ -	$ 9	$ 9	$ 11,001
8	$ 28,283	$ -	$ -	$ 28,283	$ 10,453	$ -	$ -	$ 9	$ 9	$ 10,444
9	$ 30,760	$ -	$ -	$ 30,760	$ 9,924	$ -	$ -	$ 9	$ 9	$ 9,915
10	$ 33,455	$ -	$ -	$ 33,455	$ 9,422	$ -	$ -	$ 9	$ 9	$ 9,413
11	$ 33,658	$ -	$ -	$ 33,658	$ 2,901	$ -	$ -	$ 9	$ 9	$ 2,893
12	$ 33,863	$ -	$ -	$ 33,863	$ 893	$ -	$ -	$ 9	$ 9	$ 885
13	$ 34,069	$ -	$ -	$ 34,069	$ 275	$ -	$ -	$ 9	$ 9	$ 267
14	$ 34,276	$ -	$ -	$ 34,276	$ 85	$ -	$ -	$ 9	$ 9	$ 76
15	$ 34,485	$ -	$ -	$ 34,485	$ 26	$ -	$ -	$ 9	$ 9	$ 18
16	$ 34,695	$ -	$ -	$ 34,695	$ 8	$ -	$ -	$ 9	$ 9	$ (0)
17	$ 34,906	$ -	$ -	$ 34,906	$ 2	$ -	$ -	$ 9	$ 9	$ (6)
18	$ 35,118	$ -	$ -	$ 35,118	$ 1	$ -	$ -	$ 9	$ 9	$ (8)
19	$ 35,332	$ -	$ -	$ 35,332	$ 0	$ -	$ -	$ 9	$ 9	$ (8)
20	$ 35,547	$ -	$ -	$ 35,547	$ 0	$ -	$ -	$ 9	$ 9	$ (8)
21	$ 35,763	$ -	$ -	$ 35,763	$ 0	$ -	$ -	$ 9	$ 9	$ (9)
22	$ 35,980	$ -	$ -	$ 35,980	$ 0	$ -	$ -	$ 9	$ 9	$ (9)
23	$ 36,199	$ -	$ -	$ 36,199	$ 0	$ -	$ -	$ 9	$ 9	$ (9)
24	$ 36,419	$ -	$ -	$ 36,419	$ 0	$ -	$ -	$ 9	$ 9	$ (9)
25	$ 36,641	$ -	$ -	$ 36,641	$ 0	$ -	$ -	$ 9	$ 9	$ (9)
PV (3%)	$ 505,784		$215,458	$ **290,326**	$ 132,653				$28,079	$ **104,574**
PV (7%)	$ 325,262		$215,458	$ **109,804**	$ 116,808				$28,033	$ **88,775**

(2) Kleidam shoreline protection scenarios.

	Kleidam (Center)										
	Scenario B1. Mangroves enhancement ($'000)				Scenario B2. Earthen dyke with rock sides ($'000)						
	Benefits	Costs			Benefits	Costs					Net Benefit
Year (2016-2040)	Avoided proporty damage	buy back "setbacks"	Total	Net Benefit	Avoided proporty damage	Dyke construction	purchasing land for building dykes	Dyke maintanence	Mangroves removal	Total	(lower restoration cost)
1	$ 10,994	$ 88,898	$ 88,898	$ (77,905)	$ 15,748	$ 325	$ 18,621	$ -	-	$ 18,946	$ (3,198)
2	$ 11,536	$ -	$ -	$ 11,536	$ 13,489	$ -	$ -	$ 7	$ -	$ 7	$ 13,482
3	$ 12,105	$ -	$ -	$ 12,105	$ 11,554	$ -	$ -	$ 7	$ -	$ 7	$ 11,547
4	$ 12,633	$ -	$ -	$ 12,633	$ 10,007	$ -	$ -	$ 7	$ -	$ 7	$ 10,001
5	$ 13,184	$ -	$ -	$ 13,184	$ 8,668	$ -	$ -	$ 7	$ -	$ 7	$ 8,661
6	$ 13,387	$ -	$ -	$ 13,387	$ 6,947	$ -	$ -	$ 7	$ -	$ 7	$ 6,941
7	$ 13,593	$ -	$ -	$ 13,593	$ 5,568	$ -	$ -	$ 7	$ -	$ 7	$ 5,562
8	$ 13,803	$ -	$ -	$ 13,803	$ 4,463	$ -	$ -	$ 7	$ -	$ 7	$ 4,456
9	$ 14,016	$ -	$ -	$ 14,016	$ 3,577	$ -	$ -	$ 7	$ -	$ 7	$ 3,571
10	$ 14,232	$ -	$ -	$ 14,232	$ 1,192	$ -	$ -	$ 7	$ -	$ 7	$ 1,186
11	$ 14,232	$ -	$ -	$ 14,232	$ 397	$ -	$ -	$ 7	$ -	$ 7	$ 391
12	$ 14,232	$ -	$ -	$ 14,232	$ 133	$ -	$ -	$ 7	$ -	$ 7	$ 126
13	$ 14,232	$ -	$ -	$ 14,232	$ 44	$ -	$ -	$ 7	$ -	$ 7	$ 38
14	$ 14,232	$ -	$ -	$ 14,232	$ 15	$ -	$ -	$ 7	$ -	$ 7	$ 8
15	$ 14,232	$ -	$ -	$ 14,232	$ 5	$ -	$ -	$ 7	$ -	$ 7	$ (2)
16	$ 14,232	$ -	$ -	$ 14,232	$ 2	$ -	$ -	$ 7	$ -	$ 7	$ (5)
17	$ 14,232	$ -	$ -	$ 14,232	$ 1	$ -	$ -	$ 7	$ -	$ 7	$ (6)
18	$ 14,232	$ -	$ -	$ 14,232	$ 0	$ -	$ -	$ 7	$ -	$ 7	$ (6)
19	$ 14,232	$ -	$ -	$ 14,232	$ 0	$ -	$ -	$ 7	$ -	$ 7	$ (6)
20	$ 14,232	$ -	$ -	$ 14,232	$ 0	$ -	$ -	$ 7	$ -	$ 7	$ (6)
21	$ 14,232	$ -	$ -	$ 14,232	$ 0	$ -	$ -	$ 7	$ -	$ 7	$ (6)
22	$ 14,232	$ -	$ -	$ 14,232	$ 0	$ -	$ -	$ 7	$ -	$ 7	$ (6)
23	$ 14,232	$ -	$ -	$ 14,232	$ 0	$ -	$ -	$ 7	$ -	$ 7	$ (6)
24	$ 14,232	$ -	$ -	$ 14,232	$ 0	$ -	$ -	$ 7	$ -	$ 7	$ (7)
25	$ 14,232	$ -	$ -	$ 14,232	$ 0	$ -	$ -	$ 7	$ -	$ 7	$ (7)
PV (3%)	$ 243,219		$ 88,898	**$ 154,320**	$ 75,053					$ 19,056	**$ 55,997**
PV (7%)	$ 166,321		$ 88,898	**$ 77,423**	$ 67,694					$ 19,021	**$ 48,673**

(3) shoreline protection scenario in Riverdijke area

	Riverdijke (East)					
	Scenario C1. Concrete sea wall ($'000)					
	Benefits	Costs				
Year (2016-2040)	Avoided property damage	Dyke construction	purchasing land for building dykes	Dyke maintanence	Total	Net Benefit
1	$ 92,796	$ 8,498	$ -	$ -	$ 8,498	$ 84,299
2	$ 87,793	$ -	$ -	$ 170	$ 170	$ 87,623
3	$ 83,060	$ -	$ -	$ 170	$ 170	$ 82,890
4	$ 77,689	$ -	$ -	$ 170	$ 170	$ 77,519
5	$ 72,664	$ -	$ -	$ 170	$ 170	$ 72,494
6	$ 70,289	$ -	$ -	$ 170	$ 170	$ 70,119
7	$ 67,991	$ -	$ -	$ 170	$ 170	$ 67,821
8	$ 65,768	$ -	$ -	$ 170	$ 170	$ 65,598
9	$ 63,618	$ -	$ -	$ 170	$ 170	$ 63,448
10	$ 61,539	$ -	$ -	$ 170	$ 170	$ 61,369
11	$ 61,539	$ -	$ -	$ 170	$ 170	$ 61,369
12	$ 61,539	$ -	$ -	$ 170	$ 170	$ 61,369
13	$ 61,539	$ -	$ -	$ 170	$ 170	$ 61,369
14	$ 61,539	$ -	$ -	$ 170	$ 170	$ 61,369
15	$ 61,539	$ -	$ -	$ 170	$ 170	$ 61,369
16	$ 61,539	$ -	$ -	$ 170	$ 170	$ 61,369
17	$ 61,539	$ -	$ -	$ 170	$ 170	$ 61,369
18	$ 61,539	$ -	$ -	$ 170	$ 170	$ 61,369
19	$ 61,539	$ -	$ -	$ 170	$ 170	$ 61,369
20	$ 61,539	$ -	$ -	$ 170	$ 170	$ 61,369
21	$ 61,539	$ -	$ -	$ 170	$ 170	$ 61,369
22	$ 61,539	$ -	$ -	$ 170	$ 170	$ 61,369
23	$ 61,539	$ -	$ -	$ 170	$ 170	$ 61,369
24	$ 61,539	$ -	$ -	$ 170	$ 170	$ 61,369
25	$ 61,539	$ -	$ -	$ 170	$ 170	$ 61,369
PV (3%)	$1,223,459				$11,376	$ 1,212,084
PV (7%)	$ 877,992				$10,447	$ 867,545