ADAPTATION OPTIONS FOR COASTAL AREAS AND INFRASTRUCTURE: AN ANALYSIS FOR 2030

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Executive Summary

This report explores what is a very difficult question to answer "what are the financial needs for coastal adaptation in 2030 given climate change?" Hence the results are a preliminary first estimate of the possible needs and show that significant further analysis of the topic is necessary.

In terms of climate change, the impacts of sea-level rise is the climate driver that is analysed, and enhanced storm impacts would exacerbate the adaptation investment needs above those estimated in this report. The methods use the DIVA global impact and adaptation model to explore selected impacts (land loss costs, coastal flood costs and number of people flooded) and the costs of two adaptation policies (beach nourishment and sea dike construction). These are applied in a standard way around all the world's coasts using benefit-cost criteria. Following several earlier analyses, DIVA suggests that adaptation would be widely applied based on this decision making approach, and the actual damages of sea-level rise will be much lower than the potential damages of sea-level rise, ignoring adaptation. The resulting adaptation costs are interpreted in a broad sense based on information on current investment in coastal adaptation and expert knowledge on the level of preparation for sea-level rise and climate change.

Two scenarios of sea-level rise are considered: a business-as-usual scenario (the SRES A1B scenario) and a surrogate mitigation scenario (the SRES B1 scenario). Both the mean change and the maximum rise in sea level in 2030 are considered, as well as different attitudes to proactive adaptation in terms of anticipating future sea-level rise in additional sea dike height. The costs of anticipating sea-level rise reduce the long-term costs of response, but this requires additional investment in 2030, and anticipation time scales of 0, 50 and 100 years are considered assuming the maximum rise in sea level as the design scenario. With a scenario of no global-mean sea-level rise, this gives a total of 9 climate/adaptation scenarios.

The major conclusion is that it is hard to distinguish the two climate scenarios in 2030 in terms of impacts or adaptation costs, assuming comparable assumptions on adaptation. Under both climate scenarios there is a significant need to adapt to sea-level rise and climate change around the world's coasts independent of climate policy. Flooding dominates both the adaptation costs (of dikes) and the damages due to the residual risk. Sea-level rise does not have a large effect on damages – the main effect is an increased investment in adaptation. Compared to the situation of no sea-level rise, investment in nourishment could increase 5 times, while investment in dikes would grow 2.6 to 2.9 times if a long-term (100 year) view of upgrade is considered. In DIVA, the costs of proactive adaptation are up to 37% greater than reactive adaptation, but in practise, a proactive strategic approach will almost certainly be cheaper, especially in the longer term. While the absolute investments estimated by DIVA are large, at up to $22 billion per year, they are sums that present investment in coastal adaptation suggests could be feasibly mobilised if desired.

Putting these results in context, it is not clear that all the investments that DIVA suggests are prudent are being made, even under today's conditions. Thus, the barriers to adaptation need to be considered. Clearly, a wider range of adaptation options will be considered that may lead to successful adaptation strategies that cost less than the costs estimated by DIVA. However, realising these benefits will require long-term strategic planning and more integration across coastal planning and management. Few if any countries have this capacity today and an enhancement of institutional capacity towards integrated coastal management would seem prudent for climate change (as well as realising benefits for non-climate issues). While all countries need to develop and enhance such capacity, the need is greater in poorer countries, with small islands, populated deltaic areas, and Africa's coast having some of the greatest challenges. In these areas, the need to capacity development of coastal management institutions linked to disaster preparedness is largest, and this is an important issue for aid.

1. Introduction to the topic with a brief discussion of methodology and limitations. (The methodology should describe which sources are used for the data collection and how the analyses are conducted.)

The goal of this report is to estimate the total investment in adaptation options for coastal areas and infrastructure during the year 2030 (see Appendix 1 for more detailed terms of reference). In making this assessment, the adaptation being implemented in 2030 is assumed to be "smart" and anticipatory. Hence the estimates of investment need to reflect the required additional freeboard in the design of adaptation infrastructure to some time beyond 2030. For coastal defence structures the design life can be significant, being at least 50 years, and as long as 100 years in some cases (example, DEFRA, 2006a; DCLG, 2006). The growing moves to proactive adaptation planning for climate change suggest that such a long perspective will increase significantly during the early 21st Century. Hence, expectation of sea-level rise as far as 2130 might influence investment needs in 2030. This important issue is developed below.

Two climate scenarios are explored, which reflect two contrasting pathways for climate policy:

- A Business-as-Usual (BAU) world with no climate policy based on the SRES A1B emissions scenario;
- A Mitigation Scenario with reductions in greenhouse emissions compared to the A1B scenario. In the absence of a SRES-based mitigation scenario, the SRES B1 scenario is used as a surrogate mitigation scenario (arguably equivalent to stabilisation at 550 ppm CO_2 (see Swart et al., 2002).

The socio-economic development pathway (which is specified in broad terms by the SRES scenarios) will also influence impacts and adaptation investment, independent of the magnitude of climate change, although the differences will probably be quite small by 2030 (Nicholls, 2004; Nicholls and Tol, 2006). In particular, the A1 and B1 population scenarios are identical, and the GDP scenarios are very similar in 2030 (Arnell et al., 2004). Hence, A1B socio-economic scenarios are considered and the differences between the results provided in this report are entirely due to differences in the magnitude of sea-level rise and differences in the assumptions concerning how adaptation is applied.

The methods use the DIVA global impact and adaptation model to explore selected impacts (land loss costs, coastal flood costs and number of people flooded) and the costs of two adaptation policies (beach nourishment and sea dike construction). These are applied uniformly around all the world's coasts with the adaptation using benefit-cost criteria. The resulting adaptation costs are interpreted in a broad sense based on information on current investment in coastal adaptation and expert knowledge on the level of preparation for sea-level rise and climate change.

The quantitative analysis uses the Dynamic Interactive Vulnerability Analysis (DIVA) tool for this analysis (DINAS-COAST Consortium, 2006; Hinkel and Klein, 2007; Nicholls et al., 2007a). DIVA comprises a dedicated global database on the world's coasts and a series of linked modules which describe the impacts and adaptation responses to sea-level rise for user prescribed sea-level rise and socio-economic scenarios and adaptation responses. In this analysis the model uses benefit-cost analysis to look at the choice between protect and retreat for coastal flooding (related to the threatened GDP) and beach erosion (related to the tourism value). It is a substantial improvement on earlier analyses such as Fankhauser (1995) and Nicholls and Tol (2006), but still has important limitations as discussed below. The investments are reported in constant USD for the year 1995. The results are considered in terms of the current financing of coastal adaptation, and the increases that the DIVA simulations suggest are required.

The strength of the results is that a self-consistent view of the impacts and adaptation costs is developed. The results are provided globally, for the national scale and at aggregated regions and as a reference case, impacts and costs are provided for no global-mean sea-level rise. In this regard, the results are unique and the DIVA tool is only just beginning to be exploited in climate policy analyses.

In terms of limitations, the DIVA (and all earlier global model) results are only considering a sub-set of the possible responses to sea-level rise. Adaptation is most easy to analyse at the local scale, and becomes increasingly difficult to consider at regional to global scales. To overcome this problem, DIVA follows all previous global analyses, and explores uniform adaptation responses for consistency (although in this regard DIVA is considering more adaptation choices than any previous analysis). While these adaptation responses are caricatures of the potential responses, they provide meaningful costings of the potential responses for that adaptation choice. Superficially, it might be assumed that the methodology lends itself to a bias towards richer countries having a higher cost benefit ratio. However, it has been found that coastal areas are so valuable, even in developing countries that widespread protection responses appear rational under benefit-cost analysis (Nicholls and Tol, 2006). This is true for the DIVA results presented here.

Integrated Coastal Zone Management (ICZM) is often presented as an integral part of the response to sea-level rise and climate change. A coastal management process is required to deliver adaptation measures such as dikes and beach nourishment, and wider disaster preparedness and planning, and integration will enhance its effectiveness. Therefore, developing capacity in coastal management is an important requirement for successful coastal adaptation to climate change, especially in poorer countries. However, the costs of accomplishing this goal are difficult to determine. As the financial costs of coastal management are generally small compared to the dike construction and beach management costs provided by DIVA, they are only considered in terms of capacity enhancement. (It should also be noted that ICZM is required without climate change, as climate change is just one of the multiple stresses that the world's coasts face so the costs of developing ICZM should not be seen as solely a climate change cost.)

The report is structured as follows. First sea-level rise, climate change and the coast are introduced. Then the current financial arrangements for coastal adaptation are considered. Then the A1B and B1 scenarios used in the analysis are considered in detail. The next sections consider the impacts and adaptation needs in the each case, and the financial implications of these results are considered.

2. Sea-Level Rise, Climate Change and The Coast

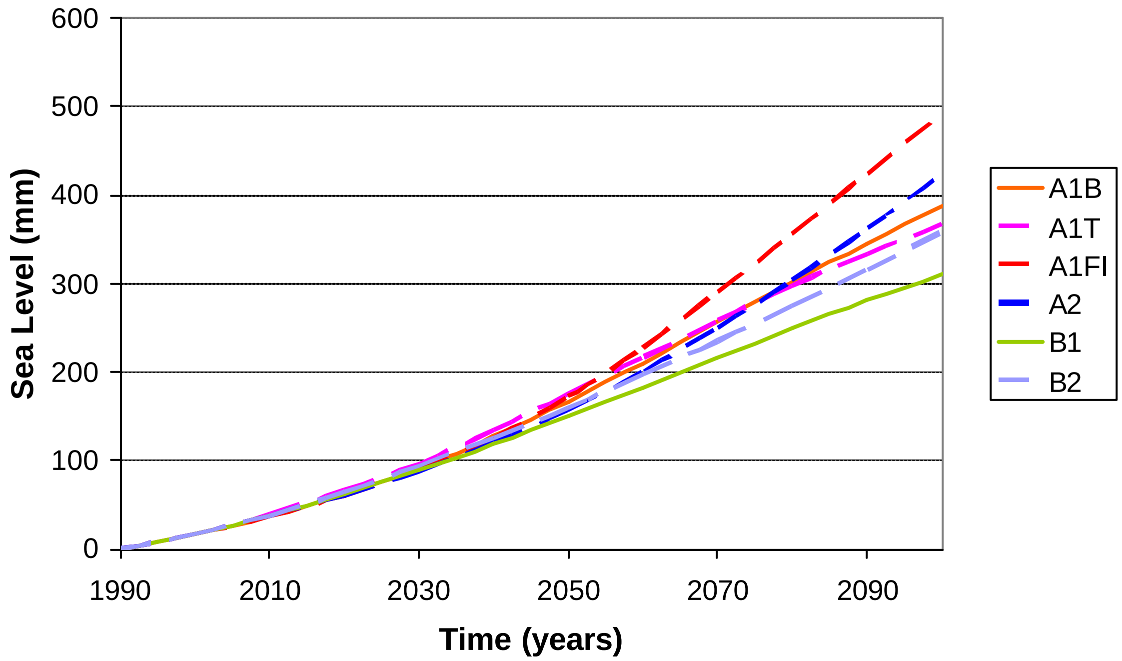
2.1 Sea-level rise scenarios

One of the more certain impacts of human-induced climate change is a global-mean rise in sea level (example, Church et al, 2001; IPCC, 2007). While the resulting impacts and adaptation needs are confined to coastal areas, these are the most densely populated land areas on earth and they support important and productive ecosystems that are sensitive to sea-level change (Nicholls et al., 2007b; McGranahan et al., 2007; Dasgupta et al., 2007).

During the 20th Century, global-mean sea-level rise occurred at a rate of 1.7 mm per year (or 17 cm per century), with an increase in this rate of rise during this period (Church and White, 2006). From 1993 to the end of 2006, near global measurements of sea level (between 65° N and 65° S) completed using high quality satellite altimeters indicate global average sea level has been rising at 3.1 ± 0.4 mm per year (or 31 cm per century) (Nerem et al. 2006) (see also IPCC, 2007). The observations are still too short to be clear if this is a variation around the long-term trend or a systematic acceleration due to global warming.

In the 21st Century, global-mean sea-level rise is expected to accelerate based on models of thermal expansion and ice sheet response to global warming (Church et al., 2001; IPCC, 2007). In the first half of the 20th Century, the magnitude of the rise appears almost insensitive to the emissions scenario considered (Figure 1), reflecting that we are already committed to significant rises in sea level. Looking beyond 2050, the magnitude of sea-level rise becomes more sensitive to the emissions scenario selected, and hence climate policy can influence these future changes, especially beyond 2100 (Nicholls and Lowe, 2006).

Figure 1. Mean sea-level rise scenarios from 1990 to 2100 for each of the SRES emissions scenarios as reported in the IPCC Third Assessment Report. The A1B and B1 scenarios are emphasized. Data source: Appendix II.5: Sea Level Change (mm) In: Houghton et al (2001).



The fact that the scenarios for 2030 are common means that the impacts of sea-level rise and the adaptation costs to avoid them in 2030 will be indistinguishable for the BAU and mitigation scenarios defined above. However, coastal defences have a long life of at least 50 years, and up to 100 years (example, Eurosion, 2004; DEFRA, 2006a). Many major coastal adaptation projects such as storm surge barriers also take several decades to implement, as discussed by Nicholls (2004). Therefore, when we consider "smart" and anticipatory adaptation, expectations about sea-level rise after 2030 will have a significant influence on adaptation costs during 2030. The extent of this influence, will depend upon on the planning timescale that is considered. A 50-year life for defence structures is considered quite normal, and a longer life of up to 100 years are reasonable. To explore this effect, defence lives of 50 to 100 years are considered in this report, so that the reader can see these effects.

2.2 Impacts and Adaptation Responses

Relative sea-level rise has a wide range of physical impacts (Table 1). In addition to raising mean sea level, all the coastal processes that operate around sea level are raised. Therefore, the immediate effect is submergence and increased flooding of coastal land, as well as saltwater intrusion of surface waters. Longer-term effects also occur as the coast adjusts to the new environmental conditions, including increased erosion and saltwater intrusion into groundwater. These lagged changes interact with the immediate effects of sea-level rise and often exacerbate them. For instance, coastal erosion will generally increase coastal flood risk as it degrades natural buffers and barriers such as coastal marshes and dunes.

Table 1. Major physical impacts and potential adaptation responses to sea-level rise. Protection, Accommodation and Retreat are discussed below (adapted from Nicholls and Tol, 2006).

Physical Impacts		Examples of Adaptation Responses (P – Protection; A – Accommodation; R – Retreat)
1. Inundation, flood and storm damage	a. Surge (sea) b. Backwater effect (river)	Dikes/surge barriers (P) Building codes/floodwise buildings (A) Land use planning/hazard delineation (A/R)
2. Wetland loss (and change)		Land use planning (A/R) Managed realignment/ forbid hard defences (R) Nourishment/sediment management (P)
3. Erosion (direct and indirect change)		Coast defences (P) Nourishment (P) Building setbacks (R)
4. Saltwater Intrusion	a. Surface Waters	Saltwater intrusion barriers (P) Change water abstraction (A)
	b. Groundwater	Freshwater injection (P) Change water abstraction (A)
5. Rising water tables and impeded drainage		Upgrade drainage systems (P) Polders (P) Change land use (A) Land use planning/hazard delineation (A/R)

Table 2 links natural system effects to their most important direct socio-economic impacts by sector. There are also a range of additional indirect impacts (example, human health) that are not shown. Thus, sea-level rise has the potential to produce a cascade of impacts through the socio-economic system. The uncertainties about the actual socio-economic impacts are also large, as they will depend on the magnitude of natural system change and our ability to adapt, which is now discussed.

Table 2. The more significant *direct* socio-economic impacts of relative sea-level rise on different sectors in coastal zones, including uncertain cases (adapted from Nicholls, 2002).

	Physical Impact (from Table 1)						
	Inundation, flood and storm damage				Saltwater Intrusion		
SECT0R	Surge	Backwater Effect	Wetland loss	Erosion	Surface	Ground	Rising water tables/ drainage
Water Resources	?				?	?	
Agriculture	?	?			?	?	?
Human Health	?	?			?	?	
Fisheries	?	?	?		?		
Tourism	?		?	?	?		
Human Settlements	?	?		?	?	?	?
Coastal Biodiversity	?	?	?	?	?	?	?

For coastal zones, there are numerous adaptation strategies available and these can be classified in a variety of ways (Nicholls and Klein, 2005; Nicholls et al., 2007c). One approach which has been widely adopted was proposed by IPCC CZMS (1990) and subsequently elaborated Klein *et al.* (2001):

- Protect — to reduce the risk of the event by decreasing the probability of its occurrence;
- Accommodate — to increase society's ability to cope with the effects of the event;
- Retreat — to reduce the risk of the event by limiting its potential effects.

While each of these strategies is designed to protect human use of the coastal zone, if applied appropriately, they have different consequences for coastal ecosystems. Retreat and accommodation avoid "coastal squeeze" between fixed defences and rising sea levels, as onshore migration of coastal ecosystems is not hindered. In contrast, protection will lead to a coastal squeeze, although this can be minimised using soft approaches to defence such as beach nourishment and sediment re-cycling. In terms of timing, accommodate and retreat are best implemented in a proactive manner, while protection can be implemented in a proactive or reactive manner. Table 1 lists some examples of the adaptation responses that are appropriate to each physical impact. It is apparent that there are a diverse range of adaptation options available for coastal areas, and many more measures are described by Klein et al. (2001).

These adaptation measures are all potential elements of an integrated coastal management approach, with each being appropriate in different settings. The approaches are not incompatible and areas that are protected may buy insurance as an accommodation strategy to manage the residual risk represented by defence failure. Specific methods to achieve these three adaptation approaches in coastal areas are elaborated by Klein et al (2000; 2001). There is already significant experience with a wide range of coastal adaptation technologies and methods, most especially protection via hard and soft methods. However, coastal adaptation interventions are evolving rapidly including a move from hard technologies such as dikes, to a much wider portfolio of methods including softer measures and living with coastal dynamics (example., Klein et al., 2001).

3. An overview of c urrent source of financing for dealing with current impacts identified. (example, what is available for adaptation, including implicit and explicit sources, now that a great deal of activities not intended to cover adaptation do actually contribute to it)

The goal of this section is develop estimates of the finance that is available for planned coastal adaptation to today's hazards, as a benchmark for future investments needs for climate change. Increasingly the world's coasts are 'engineered' and modified directly or indirectly by human agency. In some limited cases, present adaptation investment includes anticipating climate change, but in general this is not yet the case (example, Tol et al., 2007). Some of the limited cases of anticipatory adaptation are highlighted below. Even without climate change, growing populations and economic wealth in coastal areas suggests that investment in coastal adaptation would continue through the 21st Century. Therefore, substantial financial resources are availa ble to be tapped when considering the needs of coastal adaptation to climate change.

Unlike adaptation in many other sectors, many coastal adaptation measures usually represent a collective government-lead activity, reflecting that the coast is a shared resource (Klein et al., 2000). Hence while some adaptation will need to be funded by private investment (e.g. harbour upgrade), much of the finance costs falls on government funding. However, individual adaptation measures are also apparent. Insurance is a mechamism that helps private individuals gain resources to recover from disaster such as coastal flooding and is potential an important response mechanism (Clarke, 1998; Grossi and Muir Wood, 2006). The availability of appropriate insurance varies greatly between coastal countries – it is unavailable in many developing countries, and in mainland Europe (as the government is the insurer of last resort), while in the UK and USA it is the norm.

While there is significant interest in elaborating coastal adaptation measures and understanding their costs (example, UNFCCC, 1999; Klein et al., 2001; Bosello et al., 2007), hard numbers on investment in coastal adaptation are hard to identify as there is never a single "Ministry for Coastal Adaptation" with published accounts in any country. The reality is that coastal adaptation costs fall between government and the private sector, and different ministries are responsible for different aspects of the coastal adaptation process. For instance, in England and Wales, the major investment in coastal adaptation is in flood and erosion management, but the budget covers all flood and erosion management: i.e. flood management of all flood mechanisms, including inland flooding. Integrated coastal management in England and Wales is covered by a separated budget, and this investment is quite small compared to that invested in flood and erosion management.

In the 20th Century, most investment in adaptation was in hard protection, with major investments in Europe and East Asia (example, Eurosion, 2004; Li et al., 2004). Subsiding coastal megacities in Asia have been particular areas of investment in protection, including Tokyo, Osaka, Tianjin, Shanghai and Bangkok (Nicholls, 1995). This will need to continue as the risks of flooding due to global sea-level rise will continue to be compounded by ongoing subsidence. However, in the last few decades, there has been rapidly growing investment in soft protection, most especially in wealthy OECD countries where the beach provides multiple protection, recreational and environmental functions (example, Klein et al., 2001; Hansen et al., 2002; Hanson, 2003). Accommodation approaches have been developed with programmes such as the U.S. National Flood Insurance Program (NFIP), which provides flood insurance. To obtain this flood insurance, participating communities must adopt building standards which are sufficient to 'accommodate' a 100-year flood, including flood plains in coastal areas. Rising sea levels and associated coastal erosion exacerbate those risks over time (example, FEMA, 1991). Retreat is being increasingly applied on eroding coasts via building setbacks (example, McLean et al., 2001). For coastal flood plains, retreat is less developed with most application in northern Europe and in parts of the USA, especially around San Francisco Bay (example, Rupp and Nicholls, 2007). The costs of these measures are not systematically recorded. In general terms, it is much easier to cost protection than accommodation and retreat.

As there are no consolidated accounts of adaptation costs, examples of recent estimates of funding are presented as developed from the literature and personal contacts. Both national/regional and major project/event adaptation costs are included to illustrate the available information.

1. National/Regional Estimates

- European Union. The Eurosion (2004) review reported that the total annual cost of coastal adaptation for erosion and flooding across the European Union was an estimated 3,200 million euros (in 2001). These measures mainly comprised protection. The breakdown of the numbers by nation or by adaptation activity is not readily apparent, but independent national estimates for the UK and the Netherlands are provided below.
- UK. The Flood and Coastal Management budget has increased substantially since 2000/01 from of order £300 million to more than £500 million per annum in 2005/06, and now following the 2007 floods, £800 million per annum from 2009/10. However, coastal investment is not directly defined and is only one element of this

budget and is estimated to be about half the investment at £250 million per annum. The storm tide warning warning service is an important element of coastal management and defence as operationally it provides estimates of extreme water levels that are used to close storm surge barriers and issue evacuation orders if defences are going to fail. Costs of running this service are difficult to estimate but are small compared to the above budget, and are estimated at <£10 million per annum.

- Japan – based on information from the Ministry of Public Works (Mimura, personal communication), the annual budget for coasts including coastal protection against storm surges, high waves and beach erosion, and improvement of coastal environment were:

(year)	(budget in billion yen in the stated years prices)
2003	146.5
2004	133.3
2005	122.0
2006	117.6

  Gradual decreases in spending are due to strong control of national budget by the government. These do not include adaptation to climate change and only consider present natural hazards.
- Netherlands. This is the archetypal country threatened by sea-level rise and it invests large sums in erosion and flood management. However, in proportion to the economy they are relatively small and amount to 0.1 to 0.2 per cent of GDP at present, which is estimated at US $600 to $1,200 million (in 2006 prices)
- Bangladesh has experienced the highest death toll from coastal flooding of any country on earth (Nicholls, 2006), and is a good example of a vulnerable deltaic country. Following the 1970 and 1991 cyclones, when at least 400,000 people died, an accommodation strategy was implemented via a system of flood warnings and the construction of more than 2,500 elevated storm surge shelters (http://banglapedia.search.com.bd/HT/C_0397.htm). Despite recent severe storms, the death toll for people (and their animals via associated raised shelters) has fallen markedly. As these projects are carried out by a wide range of organisations, costings have been hard to obtain.
- The Maldives are a good example of a vulnerable atoll nation where sea-level rise could literally extinguish the nation over the coming century without adaptation. However, adaptation is occurring on the island and based on Shifaz (personal communication) the following technical and financial information is available. After a significant southern ocean swell event which flooded much of the capital Male in the 1980s (Pernetta, 1992), a large one-off seawall was built around the city by the Japanese government under a grant aid scheme. The total cost was USD 48 million and the wall was completed in 2002. No other islands fully protected like the capital. More recently after the Indian Ocean Tsunami of 2004 there has been interest in developing tsunami shelters, which may also have a function against climate change. Rough figures for coastal adaptation (for the last 3 years) provided by the Ministry of Environment are: (1) 2005 about 500,000 USD, (2) 2006 about 1 million USD, and (3) 2007 approximately 3 million USD. Most of this coastal adaptation was erosion protection rather than flood defense. The rise in expenditure reflects both concern about climate change and the experience of the Indian Ocean 2004 tsunami. Post-tsunami projects called ”Safe Island ” Projects are also under way. This involves the selected island being increased in size by reclamation with revetments constructed around the island, and also constructing areas of high ground constructed. One project (the Vilifushi project) has been completed so far, and four more such projects are in the tender stage. The cost of reclamation and coastal protection including

harbor works for the Vilifushi project is about USD 22.8 million: these costs are in addition to the annual amounts above.

2. *Major Project/Event Estimates*

- Venice subsided due to groundwater pumping during the 20th Century and also experienced a small rise in sea level in the Mediterranean of probably about 10 cm – this greatly increased the frequency of flooding in the city. The MoSE Project is constructing three inlet gates to the Venice lagoon to stop flooding of Venice at a cost of roughly 4,000 million euros. Smaller scale works to raise the ground levels and provide one-way valves around the edge of Venice are also occurring so that gate closures are only required for significant events in the Adriatic. It is a controversial response to the flooding as there is significant debate about how much sea-level rise the design can handle.
- St Petersburg is threatened by severe floods due to surges in the Gulf of Finland. The St Petersburg Flood Protection Barrier, Russia was started in the 1980s, and then mothballed while unfinished when the Soviet Union ended due to environmental concerns and lack of money. It requires 440 million euros to be completed, and this is now occurring via a loan of 225 million euros from the European Bank for Reconstruction and Development (http://www.ebrd.com/projects/psd/psd2002/18221.htm). Sea-level rise is not an explicit part of the design, but there is significant freeboard in the design.
- London's Thames Barrier, UK was officially opened on 8 May 1984 about 30 years after the 1953 North Sea floods that triggered the effort to improve London's flood defences. Total construction cost was around £534 m (£1.3 billion at 2001 prices) with an additional £100 m for upgrade of defences downstream of the Barrier along the Thames estuary. The Barrier will reach the end of its design life around 2030 (Gilbert and Horner, 1984; Lavery and Donovan, 2005), and presently, the Thames Estuary 2100 Project is investing £15 million on appraising the options for extending the life of the existing Barrier to 2100, or other options such as building a completely new downstream Barrier (Ramsbottom and Lavery, 2007). While nothing has been decided, costs of £4 to £6 billion have been mentioned for upgrade, while £10 to £20 billion has been mentioned for a new downstream barrier. These costs are substantial in relation to national funding available (see above) and a dedicated investment stream will probably be required for these works, as occurred for the construction of the current Barrier.

In general, adaptation investment is only including climate change in a few limited cases (as indicated), with countries such as the UK, Germany, the Netherlands, Poland and Japan preparing most systematically for climate change (example, Tol et al., 2007). In many cases, adaptation to climate change simply requires small changes to existing investments (example, increased freeboard), which can be incorporated within the standard renewal cycle (Bijlsma et al., 1996). The alternative of retrofitting infrastructure often raises costs substantially and is often prohibitively expensive. This shows the benefits of a proactive approach to adaptation.

Some examples of projects where accelerated sea-level rise has been included in the project design, although the additional costs are generally not known (Nicholls and Leatherman, 1995; Smith et al., 1998):

- The Prince Edward Island bridge was raised 1-m throughout its length to allow for sea-level rise.
- The design of a water treatment works on an island in Boston was raised 0.46m so that discharges could continue given this amount of sea-level rise under gravity without resorting to pumped drainage. (Originally, they were going to lower the island to lower pumping costs, but they abandoned this idea when they considered

sea-level rise, so construction costs were actually reduced, but running costs were raised.

- New land reclamations in Hong Kong have been raised 0.8 m to allow for sea-level rise – as old reclamations are redeveloped, it is proposed to consider raising them for sea-level rise as well.
- New defences in England and Wales, the Netherlands and Japan must include an additional allowance for sea-level rise. The allowance in England and Wales has just been extended to 100 years as outlined in DEFRA (2006b) guidance. (In general this is an extension of existing practise which was to include observed secular sea-level rise trends as measured with long-term tide gauges or other observational methods in engineering design. For instance, the Thames Barrier allowed 50 cm additional freeboard for rising extreme water levels based on trends in historic measurements at London Bridge (Gilbert and Horner, 1984), long before there were any concerns about human-induced global warming.

In areas subject to settlement allowances for settlement (or relative sea-level rise) have also been included for long periods, and this approach is easily modified and extended to deal with global climate change,

4. Sea-Level Rise and Socio-Economic Scenarios for the Analysis

Sea-level rise scenarios are available from Church et al (2001) based on the Intergovernmental Panel in Climate Change (IPCC) Third Assessment Report (TAR), and the more recent IPCC Fourth Assessment Report (AR4), which has only just been published in summary form (IPCC, 2007). A comparison between the TAR and AR4 by Church et al (2007) shows that the results are very similar when presented in a consistent manner, except for the minimum estimates of the range of uncertainty, which are raised about 10 cm at the end of the 21st Century by AR4. As the AR4 results are not readily available, the analysis has been based on the TAR results. The rise in sea level from 1990 to 2030 is shown in Table 4. As already noted, the results are very similar between SRES scenarios, although there is considerable uncertainty within each scenario. Hence, the impacts under both the mean and maximum rise are considered for the A1B and B1 scenarios.

Table 4. The range in sea-level rise by 2030 (relative to 1990) expected for each SRES scenario (Units: mm). Source: Appendix II.5: Sea Level Change (mm) In: Houghton et al (2001).

	SRES Emissions Scenario					
	A1B	A1T	A1FI	A2	B1	B2
Minimum rise	34	33	36	31	32	34
Mean rise	91	97	90	88	89	94
Maximum rise	153	164	153	149	151	159

For anticipating dike heights, a precautionary approach is to add the maximum rise as additional freeboard in design. As an example, this is current practise in the UK, which has recently updated its design guidance (DEFRA, 2006b). Hence, the figures in Table 5 are those that are appropriate for design purposes. Here design lives of 50 and 100 years are considered to illustrate the effects of different levels of anticipation. Note that in 2080, the difference between the A1B and B1 scenario is only 8 cm, while in 2130 (based on extrapolated data), it is 21 cm (Table 6), reflecting the large inertia of sea-level rise as a climate factor. Note that the A1FI scenario is higher than the A1B scenario, so a conservative planner might plan for A1FI scenario instead of A1B scenario (following DEFRA, 2006b).

The differences between the B1 (mitigation scenario) and the worst-case A1FI scenario is 17 cm in 2080 and 55 cm in 2130, respectively.

Table 5. The maximum rise in sea-level rise expected for each SRES scenario (Units: mm). The values for 2130 have been extrapolated with second order polynomial fits to the trend for the appropriate scenario from 2050 to 2100. Source: Appendix II.5: Sea Level Change (mm) In: Houghton et al (2001).

Year	SRES Emissions Scenario					
	A1B	**A1T**	**A1FI**	**A2**	**B1**	**B2**
1990	0	0	0	0	0	0
2030	153	164	153	149	151	159
2080	527	529	612	526	444	488
2100	694	671	859	743	567	646
2130	960	870	1 300	1 140	750	910

Table 6. The difference in the maximum rise in sea level expected for the A1B and B1 SRES scenarios (Units in mm).

	A1B	B1	Difference
1990	0	0	0
2030	153	151	2
2080	527	444	83
2100	694	567	127
2130	960	750	210

Beach nourishment is a more flexible adaptation measure than dikes, and there is more scope to pump sand as it is needed, rather than needing long-term anticipation. Hence, only sea-level rise to 2030 is included in nourishment costs.

In 2030, the global population in both the A1 and B1 world's is assumed to be 8.18 billion people. The global GDP is assumed to be US $90,720 billion in the A1 world, and this is applied in all scenarios so the differences in impacts and costs are due to the differences in the sea-level rise scenarios and the approach to adaptation. These scenarios are downscaled to each national or sub-national entity within DIVA (DIVA recognizes approximately 2,000 administrative units with discrete socio-economic data in terms of population and GDP) assuming that all the members of a region behave similarly. In this case, no coastward migration is considered, and coastal population change is uniform.

To fully explore the possible impacts and adaptation costs, the following nine simulation of impacts and costs for 2030 are explored, assuming benefit-cost assessment of protection measures:

- No SLR – Impacts and costs assuming no sea-level rise from 1995 to 2030. This provides a reference case, assuming no human-induced climate change.
- A1B Mean 2030 – Impacts and costs assuming the mean A1B scenario for 2030. No anticipation of sea-level rise is considered in adaptation.
- B1 Mean 2030 – Impacts and costs assuming the mean B1 scenario for 2030. No anticipation of sea-level rise is considered in adaptation.
- A1B Max 2030 – Impacts and costs assuming the maximum A1B scenario for 2030. No anticipation of sea-level rise is considered in adaptation.
- B1 Max 2030 – Impacts and costs assuming the maximum B1 scenario for 2030. No anticipation of sea-level rise is considered in adaptation.

- A1B Max 2080 – Impacts and costs assuming the maximum A1B scenario for 2080. 50 years of anticipation of sea-level rise is considered in adaptation.
- B1 Max 2080 – Impacts and costs assuming the maximum B1 scenario for 2080. 50 years of anticipation of sea-level rise is considered in adaptation.
- A1B Max 2130 – Impacts and costs assuming the maximum A1B scenario for 2130. 100 years of anticipation of sea-level rise is considered in adaptation.
- B1 Max 2130 – Impacts and costs assuming the maximum B1 scenario for 2130. 100 years of anticipation of sea-level rise is considered in adaptation.

In addition, to the reference case, there are four simulations each of the A1B and B1 scenarios. The proactive adaptation assumes that the investment to upgrade the defences to the selected scenario occurs over a 50 year period (occupying the period 2030 to 2080) in all cases.

The following impact and adaptation parameters have been selected as most meaningful for this analysis and are reported in the following sections:

- Beach nourishment costs – the annual investment in pumping sand to maintain beaches against sea-level rise for tourist purposes.
- (Residual) Land loss costs – the annual value of land that is lost due to sea-level rise (after considering the benefits of protection).
- (Residual) People actually flooded – the number of people per year estimated to experience flooding from extreme water levels during storms (after considering the effects of sea dikes).
- Sea dike costs – the annual cost of investment in sea dikes.
- (Residual) Sea flood costs – the annual damages due to sea floods (after considering the effects of sea dikes).

DIVA is outlined in Appendix 2 and the results are summarised for the globe in Appendix 3 and by regions in Appendix 4.

5. Impacts and adaptation needs assuming no climate change (the reference scenario)

The reference scenario has no global sea-level rise, but there is still relative sea-level rise due to uplift and subsidence based on geological processes. This triggers some beach nourishment (but much less than observed today as sea-level rise is only one of the factors driving beach erosions). There is also still flood risk in coastal lowlands due to extreme water levels induced by storms. Following observed changes in societal tolerance of flooding, as people become wealthier, they are willing to pay more to reduce risk. In DIVA this translates into higher optimum dike heights. Hence, the significant growth of the A1 socio-economic scenario implies significant investment without any climate change. Hence there are coastal damages and adaptation with no climate change under benefit-cost analysis.

Global costs are estimated at $10 billion per year in DIVA. In terms of all costs, the costs of flooding dominate, with flood damage being 51% of the costs, and the construction of sea dikes being 45% of total costs. The residual risk of flooding is also illustrated by the estimate that there are 1.2 million people per year who experience flooding due to sea-level rise (note that this is lower than the estimated impacts today despite population growth due to the benefits of the higher dikes).

Regionally, most of the flood damage and the sea dike costs fall in Developing Asia. Compared to the global totals, this is the location of 65% of the flooded people, and 82% of the flood damage. Further, 29% of the investment in sea dikes is occurring in this region.

The overall numbers emerging from DIVA in terms of investment costs under this scenario are about US $5 billion per year. This roughly equals the EU and Japanese estimates of investment as reported in Section 2, and global investment in adaptation is higher than estimated by DIVA. This makes sense as the costs reflect a situation where sea-level rise was rising slowly, and they address issues that are not concerned directly with climate change. So pragmatically, we assume the DIVA costs appear reasonable.

6. Impacts and adaptation needs under BAU (A1B) scenario

Four cases are shown for the A1B scenario, which are all based on benefit-cost analysis. The global summary of the impacts and adaptation costs to sea-level rise under the A1B scenario are given in Appendix 3, while the regional impacts and adaptation costs to sea-level rise are reported in Appendix 4.

Comparing the global results to the reference case, flooding (combined damage and sea dike costs) is the dominant cost, being in the range of 87 to 90% of global costs across the four scenarios. (Note that land loss costs are very low as only low value land is allowed to be lost under the benefit-cost assumptions). Absolute costs of flood damage do increase, but not as substantially as one might expect as under the benefit-cost assumptions, a larger increase in investment in sea dikes is triggered by the global rise in sea level. Globally, annual damage costs increase by up to 27%, while the number of people flooded per year increases by 50%, and the investment is sea dikes grows by 110% (assuming no proactive adaptation -- A1B Max 2030 scenario), or up to 189% (assuming proactive adaptation -- A1B Max 2130 scenario). The greater increase in the number of people compared to damage reflects that the people who are being impacted are preferentially located in poorer countries. Investment in beach nourishment grows up to 5 times the case with no sea-level rise, but at its largest, it is only about 20% of global investment in adaptation to climate change, and 13% of total costs.

The issue of reactive versus proactive adaptation using sea dikes has been emphasised in the report, and this issue is worth exploring in more detail. If no proactive adaptation is assumed, then the investment is 110% above the baseline for the maximum rise scenario (A1B Max 2030 scenario). However, with 50 years and 100 years proactive adaptation, these increases are about 146 and 184%, respectively (A1B Max 2080 and A1B Max 2130 scenarios, respectively). The assumption in this analysis was that the proactive adaptation began in 2030, so the benefits of this investment increase progressively with time and do not have a significant effect on the impacts in 2030. (If we considered the impacts 50 years later in 2080, when the proactive adaptation was complete, the residual risk would be significantly reduced by there investments [add reduction?]). Hence, the magnitude of the impacts depends on the assumptions about adaptation and 2030 costs are highest if we assume proactive adaptation, but in the longer run this approach leads to substantial savings, which exploit the long life of flood defence infrastructure such as sea dikes.

Regionally, at least 65% of the people impacted by flooding are in Developing Asia across all four scenarios. Africa is the second region with at least 13% of the people impacted by flooding across all four scenarios. For sea flood damage, the results are more strongly located in Developing Asia, reflecting the relative poverty of Africa – at least 75% of the damage occurs in this region. Demand for investment in sea dikes is distributed more uniformly across the globe with investment above 10% of the global total for sea dikes in 5 regions: Developing Asia, Latin America, OECD North America, OECD Europe and Africa. Beach nourishment is also spread across the world with investment above 10% of the global total for beach nourishment in 4 regions: OECD North America, Africa, OECD Europe and Developing Asia. The large spending in Africa is driven by growing demand for international tourists, primarily from Europe. In all cases, the relative spending across the regions appears to be largely independent of the adaptation assumptions.

7. Impacts and adaptation needs under mitigation (B1) scenario

Four cases are shown for the B1 scenario, which are all based on benefit-cost analysis. The global summary of the impacts and adaptation costs to sea-level rise under the B1 scenario are given in Appendix 3, while the regional impacts and adaptation costs to sea-level rise are reported in Appendix 4.

In broad terms, the global results are very similar to those described in Section 6 for the BAU scenario as the sea-level rise scenario is very similar in magnitude. This is also true for the regional results.

The major difference is that the investment in sea dikes is reduced as we consider proactive adaptation further into the future. If we compare the A1B Max 2080 and B1 Max 2080 scenarios, investment in dikes is reduced by about USD 800 million/year (or 7% of the A1B Max 2080 investment), while if we compare the A1B Max 2130 and B1 Max 2130 scenarios, investment in dikes is reduced by about USD 1400 million/year (or 10% of the A1B Max 2080 investment). This proportionally small benefit in avoided investment needs illustrates how slowly sea-level rise responds to climate mitigation

8. An estimation of total investment needed for adaptation under the BAU (A1B) scenario.

The investment costs for the four different sea-level rise and adaptation assumption cases under the A1B scenario are shown in Appendix 3 (Global) and Appendix 4 (Regional). The two investment costs are beach nourishment and sea dike costs, with sea dike costs always being at least 80% of the investment – assuming the A1B Max 2130 scenario, this rises to 84% of the investment. Regionally, investment is above 10% of the global total for sea dikes in 5 regions: Developing Asia, Latin America, OECD North America, OECD Europe and Africa. For beach nourishment, investment is above 10% of the global total in 4 regions: OECD North America, Africa, OECD Europe and Developing Asia.

While these do not represent all investment needs (a much more diverse set of adaptation options are likely to be applied in practise) they represent a good benchmark of costs. Absolute costs are estimated at US $9 to $16 billion per year. In practise, a combined precautionary and proactive approach to adaptation is prudent and hence likely to be preferred as countries develop their adaptation policies, so the adaptation costs are more likely to be at the high end of the range. The numbers can also be referenced to the reference case with no sea-level rise to see the increase in investment needs that each case relative to a case with no climate change. This is shown globally in Table 7 and for the regions in Table 8.

Table 7. Percentage increase in global investment needs under the BAU scenario above the reference case (no sea-level rise) for 2030.

Adaptation Measures	A1B mean 2030	A1B max 2030	A1B max 2080	A1B max 2130
Beach nourishment costs (millions USD/year)	225	431	431	431
Sea dike costs (millions USD/year)	61	110	146	189

Table 8 Percentage increase in global investment needs under the BAU scenario above the reference case (no sea-level rise) for 2030.

	Beach Nourishment Costs				Sea Dike Costs			
Region	A1B Mean 2030	A1B Max 2030	A1B Max 2080	A1B Max 2130	A1B Mean 2030	A1B Max 2030	A1B Max 2080	A1B Max 2130
Developing Asia	272	540	540	540	49	87	115	148
Latin America	137	292	292	292	50	90	119	153
Middle East	46	146	146	146	60	105	138	177
North Africa	138	231	231	231	55	93	122	155
OECD Europe	246	491	491	491	115	219	297	388
OECD North America	333	558	558	558	98	169	223	286
OECD Pacific	147	364	364	364	109	192	254	327
Transition Economies	9 900	13 900	13 900	13 900	41	81	108	140
Africa	180	366	366	366	34	59	78	100

Investment in nourishment is predicted to grow more quickly than sea dikes, but investment in sea dikes still continues to dominate the absolute global investment. Regionally, investment in beach nourishment is predicted to at least double in each region for the A1B max scenarios. The growth in investment in sea dikes is greater in the OECD countries under the A1B Max 2080 and A1B Max 2130 scenarios, reflecting their high wealth.

9. An estimation of total investment needed for adaptation under the mitigation (B1) scenario

The investment costs for the four different sea-level rise and adaptation assumption cases under the B1 scenario are shown in Appendix 3 (Global) and Appendix 4 (Regional). The two costs are beach nourishment and sea dike costs. In broad terms they are similar to the BAU (A1B) results, except for the B1 Max 2080 and B1 Max 2130 scenarios, where the investment in sea dikes are reduced by 7 to 10 per cent, depending on the timescale of the anticipation.

While these do not represent all investment needs they represent a good benchmark and can be referenced to the reference case to see the increase in investment needs that each case requires relative to a case with no climate change. Global results are shown in Table 9, while regional results are shown in Table 10.

Table 9. Percentage increase in global investment needs under the mitigation scenario above the reference case (no sea-level rise) for 2030.

Adaptation Measures	B1 mean 2030	B1 max 2030	B1 max 2080	B1 max 2130
Beach nourishment costs (millions USD/year)	197	404	404	404
Sea dike costs (millions USD/year)	52	100	129	159

Table 10. Percentage increase in global investment needs under the mitigation scenario above the reference case (no sea-level rise) for 2030.

	Beach Nourishment Costs				Sea Dike Costs			
Region	A1B Mean 2030	A1B Max 2030	A1B Max 2080	A1B Max 2130	A1B Mean 2030	A1B Max 2030	A1B Max 2080	A1B Max 2130
Developing Asia	226	487	487	487	41	79	101	124
Latin America	114	276	276	276	42	82	105	128
Middle East	31	146	146	146	52	96	122	149
North Africa	123	223	223	223	47	86	108	132
OECD Europe	217	463	463	463	96	198	259	324
OECD North America	305	532	532	532	83	155	197	241
OECD Pacific	122	333	333	333	93	176	224	275
Transition Economies	7 900	12 900	12 900	12 900	35	73	95	117
Africa	157	341	341	341	29	54	69	84

10. Assessment of needed changes in financial arrangement to meet the requirement of additional costs unde r the BAU and mitigation scenario (changes to existing mechanisms and sources and some insight of what new ones could be used)

A major conclusion of this work is that the costs of adaptation to sea-level rise in coastal areas is not especially sensitive to mitigation, as the magnitude of sea-level rise in 2030 is similar regardless of near-future emissions. Sea-level rise is known to have the greatest inertia of all climate change parameters, and the benefits of mitigation lie further in the future than 2030, especially if deglaciation of Greenland and West Antarctica can be avoided (Nicholls and Lowe, 2004; 2006). Under both climate scenarios there is a significant need to adapt to sea-level rise and climate change around the world's coasts independent of climate policy. The actual amount of investment that is required to adapt to sea-level rise by 2030 and beyond through this Century will depend on the attitude taken to adaptation – a more precautionary and proactive approach to adaptation that anticipates worse-case risks and recognises the long lead times in coastal planning and the long life of coastal defence structures will be a more effective approach to managing future risks. However, the required investment may cost more in 2030 to derive these benefits, especially if a protection response is widely followed, as considered in the DIVA simulations that were considered here.

Globally, it seems that investment needs to rise as much as three times present levels, based on the DIVA results. Even if other lower cost adaptation approaches are followed in practise, substantial increases in investment in adaptation are required under the BAU and the mitigation scenario, and this increase in investment is required across all coastal regions of the world. This will include hard and soft infrastructure, and the capacity (or lack thereof) for coastal management and coastal planning is significant issue to consider.

In the developed world and in parts of the developing world, the necessary financial resources are probably available if the importance of the issue is recognised. As national adaptation plans are developed, so this recognition is likely to grow. However, certain settings and regions present particular challenges as identified in the recent IPCC AR4 assessment of coastal areas (Nicholls et al., 2007b). In terms of coastal settings and types, deltaic regions and small islands have the greatest potential problems under sea-level rise and climate change. The large coastal deltas in Asia and a lesser extent Africa present significant issues in terms of responding to sea-level rise and climate change, and the wider issues of sustainable development (Ericson et al., 2006; Woodroffe et al., 2006). The simple measures considered in the DIVA analysis contained in this report are inadequate to adapt a delta to sea-level rise and there is a major challenge in understanding successful adaptation in deltaic settings. Deltas are also environments under multiple stresses, and the response to climate change needs to be placed in a wider context of managing all the issues facing the deltaic area. Small islands in many ways present even greater challenges due to their limited populations and resource base. GEF-funded initiatives such as CPACC and MACC in the Caribbean (http://www.manystrongvoices.org/Belize%202007%20powerpoints/Neville%20Trotz-%20Caribbean%20Approaches%20to%20Climate%20Change%20Adaptation.pdf) and PICCAP (http://unfccc.int/files/meetings/workshops/other_meetings/application/pdf/new_zealand.pdf) are important to build the capacity to adapt to these challenges. It is noteworthy that there have been no regional initiatives for the Indian Ocean islands. Similar networks for deltaic regions could provide tremendous benefits and develop important ICZM capacity.

As a region, coastal areas of Africa stands out as being vulnerable to climate change and sea-level rise, and they have one of the lowest capacities to adapt (Nicholls et al., 2007b). It is difficult to see where the large investment needs predicted by DIVA for Africa will emerge, and capacity building for adaptation is important in this entire continent.

While this report may lead to large calls for monies for climate change adaptation, it is also important to reiterate that climate change is not the sole problem of the coast and it is one of a set of multiple stresses. Responding to these multiple stresses requires integrated solutions and it is important that the adaptation response recognises this need.

11. Conclusions

This report has explored what is a very difficult question to answer – what are the financial needs for coastal adaptation in 2030 given climate change? Hence, it is important to recognise that the results are a preliminary first estimate of the possible needs. Significant additional analysis of the topic is necessary if we are to provide a comprehensive answer to the question posed.

The major conclusion is that it is difficult to distinguish the two climate scenarios in 2030 in terms of impacts or adaptation costs, assuming comparable assumptions on adaptation. Under both climate scenarios there is a significant need to adapt to sea-level rise and climate change around the world's coasts independent of climate policy. Flooding dominates both the adaptation costs (of dikes) and the damages due to the residual risk. In the DIVA model, sea-level rise does not cause a large increase on damages – the main effect is an increased investment in adaptation (which is why the damages do not increase more dramatically). Compared to the situation of no sea-level rise, investment in nourishment could increase 5 times, while investment in dikes would grow 2.6 to 2.9 times if a precautionary and long-term (100 year) proactive view of adaptation is considered. The costs of proactive adaptation are greater than reactive adaptation, but the costs are only up to 37% higher taking a 100 year perspective within DIVA. In practise a proactive strategic approach will almost certainly be cheaper, especially in the longer term. While the absolute investments are large, at up to $22 billion per year, they are sums that the present level of investment in coastal adaptation suggests could be feasibly mobilised if the need is recognised. National adaptation planning may be important in this regard.

Putting the DIVA results in a broader context, it is not clear that all the investments that DIVA suggests are prudent are actually being made, even under today's conditions. Thus, the barriers to adaptation are important and need to be understood. In practise, a wider range of adaptation options will be considered that may lead to successful adaptation strategies that cost less than the costs estimated by DIVA. However, realising these benefits will require long-term strategic planning and more integration across coastal planning and management. Few if any countries have this capacity today and an enhancement of institutional capacity towards integrated coastal management is a prudent response to climate change (as well as realising benefits for non-climate issues). While all countries need to develop and enhance such capacity, the need is greater in poorer countries. Small islands and populated deltaic areas are particularly vulnerable coastal settings where the institutional and technical challenges for successful adaptation are significant. Greater investment in regional networks to increase the capacity to adapt is a pressing need which requires financial support. Existing networks of small island states in the Caribbean and the Pacific should be sustained, and a comparable network developed in the Indian Ocean developed. Similar networks for deltas could be beneficial taking the Asian megadeltas as an example, although other networks could be configured (see Eriscon et al., 2006; Woodroffe et al., 2007). Lastly, Africa is particularly vulnerable (and its coast contains a number of the vulnerable deltas) and finance to encourage capacity building is urgently required. Within capacity development of coastal management institutions, better links to disaster preparedness and planning (which are often climate linked) is an important issue that could be promoted with appropriate financing.

12. Appendices

Appendix 1: Terms of Reference

The requirements stated at the outset included:

- A summary of climate change impacts and adaptation needs for the reference scenario with as much geographic and sub-sectoral detail as possible.
- A summary of climate change impacts and adaptation needs for the adaptation scenario with as much geographic and sub-sectoral detail as possible.
- An estimate of financing needs for the reference scenario with as much geographic and sub-sectoral detail as possible.
- A discussion of financing needs for the adaptation scenario with as much geographic and sub-sectoral detail as possible.
- An overview of current sources of financing (domestic, international, public private).
- An assessment of how current financing arrangements need to change to meet the requirements of the adaptation scenario.

These were elaborated through the project as follows:

- **Outputs** – total investment DURING 2030. The investment should anticipate future adaptation needs over the typical lifetime or planning horizon – adaptation to 2050 climate for facilities that have a 20 year life.
- **Timeframe** – The analysis covers investments through 2030. The analysis can focus on investments during 2030 and a recent year, such as 2000 or 2005, and interpolate the intermediate values. As noted above, investments made in 2030 should reflect anticipated climate developments over their expected lifetime or planning horizon.
- **BAU and Mitigation Scenarios.** SRES A1B or B2 emissions for the BAU scenario and SRES B1 emissions as the mitigation scenario.
- **Development.** Realistic additional development (i.e. socio-economic scenarios) should be considered.
- **Regional Disaggregation.** At a minimum, results should be provided for at least the IPCC regions and preferably many more countries and regions. Small Islands region consists of Small Island States in the Caribbean and Indian and Pacific Oceans. The Polar region as the area within the Arctic circle (north of 60 degrees N) and the Antarctic continent and surrounding ocean.
- **Smart, anticipatory adaptation --** The investments during a given year should be “smart” and anticipatory. The investment should anticipate future adaptation needs over the typical lifetime or planning horizon – example, adaptation to 2050 climate for facilities that have a 20 year life.
- **Currency.** The investments should be reported in constant USD for a defined base year.

Appendix 2 Dynamic Interactive Vulnerability Assessment (DIVA)

Most integrated assessment tools for sea-level rise have only considered selected aspects of the impacts and responses of sea-level rise (Nicholls et al., 2007d). DIVA (DIVA Consortium, 2006) was developed to be a more comprehensive assessment tool that considers most of the major impacts of sea-level rise, together with three selected adaptation approaches where a generalised broad-scale approach is feasible (Table A2.1). The logic of the DIVA tool is shown in Figure A2.1. It is the most comprehensive assessment tool that is available for looking at sea-level rise impacts, to date. DIVA combines a new global database on coastal zones with a suite of algorithms authored by a group of people within the DINAS-COAST research consortium (Hinkel, 2005; Hinkel and Klein, 2007). Unlike earlier models which only resolved broad regions or at best individual countries as the base polygons of analysis (example, Hoozemans et al., 1993; Tol, 2004), DIVA has divided the world's coast into 12,148 segments of variable length, and developed a database containing about 100 parameters based on this functional typology (McFadden et al., 2007; Vafeidis et al., 2004a; 2004b; 2007). A major benefit of DIVA is that consistent perspectives can be developed across the range of sea-level rise impacts, including a range of protection responses, from no protection to total protection. An intermediate 'optimal' protection option which takes an economic benefit-cost perspective is included. Note that it can only compare no response (or effectively retreat/abandonment), versus protect options, and accommodation options are not evaluated.

Table A2.1. The physical impacts of sea-level rise and the adaptation approaches considered in the DIVA tool.

Physical Impacts		Adaptation Approach
1. Inundation, flood and storm damage	a. Surge (sea)	Hard Protection (via Dikes)
	b. Backwater effect (river)	
2. Wetland loss (and change)		Sediment Nourishment
3. Erosion (direct and indirect morphological change)		Beach Nourishment
4. Saltwater Intrusion	a. Surface Waters	'Adaptation not considered'
	b. Groundwater	

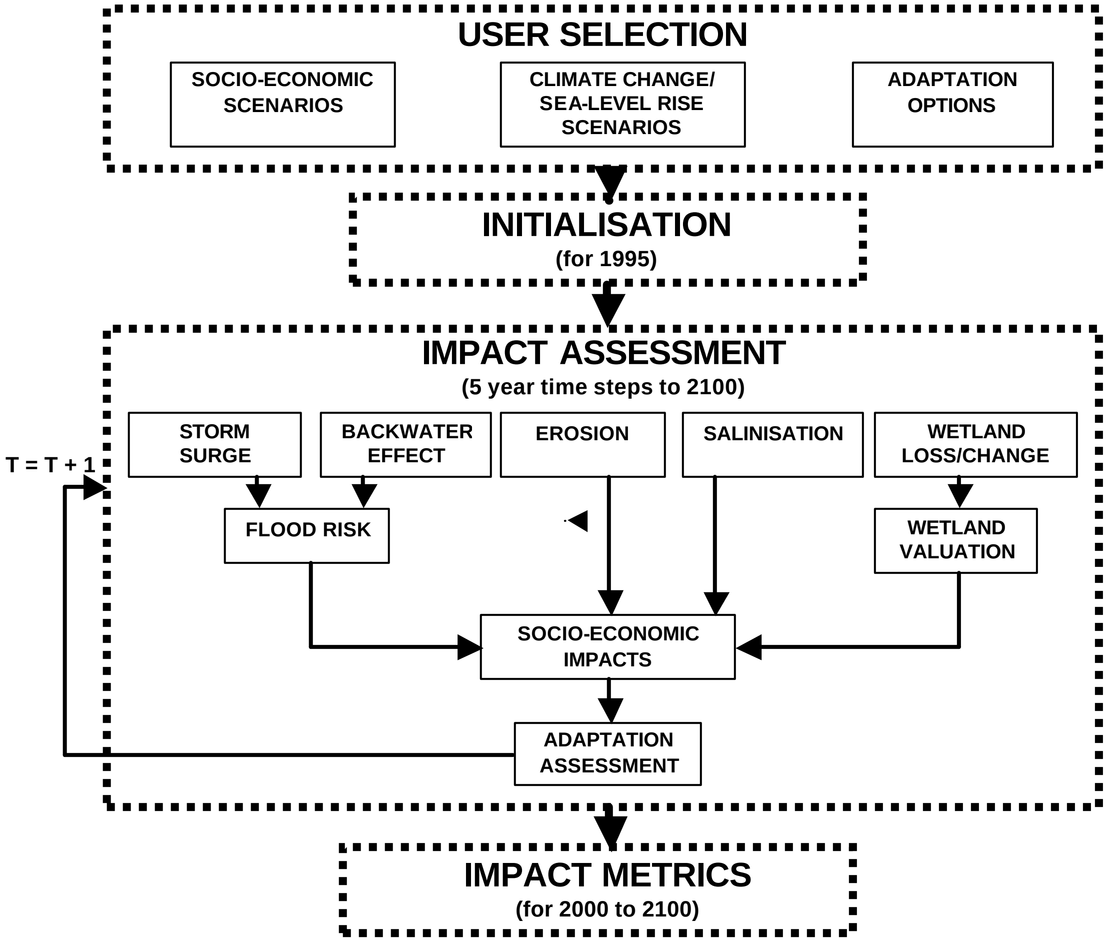


Figure A2.1. Schematic view of the operation of the DIVA tool.

For this analysis, only protection against flooding via dikes and beach nourishment against beach erosion are considered. The adaptation is based on benefit-cost analysis and balances the cost of damages against the costs of adaptation. For beach erosion, damages are based on tourism losses as expressed by the value of the beach land loss, versus the cost of pumping sand on to the beach to maintain it. For flooding, flood losses are based on depth-damage relationships again based on average GDP per area, rather than detailed databases on coastal infrastructure. The costs of beach nourishment and the cost of dike construction were both developed by Delft Hydraulics based on their global experience and expertise: the dike costs are documented in Hoozemans et al. (1993), while the nourishment costs are based on a range of recent experience.

Appendix 3. Summary Global results for the nine cases in terms of indicative impacts and adaptation costs.

		Cases								
Climate Scenario		No SLR	A1B mean	B1 mean	A1B max	B1 max	A1B max	B1 max	A1B max	B1 max
Anticipatory Adaptation (years)		0	0	0	0	0	50	50	100	100
People actually flooded	thousands/year	1 223	1 429	1 393	1 839	1 654	1 839	1 654	1 839	1 654
Beach nourishment costs	millions USD/year	468	1 519	1 388	2 486	2 360	2 486	2 360	2 486	2 360
Land loss costs	millions USD/year	0	4	3	5	5	5	5	5	5
Sea dike costs	millions USD/year	4 577	7 383	6 949	9 618	9 172	11 279	10 472	13 210	11 836
Sea flood costs	millions USD/year	5 218	5 728	5 709	6 635	6 417	6 635	6 417	6 635	6 417
Total Costs	millions USD/year	10 263	14 634	14 049	18 744	17 954	20 405	19 254	22 336	20 618

Appendix 4. Regional Results for the nine cases in terms of indicative impacts and adaptation costs.

	Appendix 4a. People actually flooded (thousands/year)								
Region	**No SLR**	**A1B Mean**	**B1 Mean**	**A1B Max**	**B1 Max**	**A1B Max**	**B1 Max**	**A1B Max**	**B1 Max**
Anticipatory Adaptation (years)	0	0	0	0	0	50	50	100	100
Developing Asia	792	938	932	1336	1154	1336	1154	1336	1154
Latin America	39	43	43	45	45	45	45	45	45
Middle East	7	8	8	9	8	9	8	9	8
North Africa	9	9	9	8	8	8	8	8	8
OECD Europe	73	75	75	76	76	76	76	76	76
OECD North America	63	65	65	67	67	67	67	67	67
OECD Pacific	25	27	27	27	27	27	27	27	27
Transition Economies	36	35	35	34	34	34	34	34	34
Africa	179	228	200	237	236	237	236	237	236
Total	1223	1428	1393	1839	1653	1839	1653	1839	1653

	Appendix 4b. Beach nourishment costs (millions USD/year)								
Region	**No SLR**	**A1B Mean**	**B1 Mean**	**A1B Max**	**B1 Max**	**A1B Max**	**B1 Max**	**A1B Max**	**B1 Max**
Anticipatory Adaptation (years)	**0**	**0**	**0**	**0**	**0**	**50**	**50**	**100**	**100**
Developing Asia	47	175	153	301	276	301	276	301	276
Latin America	59	140	126	231	222	231	222	231	222
Middle East	13	19	17	32	32	32	32	32	32
North Africa	13	31	29	43	42	43	42	43	42
OECD Europe	65	225	206	384	366	384	366	384	366
OECD North America	108	468	437	711	683	711	683	711	683
OECD Pacific	36	89	80	167	156	167	156	167	156
Transition Economies	0.1	10	8	14	13	14	13	14	13
Africa	127	356	327	592	560	592	560	592	560
Total	468.1	1 513	1 383	2 475	2 350	2 475	2 350	2 475	2 350

	Appendix 4c. Land loss costs (millions USD/year)								
Region	**No SLR**	**A1B Mean**	**B1 Mean**	**A1B Max**	**B1 Max**	**A1B Max**	**B1 Max**	**A1B Max**	**B1 Max**
Anticipatory Adaptation (years)	0	0	0	0	0	50	50	100	100
Developing Asia	0	0	0	0	0	0	0	0	0
Latin America	0	0	0	0	0	0	0	0	0
Middle East	0	0	0	0	0	0	0	0	0
North Africa	0	0	0	0	0	0	0	0	0
OECD Europe	0	3	2	3	3	3	3	3	3
OECD North America	0	1	1	2	2	2	2	2	2
OECD Pacific	0	0	0	0	0	0	0	0	0
Transition Economies	0	0	0	0	0	0	0	0	0
Africa	0	0	0	0	0	0	0	0	0
Total	0	4	3	5	5	5	5	5	5

	Appendix 4d. Sea dike costs (millions USD/year)								
Region	**No SLR**	**A1B Mean**	**B1 Mean**	**A1B Max**	**B1 Max**	**A1B Max**	**B1 Max**	**A1B Max**	**B1 Max**
Anticipatory Adaptation (years)	**0**	**0**	**0**	**0**	**0**	**50**	**50**	**100**	**100**
Developing Asia	1 326	1 973	1 873	2 474	2374	2 850	2 669	3 286	2 977
Latin America	950	1 425	1 351	1 806	1 726	2 083	1 943	2 406	2 170
Middle East	87	140	132	179	171	208	194	242	217
North Africa	69	107	102	133	128	153	144	176	160
OECD Europe	384	826	753	1 224	1 145	1 524	1 380	1 875	1 628
OECD North America	470	929	862	1 266	1 199	1 519	1 397	1 813	1 604
OECD Pacific	295	618	569	863	814	1 047	958	1 261	1 109
Transition Economies	349	494	470	631	605	727	680	838	759
Africa	640	855	823	1 018	987	1 139	1 081	1 277	1 180
Total	4 571	7 367	6 935	9 594	9 150	11 249	10 445	13 174	11 804

	Appendix 4e. Sea flood costs (millions USD/year)								
Region	**No SLR**	**A1B Mean**	**B1 Mean**	**A1B Max**	**B1 Max**	**A1B Max**	**B1 Max**	**A1B Max**	**B1 Max**
Anticipatory Adaptation (years)	4 232	4 485	4 477	4 999	4 818	4 999	4 818	4 999	4 818
Developing Asia	431	466	465	489	486	489	486	489	486
Latin America	24	30	29	54	53	54	53	54	53
Middle East	111	121	121	126	125	126	125	126	125
North Africa	116	231	226	332	309	332	309	332	309
OECD Europe	124	146	144	168	163	168	163	168	163
OECD North America	26	38	37	207	205	207	205	207	205
OECD Pacific	80	129	128	172	171	172	171	172	171
Transition Economies	73	80	80	86	85	86	85	86	85
Africa	5 217	5 726	5 707	6 633	6 415	6 633	6 415	6 633	6 415
Total	4 232	4 485	4 477	4 999	4 818	4 999	4 818	4 999	4 818

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