Coastal Adaptation Technologies

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I. INTRODUCTION

A. Background

1. At its second and third sessions, the Conference of the Parties requested the secretariat to prepare reports on adaptation technologies and to continue its work on the synthesis and dissemination of information on environmentally sound technologies and know-how conducive to mitigating, and adapting to, climate change (FCCC/CP/1996/15/Add.1, decision 7/CP.2 and FCCC/CP/1997/7/Add.1, decision 9/CP.3).

2. At its eighth session, the Subsidiary Body for Scientific and Technological Advice (SBSTA), encouraged the secretariat to continue its work on different adaptation topics (FCCC/SBSTA/1998/6, para. 58 (h)). These topics were identified at a UNFCCC expert meeting on adaptation technologies held in conjunction with an Intergovernmental Panel on Climate Change (IPCC) meeting on adaptation in Amsterdam from 20 to 22 March 1997 (FCCC/SB/1997/3, annex II) and are the subject of a series of technical reports on adaptation technology in accordance with the work programme (FCCC/CP/1997/INF.1).

3. An earlier technical paper provided on overview on adaptation technologies (FCCC/TP/1997/3). This technical paper expands upon the overview paper, focusing on various aspects of the development and transfer of coastal adaptation technologies in the context of the specific circumstances and special situations of small island states and countries with low-lying coastal areas.

B. Context for adaptation technologies

4. Human and ecological systems adapt to the negative effects of climate change, including changes in climate extremes and climate variability, through a combination of technological and behavioural adjustment. The IPCC Second Assessment Report describes the three basic response strategies to sea-level rise: retreat (managed), accommodation and protection. The SAR also identifies the six main biophysical adverse effects of sea-level rise as: increased flood frequency, erosion, inundation, rising water-tables, salt-water intrusion and biological effects.

5. Technologies which help reduce the impacts of climate change can themselves cause other problems. Coastal zone adaptation technologies are a good example. Many of the technologies incorporated within, or needed to implement, managed retreat from, accommodation of, or protection against, rising sea levels can have adverse social, economic or environmental consequences, often even when diligently executed (most hard structures such as sea walls have deleterious effects upon local ecosystems, including, in the case of many small islands, for example, fisheries and coral reefs). Few, if any, coastal adaptation technologies have no negative side-effects. Under certain circumstances these unintended side-effects can outweigh the benefits of a particular coastal adaptation technology.

6. Where possible, the paper attempts to highlight the drawbacks of particular technologies. The consideration and selection of appropriate coastal adaptation technologies is part of the wider context of the assessment of coastal adaptation options such as those described in the coastal zone chapter of the United Nations Environment Programme (UNEP) *Handbook on Methods for Climate Change Impacts Assessment and Adaptation Strategies* (Klein and Nicholls, 1998) and other relevant literature (e.g., Klein et al., 1999).

7. None of the coastal adaptation technologies described in this paper are in any way endorsed as appropriate or sustainable. The suitability of a particular adaptation technology is highly sensitive to local conditions, priorities and choices. In turn, as this paper stresses, coastal zone planning and decision-making require adequate institutional capacity.

8. Nevertheless, the development and transfer of appropriate coastal adaptation technologies can potentially help lower the cost and expand the scope of options available to adapt to sea-level rise and associated effects.

C. Objectives and scope of the technical paper

9. The purpose of this paper is to identify options to accelerate and sustain the development and transfer of coastal zone adaptation technologies to assist countries in planning for, and adapting to, sea-level rise and its associated effects.

10. Possible users of the information provided in this technical paper include the range of different stakeholders making up the community active in making decisions relating to the sustainable management of the coastal zone. These stakeholders include development banks, other loan providers and aid agencies, intergovernmental organizations, government (national, regional and local), universities, the private sector (including insurance companies) and non-governmental organizations (see section VII).

11. The paper seeks to address the following key questions:

- What technologies are available to respond to the problem of sea-level rise and its associated effects?
- What new technologies are needed?
- How are coastal adaptation technologies developed and transferred?
- What are the barriers to the development and transfer of new technologies?
- What options should be considered to accelerate the development and transfer of such technologies?

12. The paper:

- Provides information on coastal impacts and adaptation options reported in national communications;
- Describes a range of examples of coastal adaptation technologies that are in use or have been demonstrated;

- Identifies examples of coastal adaptation technology needs;
- Describes how these technologies are developed and transferred;
- Provides a preliminary review of the status of institutional capacity regarding international and regional coastal engineering and coastal zone management; and
- Identifies barriers to and options for the acceleration of the development and transfer of coastal adaptation technologies.

13. The paper does not attempt to summarize the work of the IPCC on the science of sea-level rise, or the impacts of sea-level rise in different regions. The executive summaries of these topics can be found in the IPCC Second Assessment Report[1] (IPCC, 1995a and 1995b). Further information is also contained in the IPCC report, *Regional Impacts of Climate Change* (IPCC, 1998).

D. Review process

14. This paper draws significantly on information provided by experts. A preliminary draft of this technical paper was peer-reviewed at a UNFCCC expert meeting on coastal adaptation technologies held at the Convention secretariat in Bonn, 22-23 March 1999 (referred to below as the "UNFCCC coastal adaptation expert meeting"). The current version has been prepared by the secretariat and incorporates the comments and suggestions from participants at the expert meeting (see annex I).[2]

15. The meeting was attended by experts from nine countries (Barbados, China, Fiji, Netherlands, Sierra Leone, the United Kingdom of Great Britain and Northern Ireland, the United Republic of Tanzania, the United States of America and Uruguay). Three of the experts attended as representatives of important regional and global initiatives relating to coastal adaptation. The experts from Fiji and Barbados, respectively, represented the situations of island states participating in the Pacific Island Climate Change Action Programme (PICCAP), funded by the Global Environment Facility (GEF), and the Caribbean Planning for Adaptation to Climate Change initiative (CPACC).[3] These projects are examples of regional approaches which

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[1] Chapter 7 of the Working Group I report, 'Changes in Sea Level', and chapter 9 of the Working Group II report 'Coastal Zones and Small Islands'.

[2] In addition, the UNFCCC secretariat is grateful to the following experts who did not attend the expert meeting but who were interviewed or provided written comments on various drafts of this paper: William Allsop, Robert Dean, Chris Fleming, Jim Hall, Malcolm Hendry, Richard Klein, Jon McCue, Nobuo Mimura, Robert Nicholls and Darren Price.

[3] The aim of PICCAP to assist participating Pacific island developing countries to prepare national communications. PICCAP has included a number of meetings and workshops and has generated considerable amounts of information relating to vulnerability and adaptation in the Pacific islands context. The CPACC project is an initiative of the Organization of American States (OAS) and the GEF to support Caribbean countries in preparing to cope with the adverse effects of global climate change, particularly sea-level rise in coastal and marine areas, through vulnerability assessment, adaptation planning and capacity-building.

have significantly contributed to information dissemination and capacity-building in relation to vulnerability and adaptation.

16. The expert from the United States of America attended as a lead author of the coastal adaptation technologies chapter of the *IPCC Special Report on Methodological and Technological Issues in Technology Transfer*. In some instances, the paper draws upon and cites information provided by IPCC lead authors who are also contributors to the coastal chapter of this IPCC special report, due to be completed in 2000.

II. INFORMATION ON THE IMPACTS OF SEA-LEVEL RISE AS WELL AS ADAPTATION OPTIONS AND TECHNOLOGIES REPORTED IN NATIONAL COMMUNICATIONS

17. Annex II provides a summary of impacts and adaptation response measures reported in the first national communications[4] of 11 non-Annex I countries submitted (as of 1 April 1999), as well as the second national communications of 20 Annex I countries.

18. The information provided in annex II may be synthesized as follows:

- Six of the national communications of the 11 non-Annex I countries report impacts due to sea-level rise (inundation of low-lying coastal areas, loss of coastal ecosystems), as well as associated response measures. Among these, three (the Federated States of Micronesia, Senegal and Uruguay) cite adaptation measures relating to coastal adaptation technologies;

- Two non-Annex I countries (Senegal and the Federated States of Micronesia) provide monetary estimates of the costs of protection using coastal adaptation technologies;

- Twenty Annex I countries report impacts related to sea-level rise and its associated effects in their second national communications; the most frequently cited impacts include increased likelihood of inundation of low-lying coastal areas, accelerated coastal erosion, changes in sediment budgets, saline intrusion, and damage to coastal structures; and

- Nine Annex I countries report that they have already developed, or were in the process of developing, strategic approaches to the development of a coastal zone adaptation strategy (Denmark, Greece, Iceland, Ireland, Netherlands, New Zealand, Poland, Portugal and the United States of America). Three countries provide monetary estimates of the cost of protection (Ireland, Japan and Poland).

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[4] This summary of information on coastal impacts and adaptation options contained in the national communications of the first 11 non-Annex I Parties is unlikely to be representative of the much larger group of over 130 non-Annex I Parties, approximately half of which are coastal nations or small island states.

III. DESCRIPTION OF COASTAL ADAPTATION TECHNOLOGIES

19. An array of technologies exists to support various adaptation options available to respond to different adverse effects of sea-level rise. Technologies can be divided into three groups:

- Technologies which enhance understanding of the basic geomorphological characteristics of the coast as well as its dynamic processes (annex III, table 1), including: data gathering (gauges, sensors, remote sensing and monitoring), management and decision technologies (Geographic Information Systems, models, databases);

- Technologies which are incorporated within, or required to carry out, the implementation of the three main coastal adaptation options (annex III, table 2): managed retreat (e.g. movable structures, rolling easements, inland flood defences, flood warning systems), accommodation (e.g. reservoir relocation, dune management, rain/waste-water management) or protection (includes a wide array of technologies available to coastal engineers to stabilize a coastline, including soft technologies such as beach nourishment as well as hard structures such as sea walls, revetments, groynes) (e.g., Pilarczyk, 1990 and 1992; Scott et al., 1993; Tanimoto and Goda, 1992); and

- Technologies which are new, unproven, and which have not yet reached maturity (annex III, table 3): Examples include offshore reefs, berm breakwaters, bubble curtains, floating breakwaters, and wave energy devices. These are not necessarily ‘heavy’ engineering, but certainly more sophisticated structures and systems requiring careful attention to boundary conditions, advanced engineering design and construction supervision (e.g., Pilarczyk, 1994).

20. Tables 1-3 in annex III have been compiled with inputs from the UNFCCC coastal adaptation expert meeting as well as from a review of coastal engineering and protection literature (see bibliography), in particular the South Pacific Applied Geoscience Commission (SOPAC) reports[5] *Coasts of Pacific Islands* and *Coastal Protection in the Pacific Islands: Current Trends and Future Prospects,* and other sources. The list also draws upon the work being undertaken by lead authors of the coastal adaptation technologies chapter of the IPCC *Special Report on Methodological and Technological Aspects of Technology Transfer.*

21. The tables provide a short description of each coastal adaptation technology and, where appropriate, other information relating to applications, costs, drawbacks and other considerations. The coastal adaptation technologies covered in the tables vary widely in cost, sophistication, maintenance requirements and technical capacity needed to implement and maintain them.

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[5] *Coasts of Pacific Islands*, SOPAC Miscellaneous Report 222, 1996. *Coastal Protection in the Pacific Islands: Current Trends and Future Prospects*, SOPAC Miscellaneous Report 177, 1993.

IV. COASTAL ADAPTATION TECHNOLOGY NEEDS

22. A number of factors may influence the technology needs of coastal nations. The following four factors are discussed below:

- The dynamic and incremental nature of the coastal zone itself;
- The relative scale of the coastal zone problem and availability of resources;
- Different national and regional circumstances; and
- Status of relevant institutional capacity and availability of appropriate training.

23. In addition, a number of specific gaps in relation to the research and development needs identified by the UNFCCC coastal adaptation expert meeting are listed.

A. Technology needs are dynamic, incremental and unpredictable - like the coastal zone itself

24. Coasts are narrow and fragile by nature, prone to fracture due to attacks from both the land and the sea. Whether managed or not, the coastal zone is not static, but a dynamic, unpredictable, adaptive and interdependent set of subsystems. While this idea is well internalized within the coastal zone engineering and management community, these characteristics are frequently ignored in the planning, design and implementation of coastal projects. Identifying specific technologies needed to respond to sea-level rise is therefore a complex task. This partly explains why there is often no consensus about how to deal with the complexity of social and economic issues surrounding choices of appropriate coastal adaptation technologies.

25. The dynamism of the coastal zone is both a problem and an opportunity for coastal managers. On the one hand, it can be difficult to model and predict the effectiveness of a particular coastal adaptation technology, or indeed the positive or negative side-effects associated with the technology. Moreover, most existing coastal zone problems are the result of a cumulative set of maladaptive practices (e.g. development in hazardous zones, the use of inappropriate coastal adaptation technologies and sand mining). Coastal structures typically have design lives in the order of decades (UNEP, 1998). Such structures can therefore have long-term effects (positive and negative and in some cases irreversible) on the coast.

26. On the other hand, a series of positive incremental changes can result in cumulative reductions in the vulnerability of the coast to sea-level rise. “No regrets” (reversible/ experimental/empirical) responses that maintain or enhance choices available in the future are therefore important coastal adaptation technologies deserving particular priority (Klein and Nicholls, 1998).

B. Technology needs are determined by the relative scale of the problem and the availability of resources

27. The issue of climate change and sea-level rise is new to coastal engineering. Changes in the magnitude and frequency of storm surges, cyclones and coastal erosion are all likely. General and intuitive engineering assumptions include the idea that the direct effects of sea-level rise will be that deep-water waves become more extreme, and that changes in wave and wind regimes may also be accelerated/affected. The development of new technologies or innovations based on combinations of existing technologies may help to expand the scope of sustainable coastal adaptation options available.

28. Is sea-level rise a difficult problem for the coastal engineering community to solve? At one level the answer is no, not particularly. As Dean (1987) puts it:

> "When not restrained by funding, availability of materials, or work force, construction of almost any conceivable protection against sea-level rise can be carried out in a very short time; short, that is, relative to the rate of sea-level rise" (National Research Council, 1987, p. 124).

29. Of course, in practice, limited funds are available for coastal adaptation technologies which tend to be very expensive to build and maintain.

30. While the scale of the challenge that sea-level rise poses to the coastal scientists, planners and engineers may indeed be much larger than past experience, on a site by site basis, it is unlikely that problems will be encountered which are more severe than those faced at present.

31. While the coastal science, planning and engineering community will be able to incorporate sea-level rise into future plans and decisions, including the design bases of future coastal structures, the prospects for significant changes in the hard technologies used in the coastal engineering community are not great. This is partly because hard technologies are not scalable (see section VI below). It is also unlikely that much can be done to reduce the cost of concrete and steel, pumps and dredgers. However there may be significant opportunities to reduce the cost of many of the soft technologies.

32. Today's array of coastal adaptation technologies suggests it is infeasible to contemplate responding to sea-level rise by relying on the coastal protection option alone. However, while nations continue to contemplate how best to respond, the coastal planning and engineering community may adapt by seeking incremental improvements in existing technologies as well as developing innovative, low-cost and sustainable technologies.

C. Technology needs are influenced by differing national and regional circumstances

33. Technology needs for coastal adaptation will vary according to national environmental circumstances and relevant capacities to adapt to sea-level rise. A variety of characteristics

distinguish different national and regional contexts for coastal adaptation technologies, including: natural resources, human resources/skills, equipment availability; environmental factors (and attitudes); public perception/education; legal restrictions; funding sources; requirements of funding sources; time-scale over which justification for project is made (discount rates/risk perception frameworks); and political will.

34. Among developing countries, the coastal situation differs markedly. It is therefore likely that the coastal adaptation technology needs of developing countries will differ, in some cases markedly, from each other. Many of these factors suggest that local expertise/participation is necessary to identify and design appropriate coastal adaptation technologies as well as to implement and maintain them.

35. Engineering solutions developed in and for countries with coastal engineering traditions (e.g. Japan, Netherlands, the United Kingdom, the United States) cannot simply be transplanted to developing countries. Engineering solutions are sensitive to local geomorphological, ecological and botanical environments/contexts. For example, the seabed around Japan is sand and hard rocks. In many developing countries, the seabed consists of loose mud, coral sand or coral reefs. Appropriate or sustainable engineering solutions are necessarily different in each case.

36. However, ecosystems frequently traverse national boundaries. Countries in the same region therefore often share similar coastal characteristics, climate conditions and ecosystems. Equally, some countries in different regions can also share similar coastal characteristics, climate conditions and ecosystems. The IPCC Second Assessment Report identified four particularly vulnerable coastal types:

- Coral atolls (e.g. the Marshall Islands, Maldives);
- Coastal wetland areas (e.g. in the United States, the Mediterranean, the African Atlantic: Senegal, Gambia, Sierra Leone, Nigeria, Cameroon, Gabon, Angola and the coast of Australia and Papua New Guinea);
- Large deltas (e.g. in Bangladesh, Nigeria, Egypt, China - though deltas themselves are barely comparable); and
- Developed sandy shores (e.g. in the United States, Europe, the Caribbean, the Asian Pacific).

37. In the case of small island states, the ecological and socio-economic risks associated with a projected increase in sea-level are particularly significant. Many islands are likely to experience increased coastal erosion and land loss as a consequence of sea-level rise (IPCC, 1998). In many cases, much of the land area of low-lying island states is only 3-4 metres above the present mean sea level (e.g. the Bahamas, Kiribati, Maldives and the Marshall Islands).

Islands at higher elevations are also in many cases vulnerable to sea-level rise due to significant socio-economic dependencies (settlements, tourism, agriculture) on the coastal zone (IPCC, 1998; Leatherman, 1997).

38. The numerous coastal adaptation options and technologies identified in this paper are in many instances inappropriate for the particular conditions in small islands and atolls. In particular, managed retreat in response to sea-level rise is rarely an option, as are many shore protection technologies, due to their prohibitive expenses as well as the ecological and environmental risks associated with their implementation. The IPCC report on the regional impacts of climate change suggests that flexible, easily replaceable, traditional shore protection measures could be further explored, while in some cases retreat may be the only available adaptation option.

39. The scope of adaptation options available to vulnerable island states and low-lying coastal nations is in some cases limited. To expand the choices available, radically new technologies are needed. In turn, this implies a significant commitment to specific research and development programmes conducted at the national as well as international levels.

D. Status of relevant institutional capacity and availability of appropriate training

40. Annex IV provides results of a pilot survey to establish an overview of coastal zone management and engineering centres. The survey provides the following conclusions:

- There are few international or regional centres of coastal zone management, particularly in vulnerable regions, and consequently there are few regional or international coastal adaptation networks;

- There is relatively little institutional capacity in the following regions: West Africa, East Africa, Southern Africa; the Caribbean and Latin America; the South Pacific; and Asia;

- At the national level, a large number of government and university laboratories undertake activities in various aspects of coastal engineering and in some cases coastal zone management. Centres of coastal zone management generally have little interaction with institutions undertaking research, development and training in coastal engineering;

- Few coastal zone centres have specific programmes on climate change, sea-level rise and coastal adaptation and in many cases it is not clear which centres might have the capacity to conduct, for example, coastal vulnerability and adaptation assessments or specific training required to undertake these;

- The network for the diffusion of knowledge and the transfer of coastal adaptation technologies is piecemeal, underdeveloped or in some cases non-existent. In many areas which are particularly vulnerable to sea-level rise, there is little, if any, institutional capacity specifically dedicated or available to adequately consider the problem; and

- There is significant potential to enhance information sharing and capacity-building of the existing network of regional/international centres of coastal zone management and engineering.

41. Greater linkages among and between coastal zone management and coastal engineering centres would help accelerate and sustain the development and transfer of effective and appropriate coastal adaptation technologies. At the same time, the effective implementation of coastal adaptation technologies requires local scientific and technical expertise and intuition (e.g., McManus et al., 1998).

42. Options identified by the UNFCCC coastal adaptation expert meeting to build the capacities of vulnerable island states and low-lying coastal nations to undertake appropriate coastal adaptation therefore include:

- Further strengthening of the existing networks of regional and international centres for coastal zone management to consolidate regional information and studies and pool resources (in some cases this could also include information networks devoted to broader issues such as SIDSNet in the case of small island states);

- Building and incorporating engineering capacities within the framework of existing coastal zone management centres; and

- The identification of national focal centres for research and monitoring of coastal adaptation. Such centres could integrate coastal zone management and the coastal engineering resources available in the particular country or region. These focal centres could provide the linkage between the networks of national public laboratories and universities and the network of international/regional centres.

E. Coastal adaptation technologies research and development needs

43. Among the coastal adaptation technologies described in the tables in annex III, the UNFCCC coastal adaptation expert meeting identified a number of coastal adaptation technologies requiring further development/application including:

- Technologies specifically designed to assist in the protection and stimulation of coral reefs;

- Temporary plant “bridging” technologies (e.g. to allow mangroves to re-establish);

- Building with nature technologies (using local vegetation, species and geomorphological processes to adapt);
- Advanced building materials for coastal applications;
- Tools to educate and raise awareness among stakeholders;
- Specific research and development in the field of intuitive design (e.g. coconut leaves/hand-built sea walls);
- Predictive modelling (sea-level rise, cyclones, but also in particular models that can downsize from global mean sea-level predictions);
- Data collection and validation/remote sensing technologies;
- Establishment of wider, more effective national networks of wave and tide gauges;
- Research and development into the specific needs of muddy intertidal areas;
- Greater use and diffusion of geographical information systems to assess vulnerability and possible responses; and
- Diffusion and application of remote monitoring technologies (e.g. embedded sensors).

44. These are just some examples of coastal adaptation technologies which could be further developed and applied to expand the scope of coastal technologies and options available, as well as lowering their costs. In many cases, vulnerable nations will require considerable further information and institutional capacities to adequately consider their particular coastal adaptation technology needs. With this in mind, participants at the UNFCCC coastal adaptation expert meeting also listed options which could help identify coastal adaptation technology needs, including:

- Enhancing education, training and raising the public awareness of the uncertainties of and linkages between extreme climate events and global climate change;
- Increasing education, training and awareness on which options and technologies are effective and which are not;
- Undertaking national coastal adaptation technology assessments;
- Exploring the possibilities of standards for coastal technologies backed up by necessary third party certification;

- Further developing data gathering and decision support tools;
- Implementing coastal adaptation technology demonstration programmes;
- Developing more detailed scenarios of local coastal evolution (wind directions, etc); and
- Ensuring a level of institutional capacity in line with the scale of the risks and challenges associated with coastal vulnerability.

V. DEVELOPMENT AND TRANSFER OF COASTAL ADAPTATION TECHNOLOGIES

A. How coastal adaptation technologies are developed

45. The development of coastal adaptation technologies takes place through two main activities:

- National coastal construction and maintenance programmes; and
- National and international publicly funded marine and coastal research and development programmes.

B. National coastal construction and maintenance programmes

46. Many governments fund the construction and maintenance of coastal structures.[6] Within a particular country, large numbers of different central and local government departments are typically responsible for such expenditures. Some of the more significant national programmes are carried out within developed countries with ‘coastal engineering traditions’ (Verhagen, 1995). Capital and maintenance expenditures are, however, relatively small compared, for example, with national expenditures on other forms of civil engineering such as roads or energy networks.

47. The coastal engineering sector is generally characterized by a fragmented set of small and medium enterprises (including construction engineers and consulting engineers) intensely competing for a relatively fixed, national, publicly funded market, and therefore typically lacking the resources for research and development that are found in other sectors. There is generally a small national effort in developed countries to support research and development to enhance the development and competitiveness of the sector.

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[6] Accurate and systematic information on national expenditures on the construction and maintenance of coastal structures is not available.

48. Many projects are small-scale and do not provide long-term contract continuity or financial security. Firms compete and operate in conditions of generally high uncertainty. In addition, there are generally low expectations of significant growth potential of expenditures on coastal projects in both developed and developing countries.

49. Accordingly, profit margins in the industry are generally relatively low. Consequently relatively few resources are available for investment in research and development programmes.

C. Publicly funded coastal engineering research and development

50. Coastal engineering research and development is primarily carried out at the national level and mainly in the public sector. Just as expenditures on coastal construction and maintenance are themselves difficult to establish, so too are coastal engineering research and development expenditures. The Netherlands, for example, supports a national coastal research and development programme of approximately US$ 30 million, which supports basic research. The research has enabled Netherlands companies to gain an international reputation in the competition for overseas coastal contracts. Dredging is a good example. For the last 15 years or so, dredging companies have collaborated to improve the efficiency of the ‘pump ladder’ and the cutter heads. The cost/unit volume of material pumped has been significantly reduced in recent years. The main costs are in mobilization and ensuring that the right dredger is in the right place. The United States recently implemented a multi-year dredging research programme. The United States Army Corps of Engineers operates one of the largest programmes for river and coastal engineering research and development (Hammer, 1998).

51. However, there are few examples of international collaborative approaches to coastal engineering research and development. One exception is the European Marine Science and Technology (MAST) programme, which brings together *inter alia* elements dealing with coastal morphodynamics and coastal structures. The MAST programme, part of the European Union (EU) framework programme on research, technological development and demonstration, aims to foster scientific knowledge and technological development necessary to understand how marine systems relate to global change. Established in 1989, the programme includes a number of activities relating to global change and coastal zone protection.

52. At both the national and the international level, research and development programmes tend to emphasize coastal sciences and the sound understanding of coastal processes. There are relatively few activities undertaken directly on the applied ‘solutions’ side, for example relating to the spectrum of soft to hard coastal adaptation technologies. There are also almost no activities to demonstrate and verify performance and evaluate coastal adaptation technologies. The concept of coastal adaptation technologies is relatively new and has yet to attract the attention of the mainstream coastal engineering research community. Consequently the coastal research and development programmes typically do not include specific activities to address the coastal adaptation technology needs of developing countries.

D. How coastal adaptation technologies are transferred

53. There are two main pathways for the transfer of coastal zone adaptation technologies from developed to developing countries:[7]

- Bilaterally and multilaterally funded coastal projects carried out by multinational private sector coastal consulting engineers and construction companies; and
- The training of engineers from developing countries at institutions in countries with a coastal engineering tradition.

E. Coastal projects carried out by internationally operating private sector coastal consulting engineers and construction companies

54. The diffusion and transfer of coastal engineering practices/knowledge is mainly through coastal projects, involving foreign, internationally operating consulting and construction engineering companies. Many of the major coastal engineering projects in developing countries are carried out by consulting and construction engineers from developed countries. Part of the market for coastal projects is therefore global. More precisely, firms tend to dominate in their home markets - much of the work in the Netherlands is undertaken by firms based there etc. In the case of the United States, much of the market for coastal work remains in the public sector because the United States Army Corps of Engineers is responsible for river and coastal engineering.

55. The international market for construction in developing countries is greater. Firms from Europe, North America and Japan may all compete for the same coastal project, for example, in West Africa. Multinational private enterprise constitutes an important pathway for the transfer of technology - appropriate and otherwise. There is always a risk that invited coastal consultants and construction engineers from developed countries apply engineering methods already developed for other contexts. In some cases this may not be the most appropriate solution. The risk is greatest where maintenance considerations and local inputs are underemphasized in the project cycle. Other factors may also contribute to the transfer of the suboptimal solution (see section VI).

56. The project planning and implementation cycle is an important pathway via which coastal adaptation technologies are transferred in practice. Participants at the expert meeting characterized the typical project tendering process in developing countries by the following:

- Project funding is supplied through loans or bilateral aid (often provided in the return periods after severe weather events);

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[7] There are also pathways within and between developing countries. A comprehensive analysis of the various pathways will be included in the *IPCC Special Report on Methodological and Technological Issues in Technology Transfer*, due to be published in 2000.

- Following the request for tenders, projects are in many cases awarded to consultants and construction companies from the donor country (in the case of bilateral aid);

- During the planning, design and, in some cases, implementation, local experts/engineering firms may be ignored and may not be invited to participate in the process;

- In turn, this tends to encourage the reproduction of existing designs, in some cases not optimized or even suitable for local conditions; and

- Most projects do not include maintenance of the structure and training of engineers in their proposals. The result is a project left behind where, if something technical goes wrong, it cannot be addressed by local expertise.

The table below provides examples of different agencies involved in grants, loans and aid as well as providing assistance for studies identified at the UNFCCC coastal adaptation expert meeting.

Examples of agencies/countries providing grants, loans or aid for coastal projects in different regions

Funding	Africa	Asia	Caribbean	Latin America	Pacific
Bilateral aid	Canada (CIDA); Denmark (DANIDA); Netherlands (DGIS); Germany (GTZ/BMZ); Sweden (SIDA-SAREC); Norway (NORAD); European Union; United States (USAID).	Canada (CIDA); Denmark (DANIDA); Germany (GTZ/BMZ); Netherlands (DGIS); Norway (NORAD); Sweden (SIDA-SAREC).	Canada (CIDA); France (IFREMER/ IRD); Netherlands; United States (USAID).	United States (USAID).	Australia (AUSAID); China; France; Japan (JICA); United Kingdom (DIFID); United States (SEAGRANT (USAID); United Nations Development Programme; Commonwealth Secretariat.
Multilateral loans	African Development Bank; World Bank.	Asian Development Bank.	IADB; Organization of American States; World Bank.	IADB; World Bank.	Asian Development Bank; World Bank.
National		Thailand (Asian Institute of Technology); Japan	Caribbean Development Bank.		Local and regional governments; South Pacific Forum Secretariat.
Funding for studies	Netherlands (NCCAP); United Kingdom (DFID); United States (UCSP); GEF; African Development Bank.	Netherlands (NCCAP); United States (USCSP).	GEF; Inter-American Development Bank.	Canada (IDRC); Netherlands (NCCAP); United States (USCSP); GEF.	GEF.

Source: UNFCCC Expert Meeting on Coastal Adaptation, 22-23 March 1999, Bonn.

AUSAID: Australian Agency for International Development.
BMZ: German Federal Ministry for Economic Cooperation and Development.
CIDA: Canadian International Development Agency.
DANIDA: Danish International Development Assistance.
DFID: United Kingdom Department for International Development.
DGIS: Directorate General for International Co-operation.
of the Netherlands Ministry of Foreign Affairs.
GEF: Global Environment Facility.
GTZ: German Agency for Technical Cooperation.
IDRC: International Development Research Centre (Canada).
IFREMER: Institut Français de Recherche pour l'Exploitation de la Mer.
IRD: Institut de Recherche pour le Developpement (France).
JICA: Japan International Cooperation Agency.
NCCAP: Netherlands Climate Change Assistance Programme.
NORAD: Norwegian Agency for Development Cooperation.
SIDA-SAREC: Department for Research Cooperation within the Swedish International Development Agency.
USAID: United States Agency for International Development.
USCSP: United States Country Studies Program.

F. Training engineers from developing countries at centres of excellence in countries with a coastal engineering tradition

57. In most developing countries there is a shortage of trained coastal scientists, managers and engineers. Verhagen (1995) observes that whereas young engineers in countries with a tradition of coastal engineering first serve apprenticeships after their qualification, in many instances newly qualified engineers returning to their home countries are immediately given a position as "expert", often lacking someone more experienced to rely upon for help. The shortage means that most coastal engineers in developing countries are project engineers with little time to develop new coastal engineering tools or to engage in research. However training alone is not enough. Training and awareness-raising is most effective when the newly trained staff can apply their skills. In turn this requires adequate financial support.

58. An important pathway for the transfer of coastal engineering technologies is via the training of young professionals from developing countries in developed countries, mainly in the Netherlands and the United States. For example, many coastal engineers in developing countries have done further degrees at the International Institute for Infrastructural, Hydraulic and Environmental Engineering (IHE) at Delft in the Netherlands. Since 1957, IHE has trained more than 2,000 coastal engineers and scientists from many parts of the world.

59. While training is an important component of the development and transfer of coastal adaptation technologies, the particular technology needs for a given coastal situation tend to be unique. This limits the scope for developing best practice guides for the development and transfer of coastal adaptation technologies. Simply copying structures may not result in the diffusion of best practice. Structures in developed countries may be the result of political and economic compromise and may not be the best technologies or practices available. Once trained, coastal engineers from developing countries sometimes return and emulate the practices they have been taught or have seen. Concerning 'best practice', there are examples where engineers in developing countries want to copy exactly the design of structures they have seen work in other countries (perhaps due to lack of support from peers or experienced mentors). One case, for example, involved the copying of a northern European harbour design including a device relevant to reduce ice pressure, which was installed in its entirety in a tropical country.

VI. BARRIERS TO THE DEVELOPMENT AND TRANSFER OF COASTAL ADAPTATION TECHNOLOGIES[8]

60. Many examples of barriers to the development and transfer of coastal adaptation technologies are described below. The barriers are discussed under two broad themes:

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[8] This section on barriers draws upon information provided by coastal zone experts (academics as well as the private sector), the UNFCCC Expert Meeting on Coastal Adaptation Technologies (22-23 March 1999, Bonn) and from working drafts of the coastal zone chapter of the *IPCC Special Report on Methodological and Technical Issues in Technology Transfer.*

- Sectoral barriers (applicable to both developed and developing country contexts); and

- Specific barriers to the transfer of coastal adaptation technologies to developing countries.

A. Sectoral barriers to the development and transfer of coastal adaptation technologies

61. A number of generic barriers to the transfer of environmentally sound technologies have been widely cited in the literature.[9] Broadly such barriers can be classified as:

- Institutional: lack of legal and regulatory frameworks, limited institutional capacity, and excessive bureaucratic procedures, restrictive bidding procedures, restrictions on ownership and control;

- Political: instability, interventions in domestic markets (for example, subsidies), corruption and lack of civil society;

- Technological: lack of infrastructure, lack of technical standards and institutions for supporting the standards, low technical capabilities of firms and lack of a technology knowledge base;

- Economic: instability, inflation, poor macroeconomic conditions and disturbed and/or non-transparent markets;

- Information: lack of technical and financial information and of a demonstrated track record for many coastal adaptation technologies;

- Financial: lack of investment capital and financing instruments;

- Cultural: consumer preferences and social biases; and

- General: intellectual property protection, and unclear arbitration procedures.

62. In line with these generic barriers, there are a number of barriers specific to the coastal sector. These sectoral barriers to the development and transfer of coastal technologies are applicable to both the developed and developing country contexts. Key barriers include:

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[9] See for example FCCC/TP/1998/1.

- There are large uncertainties about the scale of sea-level rise and associated effects. Although sea-level rise predictions are converging, tools to understand and raise awareness about other important factors such as possible changes in future wave and wind climates are not available. In turn, these uncertainties make it difficult for governments to commit expenditures;

- There is a lack of finance to incorporate adaptation into coastal projects - coastal engineering projects are generally expensive and often there is very little money available for basic projects. Discretionary projects are generally not funded and only those projects which need to be undertaken, usually after a storm event, are undertaken. Building adaptation into new projects usually involves greater up-front capital costs.

- Short-term political and economic considerations frequently win out over longer-term approaches. Political and economic time-scales can be shorter than those associated with the research, planning and consultation necessary for major coastal projects, in some cases resulting in a lack of action;

- Few countries have integrated coastal zone management plans. In many instances, vulnerable coastal nations have yet to publish integrated coastal zone management plans. In other cases where plans have been made, there can be a lack of funds for implementation;

- Decision-makers are risk averse and frequently favour traditional hard structures over ‘softer’ or innovative coastal adaptation technologies. Generally, funding agencies and to some extent consultants have little appetite for experimentation. Very few innovative coastal engineering projects are being implemented;

- Different perceptions of risk lead to different priorities. National approaches to risk assessment vary and are evolving. A case study is the Netherlands. The great flood of 1953 prompted the Government of the Netherlands to adopt the 1 in 10,000 event criterion still used with respect to some of its sea defences. A process to move from a ‘failure’ rate criterion towards a risk-based approach involving consensus on acceptable levels of damage in the event of flooding is under way in the Netherlands. There is, therefore, a transition from a failure rate, to a flood rate of the polders, then to a damage (risk) assessment. Few countries have adopted this approach. Consequently, certain approaches including coastal adaptation technologies may be overlooked in the search to avoid solutions where accommodation of the potential risk is factored in;

- The influence of insurance, or the lack of it. In the case of coastal projects, lack of suitable insurance products may stifle innovation (see also above on risk adversity, risk perception and demonstration projects). In terms of general development and settlement trends in vulnerable coastal areas, the availability or otherwise of insurance (public or private) can significantly influence vulnerability. On the one hand, a lack of insurance can discourage high risk development and on the other its availability tied to appropriate incentives can encourage settlements at lower risk. Insurance (public or private) can be an important vehicle for raising awareness among coastal land owners of the potential risks due to climate change;

- Appropriate software, tailored to specific local needs and circumstances to assist in decision support, is mostly unavailable and costly to develop;

- Small and medium-size private enterprises can be left out. Small companies/projects do not attract much attention from government, yet small and medium-size enterprises do a good deal of the development;

- Social attitudes and behaviour are complex. Viable technical solutions for coastal adaptation must be considered in the context of social attitudes and behaviour. Sometimes it is social choices which exacerbate the vulnerability of the coast to sea-level rise;

- Coastal adaptation technologies are not easily scalable. The planning and design of coastal structures requires detailed and often complex analysis. Experience at one site can only be transferred elsewhere with caution, as the effectiveness or otherwise of a particular technology depends on site-specific conditions;

- Coastal mangers are not aware of climate change. Climate change, weather protection, and environment are not top priorities for those responsible for managing the coast. Indeed, sometimes weather protection is not recognized by coastal managers; and

- Property rights. The majority of coastal adaptation technologies are in the public domain. However in some instances - though these are relatively few compared with other sectors (a consequence of the tradition of public coastal engineering) - intellectual property rights could perhaps be a barrier to the transfer of appropriate coastal adaptation technologies. Examples of patented technologies include the shapes of so-called armour units and a new underground drainage technology developed in Denmark. The software for understanding coastal morphology/wave fluxes/sediment transport is a further area where property rights are well established. However in the case of armour units, the most widely used designs are those that are, or were, patented (versus those that have never been patented). The lack of property rights could therefore be a barrier to the development and transfer of coastal adaptation technologies.

B. Specific barriers to the transfer of coastal adaptation technologies to developing countries

63. Specific barriers to the development of coastal adaptation technologies within developing countries include:

- Coastal adaptation is not seen as a development objective. The causal chain which links economic development/poverty eradication first to good coastal zone management and then to coastal adaptation to sea-level rise is not well understood or accepted. Expenditures on coastal projects are carried out in the name of economic goals. Coastal engineering in developing countries is supported by the government to stimulate and support economic activities, such as fisheries and port development and tourism;

- Foreign coastal consulting and construction engineers sometimes engage in “technology push”, attempting to sell what is on the shelf rather than develop new *in-situ* technologies. Local expertise, needs and concerns are often overlooked;

- Foreign technology pull: at the same time there is often a strong belief on the part of coastal managers in developing countries that buying foreign is buying better. This tendency undermines long-term local capacities to develop sustainable coastal adaptation technologies;

- Lack of education, training or awareness. While a great deal of information is available in the coastal engineering literature about what works/does not work, this information can be difficult for decision-makers to access or assimilate;

- Engineers returning from training overseas often lack support to develop and implement new techniques and working practices. Newly qualified engineers are given the position of ‘expert’ before serving apprenticeships and gaining seasoned experience. There is generally a lack of supervision within the industry for young qualified engineers;

- Lack of domestic capacity to engage in research or develop new tools. Training alone does not enhance technology transfer. Coastal engineers may be assigned other administrative duties, or lack funds, instruments and even political support to engage in meaningful research to develop appropriate tools. In addition, low remuneration (and the consequent risk of brain drain), lack of resources and a lack of training means that the engineer becomes outdated and despairs. This set of problems could be addressed by a more long-term programme of training and updating skills;

- Lack of coastal centres and networks (this is described in more detail in section IV); and

- The specific challenges of developing nations lie outside the mainstream of developed countries. National and international collaborative research and development programmes of developed countries have few incentives to focus upon the unique engineering challenges for coastal adaptation technologies in other vulnerable coastal areas.

VII. OPTIONS TO ACCELERATE AND SUSTAIN THE DEVELOPMENT AND TRANSFER OF COASTAL ADAPTATION TECHNOLOGIES

64. What are the options to accelerate and sustain the development and transfer of coastal adaptation technologies ? In many cases, such options might seek to address the various barriers to the development and transfer of coastal adaptation technologies described above. As described in section V, the central pathway for the development and transfer of coastal adaptation technologies is the design, planning and implementation of coastal projects. Various opportunities exist to address such barriers in the context of the project cycle.

65. The UNFCCC coastal adaptation expert meeting identified a number of key characteristics to describe what it termed as ‘sustainable coastal adaptation technology development and transfer’. The five key characteristics of projects which contribute to sustainable coastal adaptation technology development and transfer are:

- The project proposal is supported by a sound understanding and evaluation of local coastal characteristics and processes;

- The project is located within the goals of a national or regional coastal zone management plan;

- The project cycle includes appropriate elements relating to: pre-tender awareness-raising, pre-qualification criteria, encouragement of competition and creativity, socio-economic evaluations, whole life cycle costs (projects should have maintenance costs built in) and post-project evaluation;

- During design, planning and implementation, the project seeks to contribute to the building of local and/or regional capacities to support coastal zone planning and management (e.g. use where possible of local expertise and capacities as well as on-the-job training); and

- Where possible, projects contribute to, and form part of, longer-term collaboration between government and the private sector.

66. The coastal adaptation expert meeting identified a range of options to accelerate and sustain the development and transfer of coastal adaptation technologies, which could be considered by a broad spectrum of stakeholders involved in taking decisions which affect the infrastructure and management of the coastal zone. The range of stakeholders includes:

- Development banks (and others loan providers) and aid agencies;
- Intergovernmental organizations;
- National, regional and local government;
- Universities (both research and teaching/training functions)
- Private sector (consulting and construction coastal engineers);
- Insurance companies; and
- Non-governmental organizations.

67. A detailed set of options, identified at the coastal adaptation expert meeting, relating to the roles that each of the different stakeholders could play and which could help implement sustainable coastal technology development and transfer, is listed below.

Development banks, others loan providers and aid agencies

68. Development banks, other loan providers and aid agencies play a central role in the financing and often design, planning and implementation of coastal projects. Finance providers are often in a position to foster sustainable coastal technology development and transfer, for example by:

- Encouraging national and regional governments to locate coastal projects within national and regional coastal reviews and assessments;

- Ensuring that best available technologies are integrated into project design;

- Encouraging and facilitating long-term post-project evaluations (e.g. after 10 years), perhaps as a condition on future-related loans;

- In conjunction with the private sector, helping to set up and resource independent national coastal zone assessment boards to provide adequate third party assessments of projects and post-project evaluations;

- Setting aside specific funds to encourage projects which contribute to sustainable coastal adaptation technology development and transfer as well as for demonstration projects;

- Packaging projects within longer-term cooperation frameworks to provide clearer signals to the private sector of longer-term commitment;

- Where possible, encouraging appropriate project planning to incorporate whole life cycle project costs, i.e. including operating and maintenance costs of the coastal adaptation technologies;

- Ensuring that adequate training and advice are available to prepare specifications and assess bids;

- Listening carefully to local stakeholders and providing independent and appropriate third party expert advice, together with a commitment to continual support;

- Linking aid and/or loan conditions to the undertaking and implementation of national and/or regional coastal zone management plans; and

- Integrating climate change considerations into natural disaster mitigation planning and relief.

Intergovernmental organizations:

69. Several options could be considered by appropriate intergovernmental organizations, particularly emphasizing their comparative advantages in providing information and raising awareness. Options include:

- Raising awareness and enhancing the understanding of sea-level rise and other climate change impact predictions, including translation into meaningful and effective action among the various stakeholders in the coastal zone;

- Encouraging and facilitating national governments to set appropriate technology goals for coastal adaptation technologies, while helping to establish appropriate international research and development goals and funding priorities for sustainable coastal adaptation technologies;

- Facilitating improved cooperation and coordination among multilateral and bilateral loan providers and donors (e.g. arranging workshops and seminars to share policies and experience); and

- Cooperating with existing regional centres and supporting an international network of regional clearing houses to provide coastal zone managers and engineers in developing countries with greater access to a wider variety of technical and project-related information.

National, regional and local government

70. National governments play a critical role in setting the general legal, institutional and economic framework in which projects are carried out and, together with regional and local governments, agree project terms and conditions. The options described above relating to development banks, other loan providers and aid agencies constitute a sustainable coastal adaptation technology ‘push’. In many cases, government at all levels could undertake complementary actions to ‘pull’ finance providers toward sustainable coastal adaptation technology development and transfer. In addition to these complementary options, other options include:

- Ensuring an appropriate national framework of policies, including national and/or regional coastal zone management plans as well and coastal adaptation R&D programmes (national and international);

- Providing support to sustain knowledge and expertise in the field of coastal zone management and coastal adaptation, by encouraging the development and maintenance of adequate institutional capacities (hydraulic laboratories, monitoring networks, training institutions);

- Increasing direct support for the training of both senior and junior engineers from developing countries;

- Providing clearer long-term signals to loan providers and the private sector, in particular by packaging loan and aid requests into longer-term agreements or frameworks to provide regional and local government, as well as the private sector, with greater foresight. In turn this may help encourage international private sector coastal consulting and construction engineers to establish regional offices, backed by a long-term commitment to staff and maintain them;

- Packaging coastal adaptation projects within other civil engineering programmes to provide the incentive of spin-off markets to the private consulting and construction engineering sector;

- Providing feedback to academics and the private sector on local issues, including the training of foreign consulting and construction engineers through appropriate *in-situ* knowledge exchange;

- Endogenous building up of local institutional capacities, e.g. through support for liaison officers to interact with regional and national stakeholders; and

- Helping non-governmental organizations to promote sustainable coastal adaptation.

Universities (research, teaching and training)

71. Through fundamental scientific and applied engineering research, as well as teaching and training, universities are particularly important in expanding the scope of possibilities and lowering the costs of long-term adaptation to sea-level rise and its associated effects. Particular options include:

- Undertaking research to apply existing knowledge where there are different boundary conditions, where possible stemming from practical situations;

- Engaging in partnerships with the private sector and local government;

- Supporting appropriate research on, and development of, post-project evaluation frameworks (e.g. learning from failures as well as successes);

- Providing focused teaching and training to national and foreign students, incorporating appropriate advice and feedback from the public and private sectors;

- Altering the reward structure within universities to encourage better quality teaching;

- Boosting capacities to provide distance learning/continuous improvement for coastal zone managers and engineers in the field, in particular incorporating learning processes which attempt to gain the commitment not only of young foreign-trained professionals but also of their senior managers;

- Encouraging *in-situ* “two-way” information exchange and learning between developed and developing country knowledge bases; and

- Providing additional support and guidance relating to the training of university trainers.

Private sector

72. Together with governments and finance providers, the private sector forms the third member of the typical project consortium. The private sector most closely associated with the development and transfer of coastal adaptation technologies consists mainly of coastal consulting and construction engineers who operate internationally in developing countries. Frequently it is the private sector which helps design, plan and implement coastal projects identified by national government and finance providers. Options which the private sector could consider include:

- Entering into long-term cooperation and framework agreements with national and regional governments, including the encouragement of partnerships to long-term foster responsibility for stretches of coast (design and build, and maintain);

- Building adequate and appropriate training for local companies and government into the terms of reference and project bids to ensure that projects contribute to capacity-building and knowledge exchange;

- Engaging in joint ventures between large international consultants and local small and medium enterprises;

- Setting up and maintaining regional offices in response to government incentives (e.g. long-term partnership or framework agreements, greater market potentials); and

- Promoting enhanced and perhaps innovative approaches to the training of coastal engineers from developing countries (e.g. through public-private partnerships).

Insurance companies

73. Insurance plays an important role in various parts of the project cycle. Insurance and re-insurance companies could consider options to support other key stakeholders in their pursuit of sustainable coastal technology development and transfer. This may for example include examining ways to provide guarantees for demonstration projects and activities as well as insurance products which help finance providers, governments and the private sector to equitably share and manage the risks relating to the development and transfer of sustainable coastal adaptation technologies. At the same time, insurance companies could build into project requirements many of the elements relating to sustainable coastal technology development and transfer outlined above.

Non-governmental organizations

74. Non-governmental organizations could play a critical role in raising awareness about sustainable coastal adaptation. However, such organizations would in many cases require additional support to develop suitable strategies to approach the interconnectedness of many environmental and social issues surrounding coastal adaptation responses. In addition to raising awareness on various coastal-zone-related impacts and adaptation options, non-governmental organizations may wish to consider options to help them participate in project design, planning and evaluation.

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Annex I

UNFCCC EXPERT MEETING ON COASTAL ADAPTATION TECHNOLOGIES

In response to a request from SBSTA to prepare reports on adaptation technologies, the UNFCCC secretariat convened a meeting of 12 coastal zone managers and engineers to obtain relevant advice and guidance. The objective of the meeting was to promote an exchange of views on options to accelerate and sustain the development and transfer of coastal adaptation technologies. The list of participants is provided below.

Experts discussed the context for coastal adaptation technologies, and noted that the technologies themselves are sub-components of the wider framework of coastal zone management. Participants reaffirmed that the consideration of coastal adaptation technologies should be related to the three fundamental coastal adaptation options identified in the IPCC Second Assessment Report (retreat, accommodation, protection). Participants discussed an array of technologies to support coastal adaptation. Coastal adaptation technologies include technologies to gather information about coastal characteristics and processes (e.g. gauges, monitoring technologies), decision tools (models, software) and technologies included in the design, construction and maintenance of projects designed to retreat, accommodate or protect a particular part of the coastal strip.

While the number of coastal adaptation technologies is large, the group noted that there are very few of them which do not suffer from hydrodynamic constraints, or involve significant socio-economic and environmental costs. Indeed most, if not all, technical responses to sea-level rise and associated effects have social, economic and/or environmental drawbacks.

Participants noted that applying technologies which are not properly understood or have been simply copied and applied to a new location without due attention usually results in an exaggeration of such drawbacks. In many cases, experience has demonstrated that taking action can be worse than doing nothing. Nevertheless, in specific situations where coastal processes are understood and clear political decisions have been taken in the context of an integrated coastal plan, technologies are available to attenuate or avoid particular coastal impacts. The experts identified a number of examples of gaps in the existing knowledge-base regarding coastal adaptation technologies which, if filled could support coastal adaptation (see section IV, E). They also listed options which could help identify coastal adaptation technology needs.

The coastal project cycle was presented as a practical framework within which to understand and describe the development, and in particular the transfer, of coastal adaptation technologies. Participants identified several important and specific barriers to the development of coastal adaptation technologies, many of which relate to issues concerning the project cycle.

Experts also provided feedback on the pilot survey of worldwide institutional capacity in the field of coastal zone management and engineering (see section IV, D) and identified a range of options to accelerate and sustain the development and transfer of coastal adaptation technologies. In particular experts developed the concept of sustainable technology transfer (see section VII).

List of participants

Alan Brampton: HR Wallingford Ltd., United Kingdom of Great Britain and Northern Ireland

Bilan Du: China Institute for Marine Development Strategy of State Oceanic Adm., China

Alfonse Dubi: Institute of Marine Sciences, University of Dar-es-Salaam,
United Republic of Tanzania

Ben Hamer: Halcrow International Partnership, Consulting Engineers, United Kingdom of Great Britain and Northern Ireland

Raymond Johnson: Institute of Marine Biology and Oceanography, Sierra Leone

Russell Maharaj: South Pacific Applied Geoscience Commission (SOPAC), Fiji

Frank van der Meulen: National Institute for Coastal and Marine Management/RIKZ,
The Netherlands

Antonio Rowe: Coastal Zone Management Unit, Barbados

Andrés Saizar: Unit of Environmental Impact Assessment, Uruguay

Henk Jan Verhagen: Hydraulic Engineering Department, IHE Delft, The Netherlands

Earle Buckley: IPCC Lead Author, Special Report on Methodology and Technological Issues in Technology Transfer (National Oceanic and Atmospheric Administration, Coastal Services Center, United States of America)

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Dennis Tirpak
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Annex II

INFORMATION ON THE IMPACTS OF SEA-LEVEL RISE AS WELL AS ADAPTATION OPTIONS AND TECHNOLOGIES REPORTED IN NATIONAL COMMUNICATIONS[1]

Party	Reporting of impacts of sea-level rise and methods used	Coastal adaptation options and technologies reported
NON-ANNEX I PARTIES		
Argentina	140 km^2 of different regions and ecological systems are vulnerable to inundation from a 50 cm sea-level rise.	None
Republic of Korea	Multiple impacts from a non-specific sea-level rise.	• Relocation of basic structures • Achievement of harmony between environment and industry
Mexico	Various impacts described. Five regions analysed for a 2 metre sea-level rise using satellite images, aerial photos, ground testing and topographical charts.	None
Federated States of Micronesia	Inundation from 0.2, 0.3 and 1.0 metre scenarios for different islands.	• Protection of coral reefs (which can grow in line with sea-level rise) • Large-scale mangrove reforestation • Use of Micronesian technologies and practices to promote shoreline stabilization and coastal area ecosystem preservation. • Discouragement of contemporary sea walls, groyne and revetment construction. • Encouragement of local measures such as nearshore 'sea fences', 'staggered stone sea fences' (as in Yap) and use of stilts (as in Kosrae).
Senegal	Between 1,945 and 6,073 km^2 affected by inundation and erosion, (affecting a population of 68,000-178,000) using 0.5 and 1.0 m scenarios	• No options reported, total cost of protection reported at US$ 407-2,156 million.
Uruguay	Five regions vulnerable to sea-level rise showing 5 different types of land affected using three scenarios for sea-level rise, 0.3, 0.5 and 1.0 metres. Bruun and equilibrium erosion methods cited.	• Detailed costs for sea walls and beach nourishment to protect 14 different locations for each of three scenarios. Total costs range from US$ 46.5 billion to approximately US$ 4 trillion, depending on scenario and type of protection.
ANNEX I PARTIES		
Australia	Possible increase in frequency and intensity of tropical cyclones with associated impacts. Citations from 9 case studies including wetland areas, monsoonal rainforests, mangroves. Positive impacts on coral reefs due to sea-level rise reported, though reefs may be vulnerable to increased sea surface temperatures.	• Planning principles which require that coastal developments be safe for a 30 centimetre rise in sea level; • Minimum design levels for coastal and tidal structures; • Restriction of developments in low-lying areas; monitoring and research on sea levels.

[1] Initial national communications of non-Annex I Parties; second national communications of Annex I Parties.

Party	Reporting of impacts of sea-level rise and methods used	Coastal adaptation options and technologies reported
Canada	Acceleration of erosion problems which threaten coastal structures such as harbours and sewage disposal systems.	None.
Denmark	Coastal retreat accelerated, risk to existing dyke and storm flood protection increased, reduced effectiveness of sewerage systems of coastal cities, assuming 50 cm sea-level rise by 2100	• Slowness of sea-level rise offers time to adjust construction of structures to meet the need of changed conditions. • Beach nourishment.
Estonia	Increased erosion, changes in sedimentation patterns, disappearing beaches, loss of breeding habitats for migrating birds, salt-water intrusion, assuming a 1 m sea-level rise	None.
France	Increased inundation of low-lying coasts. Increased beach and cliff erosion, saline intrusion from a 0.3 m sea-level rise	None.
Germany	Various impacts for 5 states are presented (total areas affected with and without adaptation measures), endangered population, asset loss, wetland loss. IPCC method reported. Taking into account land depression a relative sea-level rise of 50-60 cm by 2100 is estimated.	• No specific options mentioned but cost of DM 300 million per year to 2100.
Greece	None.	• Studies have been conducted as inputs to planning processes. • Development of a national regulatory framework for coastal areas is being financed.
Iceland	More frequent sea floods and damage to roads, harbours and other structures, land erosion.	• Study launched on the vulnerabilities and to seek ways to reduce impacts.
Ireland	176,000 km^2. (0.25%) of total land area believed to be at risk from sea-level rise, mainly in the west of the country. Erosion or flooding of coastal transport routes.	• Coastal zone management study initiated to provide a strategic approach. • Cost of protection by building sea defences estimated to reach Irish £ 270 billion (1990 prices).
Japan	Sea surface temperatures to rise by 1.2-1.8 degrees. Sea-level rise around the country estimated to be 20-40 centimetres. Japan to lose 57-90 per cent of its sandy beaches (for 30-100 cm sea-level rise). Coupled atmosphere-ocean general circulation model cited.	• Raising levels of breakwaters, bulkheads, mooring quay walls, wharves. Additional flood protection measures. • 12 trillion yen to maintain coastal facilities at present levels.
Lithuania	Erosion, inundation.	• Planning regulations • Coastal research programme

Party	**Reporting of impacts of sea-level rise and methods used**	**Coastal adaptation options and technologies reported**
Netherlands	Sediment losses using sediment budget analysis.	• Policy of ‘dynamic preservation’ and research to find best way to supplement loss of sediment from the foreshore (7-12 metres deep). • Design of new structures must incorporate a 50 cm sea-level rise. Rotterdam storm surge barrier (1997) was the first such structure.
New Zealand	CLIMPACTS model predicts 17-35 cm sea-level rise for New Zealand by 2050.	• New Zealand Coastal Policy Statement guides local authorities in their day-to-day management (local authorities responsible for avoiding, minimizing and mitigating the costs and effects of natural hazards.
Poland	2,200 km^2 of coastal zone, 230,000 people at risk assuming 1 m sea-level rise.	• Implementation of all feasible precautions and protective measures aiming at minimizing land loss • Total cost of protection reaches Zl 34.5 billion (1990 prices). • Establishment of protective systems along open coasts (16.3 km of dykes, 21.7 km of sea walls and 1 km. of offshore breakwaters). • Preservation of polder on periphery of Odra river estuary. • Construction of 100-280 km of new dykes and reconstruction of 240-340 km. • Modernization of the existing polders.
Portugal	Acceleration of erosion, innundation of low-lying coastal areas, increased risks of flooding close to river mouths and to coastal structures.	• Make inventory of regions at risk. • Regulations, planning measures. • Promotion of natural conservation of beaches and dunes. • Regulations to enforce consideration of problem of sea-level rise for new coastal structures.
Russian Federation	Impact of sea-level rise on ports (e.g. St. Petersburg).	• Dam constructed at St. Petersburg to prevent flooding may be seen as a protection against longer-term sea-level rise.
Spain	Inundation and beach loss, increased erosion assuming 50 cm sea-level rise by 2100 (IPCC).	None.
Sweden	Ports/bridges using 0.5 m sea-level rise scenario.	• ‘Costly adjustments’ to ports and bridges
United Kingdom	Impacts related to agricultural land, coastal aquifers, coastal flooding, fish stocks; nursery and aqua-culture sites; salmon and other migratory species.	• Planning policy guidance. • Research on climatic status of UK coastal waters.
United States	Inundation of low-lying areas, shore erosion, more coastal flooding, saline intrusions within 1 metre of mean high water.	• Fourfold strategy: hard and soft engineering management options as well as property protection strategies. • Federal Coastal Management Act requires states to consider the problems of sea-level rise in their programmes. • Coastal Risk Assessment Database developed.

Source: UNFCCC secretariat.

Annex III

DESCRIPTION OF COASTAL ADAPTATION TECHNOLOGIES

Table 1. Examples of technologies to assess coastal processes, characteristics and vulnerabilities

Technology	Description
Data gathering technologies	
Tide gauges	The ability to detect changes in relative sea level (isostatic vs. eustatic sea level) is, in itself, an extremely important aspect of adaptation. Tide gauges measure water levels relative to land. Requires very long-term commitment to maintain system of gauges and analyse data.
Wave gauges	Wave gauges are used to measure various characteristics of waves including: height, period, length, direction. There are various types of wave gauges including: wave rider buoys, pressure gauges, and wave recorders. Networks of wave monitoring stations require fairly sophisticated maintenance and long-term support.
Wind recorders	Wind recorders measure various properties of wind (e.g. strength, direction). Once installed, wind recorders require basic maintenance and data handling skills.
Current meters	Current meters are used to measure current velocity and direction as well as to map sea surface topography.
Salinometers	Salinometers are instruments to determine the degree of salt water intrusion in coastal areas.
Sediment traps, dredge grabs	Various devices, including sediment traps and dredge grabs, can be used to collect sediments for coastal sediment analysis and mapping.
Geological surveys	Geological surveys provide information on solid geology, long-term geomorphology, plus local availability of rock, sand, aggregates. Surveys can be expensive to perform.
Echo-sounders and continuous seismic profilers (CSP)	Echo sounders and CSPs are used in topographic/bathymetric surveys to obtain information about the topography of the ocean bottom.
Beach profiling	Beach profiling involves conducting surveys of the cross/long beach profiles using various manual techniques.
Habitat mapping	Field mapping of ecosystems. Numerical/qualitative *in situ* data gathering. Time series information can be collected by the field deployment of the instrumentation.
Baseline environmental surveys	Bird counts, plant surveys, fisheries surveys. However, large natural variability make direct causal links difficult.
Contingent valuation method (CVM) surveys	CVM surveys are used to solicit the views of local users (e.g. to determine the recreational value of beaches).
Shoreline monitoring	Shoreline monitoring involves the collection of various kinds of quantitative and qualitative data. Potentially low cost if community-based but can be higher technology (e.g. satellite). To be useful, data need to be checked, collated and analysed.
Historical coastline change	A variety of methods can be used to map historical coastline changes including use of old maps, charts and photos and interviews with long-term residents. Techniques can be inaccurate but can be better than nothing.

Technology	**Description**
Satellite remote sensing, aerial photography mapping	Remote sensing is the collection of various kinds of data (e.g. geophysical such as sea surface mapping and topography, biological, environmental) using satellites and in some cases aircraft. Satellites are commercially available with resolutions up to 1 metre. Examples of uses of aerial photography include lidar - a technology derived from the oil exploration industry (and described in the forthcoming IPCC Special Report). Data from remote sensing generally need support of field data.
	Data management and decision support technologies
Wave prediction	Global and regional wave propagation models may be run in real time. Most models have been developed by the private sector.
Modelling of wave processes	Wave generation and wave transformation processes can themselves be modelled. Good input data and training is necessary, while the results can be of limited accuracy.
Hydraulic laboratories	Hydraulic laboratories are important for testing the engineering properties of structures in particular hydrodynamic conditions and can support various kinds of modelling activities: experimental; numerical; dynamical. Laboratories represent essential institutional capacity to assist in coastal adaptation. However, they are expensive to establish and maintain.
Predictive climate modelling	Predictive climate modelling is a young and mainstream coastal engineering research activity. There is still a long way to go in research terms, particularly in predicting coastal change in the medium and long term. This work is clearly important when predicting the effects of climate change and assessing the impacts of alternative solutions. Particularly important are models that can translate global mean sea-level rise into regional and local implications.
Flood warning and emergency response systems	Flood warning systems consist of a series of monitors and a central database. They are an efficient means of reducing loss of life due to coastal flooding. These systems can also make an important contribution to limiting the damage to property (if, for example, people can carry their most valuable belongings upstairs). Building warning and emergency response capacity can provide measurable returns on investment. There is some evidence that if people are confident that they will not die in a flood, they will be more willing to participate in schemes for enhancing coastal resilience which may involve them making some compromises e.g. accepting lost productivity due to occasional flooding of their land. The United States National Flood Insurance Programme (NFIP), for example, requires information technology to define the hazardous zone. Eligibility for flood insurance is provided in return for obeying codes.

Source: UNFCCC Expert Meeting on Coastal Adaptation Technologies, 22-23 March 1999, Bonn.

For each of the technologies described in tables 2 and 3 of this annex, an indication of the particular adaptation option (managed retreat, accommodation or protection) which the technologies support is provided, together with a brief description of the technology and, where appropriate, other relevant information regarding, for example, costs, advantages or disadvantages.

Table 2. Examples of demonstrated technologies to support implementation of retreat (managed), accommodation or protection coastal adaptation options

Technology	Description
Replacement easements	Option supported: managed retreat Alternative easements (access routes to and from the coastal area) in some cases may need to be arranged for in advance of their erosion/submergence. Such easements may have additional impacts on land not directly affected by coastal erosion.
Inland flood defences	Option supported: accommodation Inland flood defences are structures which essentially create a new coastal strip that is vulnerable to more frequent flooding. The area behind the defence is less vulnerable. This is a potentially cheaper option than other protection technologies, though it involves the adaptation of land use near the coastline e.g. from crops to grazing.
Flood-warning systems	Option supported: accommodation Flood warning systems can provide real-time predictions of high tides, surges and wave overtopping, and disseminate warnings. However, the systems need to be backed up by refuges, escape routes etc. (see also entry in table 1 of this annex). Such systems also have the disadvantage of potentially being inaccurate, leading to complacency or fear.
Relocation of reservoirs inland above the coastal zone	Option supported: accommodation Relocation of freshwater supplies currently in the vulnerable zone to somewhere above the saline intrusion zone may be necessary. In turn this requires component technologies used for reservoir reconstruction, pumping. Disruption costs are potentially high.
Better management of rain/waste water	Option supported: accommodation Various component technologies related to drainage and sewerage schemes would be needed to improve the management of rain and waste-water to reduce potential geotechnical erosion and recession problems.
Dune management	Option supported: accommodation The active management of dunes can contribute to the reduction of human-caused stresses on the coastal zone and wind damage and allow dunes to retreat landward. Potential drawbacks include reduced access and amenity and eventual land loss on the inland side of dunes.

Technology	Description
"Building with nature" techniques	Option supported: managed retreat, accommodation "Building with nature" techniques can include the creation, maintenance or restoration of wetlands, marshlands and dune systems. In cases where re-vegetation is required to simulate natural forms of dune or back-shore protection, this may involve the use of horticultural or arboricultural technologies to produce large numbers of seedlings or young plants needed to re-vegetate large areas. Re-vegetation is a relatively low-cost approach which does not disrupt coastal processes. Indigenous "pioneer" species for dune stabilization are particularly effective as a 'bridging technique' so that natural vegetation can be restored. Mangroves, for example, are a natural form of coastal protection, though they are not suitable for all coastal conditions (they are happiest in fine-grained soft organic muds deposited in sheltered locations). Other types of vegetation such as shrubs, grasses and ground-creeping vines have also been used in re-vegetation projects. Some locations may not be suitable for plantation. Care needs to be taken to choose the right vegetation, planting and fertilization for local conditions. These natural technologies may only accelerate existing morphological trends not change them. Such approaches may only work well for small wave climates and in particular seasons. The creation of wetlands and marshlands requires space, new set-back lines, proactive thinking, relocation of existing facilities and buildings. Artificial wetlands may take decades to replace the biodiversity of natural ones. In turn, this requires a commitment to long-term planning. Techniques such as setting aside land which is allowed to become saturated with autochthonous water and in turn encourage creation of peatbogs or even lakes are important options (e.g. see Klein *et al*, 1998).
Dredgers	Option supported: managed retreat, accommodation, protection Dredgers are an essential part of the heavy equipment needed to build and maintain coastal structures. They are expensive to run and maintain. Dredgers are vessels equipped with various types of equipment suitable for moving large quantities of sand/mud from one place to another. They are an important component technology of many other techniques and practices to stabilize or grow with the coast. Dredgers are classified according to the mechanisms employed to lift and shift the sand etc. Hence there are hopper dredgers, bucket dredgers, sweep dredgers, disc cutter dredgers, cutter suction dredgers. Certain methods of pumping sand have also been given names. There is for example the 'Rainbow Method' of dredging. Dredgers are particularly important for 'beach nourishment'. Beach nourishment may be the creation of a planned beach profile by dumping large quantities of sand onto the beach, or the creation of sand or shingle groynes using a combination of dredgers and mechanical earth movers. Nourishment preserves the natural beach and does not disrupt coastal processes. Disadvantages are that nourishment requires heavy equipment and a supply of sand. Typically this is not feasible for small projects. The current scale of beach nourishment is around 30 million cubic metres per year in United States, and of that order in Europe. Over time, the sand washes away and nourishment needs to be carried out again. New, bigger dredgers which could operate at greater depths, more cheaply, could help to reduce costs and environmental impacts, though the scope for such improvements is thought to be limited. At depths greater than 100m turbidity can be damaging to dredgers. While dredging operations are highly technological, the mobilization of dredgers (getting the right dredge to the right place at the right time) is itself a significant components of overall costs. The key part of the dredger is the sand pump. It is thought there are very limited possibilities for developing cheaper, efficient sand pumps.

Technology	Description
Mechanical earth movers.	Option supported: retreat/accommodation/protection Earth movers are used to push around large quantities of sand to make planned beach and dune profiles, at relatively low cost. The equipment is generally expensive to purchase, with moderate technology and maintenance costs.
Various methods to stimulate growth of coral reefs or artificially simulate them	Option supported: protection Coral needs suitable surfaces to grow upon. The importation of a substrate of carbonate sand or rock can therefore encourage reef growth (limited to environments where coral reefs develop naturally). Reefs themselves are a particularly effective natural coastal defence technology, acting like submerged breakwaters to dissipate incoming wave energy. Concrete piles have been driven into the seabed to act as a substrate to attract reef colonization. This technology is demonstrated in the Maldives. A form of artificial coral reef has been demonstrated using wire mesh through which a low electric current is passed. Calcites then form on the mesh. A method was developed called ‘Seacrete’. Geotextiles (see below) are covered with chicken wire connected to a low voltage electrical source. The electric field induces chemical reactions with the sea water. After a few months the wire is covered by a few centimetres of calcium rock with a structure similar to natural coral stone. This technology has also been used to create underwater sculptures. It would require relatively expensive sources of electric power, though this could possibly be supplied by renewable energy. Floating or ‘surfing’ reefs are constructed and held down on the sea bed. Reefs can enhance biological diversity and be used, for example, as fisheries. Reefs and piles are unlikely to solve the problems of sea-level rise. They may themselves generate adverse effects on adjacent coasts, navigation channels.
Hand-placed rock sea walls (inclined)	Option supported: protection Local rocks combined with other materials (e.g. shingle, coconut by-products) are hand-placed to form sea walls. Hand-placed rock sea walls are a common line of protection used, for example, in the Pacific region (e.g. extensively used in Kiribati). Placed correctly and maintained, hand-placed sea walls have been demonstrated as an effective technology. Human-built structures can be surprisingly better than machine ones, as humans are good at packing and placing rocks. These walls are relatively simple to put in place but still need some skill. However, they have limited capacity to withstand waves and, like all sea walls, have some adverse hydraulic effects.
Gabions	Option supported: protection Gabions are low-cost wire or plastic baskets filled with local materials (shingle). The baskets vary in size from half to one metre cubed. Baskets are placed together as building blocks to form structures or buried revetments to act as a last line of defence in a storm. The great advantage of gabions is that they can be constructed with a minimum of equipment. They are also portable and can be removed if not effective. However, they deteriorate rapidly. Some supervision may be required to fill with suitable size and shape rocks. Gabions are particularly suited to lagoonal shores.
Timber piles	Option supported: protection Timber piles are an important component technology used for other structures (e.g. a low-cost method of making reefs or sea walls). Piles are driven into the sand. Used tyres or other material can be placed over the piles and fixed together with chains or bolts. A supply of timber resistant to biodegradation is needed.

Technology	Description
Bags made from geotextile material	Option supported: protection/retreat Geotextiles are bags, mattresses, tubes and containers made out of high-strength fabrics and filled with sand, mortar. These different shaped bags or tubes are then used to make large structures. Mattresses and bags are generally used for slope and bed protection, tubes and containers for construction of groynes, perched beaches or offshore breakwaters. The first applications of this technology started in the 1950s, with more rapid developments in the 1970s. Geotextiles are a relatively cheap alternative to riprap (rock), concrete units or asphalt as a construction material. A main obstacle to their larger scale deployment is the lack of proper design criteria for the geotextile structures (e.g. Pilarczyk, 1994). Geotextiles are particularly useful for the construction of underwater breakwaters and sills, which are not easy to construct with traditional materials. Several geotextile designs are patented. Examples include Longard tubes, Dura bags, Fabriform range, Bolsaroca, Bolsacreto, Cochacreto. Geotextile structures are not stable in the long term - a possibly attractive feature for managed retreat options.
Coastal protection units (also known as ‘armour units’)	Option supported: protection Coastal protection units or ‘armour’ units are an important component technology of coastal structures, particularly in situations where there are no local or even regional supplies of riprap. Armour units are precast high-strength concrete structures (weighing up to 2 tonnes). They are available in many different shapes and sizes. Often these shapes are specifically designed to be interlocking to give a structure made up of such units stability. The key to a successful armour unit design is one which withstands wave motion and in which the units do not start to move about. Moving causes damage to the protection units, breaking off ‘arms’ or other features, eventually rendering the structure much weaker. Armour units are generally an expensive solution often used to protect expensive infrastructure built on exposed coasts and where there is a lack of large rock (commonly known as “armour rock” or “riprap”). They also require heavy equipment. They can however be designed to suit particular wave conditions. The cost of a typical armour unit is around US$ 50. Of the order of tens of thousands are needed per kilometre of coast to be protected. Major technical breakthroughs in the design and effectiveness of coastal protection units are unlikely. Manufacturers already have incentives to create lighter, longer lasting units for less money. Any real breakthrough would most likely have to come from use of non-conventional materials. Many designs for coastal protection units are proprietary. Names for the designs of various units or concrete revetment blocks include: Gobi (ERCO), Jumbo, Shpiap, Nami Ring, Stepped, Waffle, Lok-Gard, Terrafix, Armourloc, Tri-lock, SHED, Nicolon Armourflex, A-Jacks

Technology	Description
Groynes	Option supported: protection Groynes are structures placed perpendicularly to the shore to trap sediments. They re-distribute currents along the coast, altering long-shore sediment transport as a result. Groynes are constructed using wood, other local materials, concrete or steel. The immediate sand build-up on the up-drift side of the groyne is however combined with an immediate erosion on the down-drift side (often resulting in failure of the piles). Introduction of groynes is often a direct response to an acute sediment erosion problem. Groynes can be a relatively effective and low-cost way of preventing further erosion. A major problem however is that accretion of sediment means that beaches down drift are deprived of nourishment and erode faster. Effectively, groynes will shift the erosion problem down drift. Sediments are needed for the groyne field to work. Groynes are an unnatural beach obstruction and can if badly designed force sand off the beach into deep water. This approach is generally not recommended because of detrimental effects on the coastline.
Revetments	Option supported: protection A revetment is a slope consisting of loose or interlocking protection units (geotextiles may also be used). Revetments are medium to high-cost structures which provide protection to banks or cliffs of erodible material.
Bulkheads and sea walls	Option supported: protection Bulkheads and sea walls are retaining walls made of concrete or interlocking rocks whose primary purpose is to hold or prevent sliding of the soil while providing protection from light to moderate wave action. Sea walls are stronger, larger versions of bulkheads designed to prevent the back-shore from heavy wave action. Non-vertical walls on the seaward side more efficiently prevent ‘overtopping’ as the wave hits. Several aspects of the geometrical design of sea walls together with use of other materials at the base of the wall can improve the performance characteristics of the structure. Bulkheads and sea walls are heavily engineered inflexible structures. Bulkheads and especially sea walls are generally expensive structures requiring proper design and construction supervision. They protect the land area only and frequently cause adverse hydraulic impacts in front of the wall, including down drift. Few designs can be built by manual labour and from local materials. The structures have the side-effect of encouraging beach erosion. Typically they are deployed to protect high land and capital values, where threatened property and buildings cannot easily be relocated. These hard structures with relatively long lives can prevent autonomous coastal change. They are brittle structures and can fail catastrophically with no warning. They require maintenance and can give a false sense of security. Inexpensive designs are often ineffective. The south Pacific experience, for example, with inexpensive sea walls has been generally unsuccessful with one or sometimes two generations of sea walls having failed (other examples include areas in the Majuro Atoll and in the Marshall Islands).
Breakwaters	Option supported: protection Breakwaters are double-sided structures with water on both sides, used (as their name suggests) to dissipate wave and current energy. They therefore need to be much stronger and substantial than groynes. Breakwaters use large amounts of rock material (of the order of several cubic metres of material per metre of breakwater) and require special construction equipment. They can be constructed perpendicular or parallel to the shore or to form harbours. Breakwaters are generally expensive, sophisticated structures. They are therefore more prevalent in industrialised countries with a coastal engineering tradition. Any breakthrough in materials consumption of breakwaters would require designs using large voids. One low-cost option is to construct the core of the breakwater with waste material e.g. old car tyres.

Technology	Description
Storm surge barriers	Option supported: protection Storm surge barriers are sophisticated, expensive coastal defence structures that can protect tidal inlets, rivers and estuaries from occasional surge events. They generally incorporate advanced technology, and have high capital and maintenance costs. Maintenance is crucial and requires a flood warning system. These barriers are not applicable everywhere, but are best suited to tidal inlets with narrow mouths.
Flooding and storm drains	Option supported: accommodation/protection Flooding and storm drains are technologies to manage the run-off of rain water. They can prevent serious erosion during storms
Polders	Option supported: protection Polders are areas with an artificially controlled water level. The polder technique is a method to encourage the accumulation of sediment. Polders themselves may not reverse erosion trends.

Source: UNFCCC Expert Meeting on Coastal Adaptation Technologies, 22-23 March 1999, Bonn.

Table 3. Examples of new technologies to support implementation of retreat (managed), accommodation or protection coastal adaptation options

'Coastal Drain Beach Management System'	Option supported: protection (beach nourishment) Lowering the water table below a beach can alter the beach profile. A novel approach to beach nourishment has recently been demonstrated which does not require the use of dredgers. A channel is dug along the beach about 5 metres from mean tide level (the 'uprush' zone) and 4 metres deep. Drainage pipes are inserted in the channel together with a pumping system to drain the pipes. Sand is replaced. This is a relatively new technology demonstrated in non-macro-tidal areas. The technology represents a very local solution to a larger problem. Energy costs could be considerable. Emissions could be reduced by using renewable energy.
Bubble curtains	Option supported: protection Bubble curtains have been demonstrated in the laboratory as a wave dissipation technology. Air is pumped and dissipated through tubes. A wall of bubbles has been shown to be effective at dampening wave forces. The technology has not been demonstrated on a large scale. Air pumps require energy. One possibility is that this could be renewable energy.
Self-priming buried sand pumps	Option supported: protection An innovative idea is that self-priming pumps could be buried on the sea floor. Potentially such a technology could be an effective part of a beach management system for recycling material, particularly if powered by renewable energy sources. These pumps would provide additional long-shore transport of sand from areas of accretion. However, the technology may be expensive to run and may require substantial maintenance.
Movable structures	Option supported: managed retreat In order to be able to retreat it would be beneficial to have movable structures, perhaps on a modular basis, which can be disassembled quickly and relocated to a set-back position. Potential drawbacks include conflicts with local or traditional planning practices.
Field of underwater screens/horizontal slabs	Option supported: protection Fields of underwater screens have been demonstrated in the laboratory as a potentially effective wave dissipation and near-shore stabilization technology. Concrete slabs can be buried vertically in the seabed. Prototypes have been demonstrated to dissipate incoming wave energy and prevent sediment loss. The design of correct field structure for local conditions would require sophisticated modelling and monitoring technologies. Horizontal concrete slabs placed under the surface water attenuate incoming wave energy. In some instances they have been demonstrated to be better at attenuating waves than vertical ones (see Bouchet, 1992).
Underwater pneumatic breakwaters	Option supported: protection (wave dissipation) Underwater pneumatic breakwaters are a high technology solution to attenuate waves. They oscillate in harmonic sequence with incoming waves and kill them almost completely if tuned exactly to the incoming wave period. This technology is unproven, expensive, and would require high maintenance. Sophisticated sensing equipment would be needed to tune to incoming waves. May require an energy supply.

Wave energy generating floating breakwaters	Option supported: protection Designs for wave energy generating breakwaters have included rows of buoyant 'wedges' strung together which oscillate with incoming waves. The waves behind the floating breakwaters are significantly damped. While wave energy generation technologies have been demonstrated for over two decades, they have proved expensive and unreliable. They may however be suited to generally calmer conditions where stresses are less. More attractive if there is a need for electricity as well as coastal protection.
Floating/inflatable breakwaters	Option supported: protection Tyres have been used as a buoyant material for floating breakwaters. Tyres are fixed together to form floating rafts. These rafts dampen incoming waves. These are small-scale structures suitable for small-scale waves. The 'Wave Maze' rubber tyre floating breakwater is patented and cannot be used without payment of royalties. Goodyear tyre company has also developed a design which may be used without charge. Relatively high technology is needed for the connections and high maintenance. Geotextiles with an impervious layer can be filled with air. These devices are lashed together and fixed down to the seabed. Floating breakwaters have been demonstrated in sheltered waters with locally generated waves. They are not thought to be effective in open ocean conditions.

Source: UNFCCC Expert Meeting on Coastal Adaptation Technologies, 22-23 March 1999, Bonn.

Annex IV

OVERVIEW OF COASTAL ZONE MANAGEMENT AND ENGINEERING CENTRES: A PILOT SURVEY [1]

The UNFCCC secretariat has undertaken a pilot survey of international centres of coastal zone management and coastal engineering with the cooperation of the Coastal Zone Management Centre (CZMC) in the Netherlands. The purpose of the survey was to establish an overview of the national, as well as international, institutional capacity available to support coastal adaptation.

The survey was undertaken through:

- A literature review (including the Tropical Coast Journals 1996-1998);
- An Internet search; and
- Inputs from experts from the Coastal Zone Management Centre and the International Institute for Infrastructural, Hydraulic and Environmental Engineering (IHE) in the Netherlands, including surveys of attendance at important coastal zone management and engineering meetings.

A number of preliminary conclusions can be drawn from the pilot survey regarding the status of national and international coastal zone management and engineering centres and networks. At the national level, the survey revealed that, in many countries, a wide variety of centres and individuals are working in the field of coastal zone management and engineering. Typically, five broad categories of institutions operate at the national level, including:

- National laboratories for civil and coastal engineering
- National departments of fisheries, environment, tourism, planning etc.
- National science and technology universities
- Private sector consulting and construction firms
- Non-governmental organizations

Industrialized countries with long coastal engineering traditions (e.g. the Netherlands, Denmark, the United Kingdom, the United States of America, Japan, France, Spain, New Zealand, Australia, Greece) tend to have a variety of institutions in each category. Developing countries, on the whole, tend to have fewer institutions, with some more than others. At the international level, the pilot survey identified nine examples of international or regional centres which are particularly active in facilitating the development and transfer of knowledge and

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[1] Extracts from the following report prepared for the UNFCCC secretariat: “Worldwide overview of coastal zone management centres and coastal engineering centres”. Netherlands Coastal Zone Management Centre, National Institute for Coastal and Marine Management, Ministry of Transport, Public Works and Water Management, P.O. Box 20907, 2500 EX The Hague, The Netherlands.

expertise in the field of coastal zone management and engineering (distinct from a wider group including centres of expertise in coastal sciences) (see table). Further conclusions regarding the pilot survey are also described in section IV. D.

Examples of international and regional centres active in facilitating the development and transfer of knowledge and expertise in the field of coastal zone management and engineering

Centre	Regional/national coverage
Coastal Zone Management Centre (CZMC) http://www.minvenw.nl/projects/netcoast/index.htm	South Asia, Southeast Asia, Central America, Baltic area, Southeast Africa, North Africa, Caribbean, Black Sea region
Coastal Resource Centre (CRC) http://crc.uri.edu	Regional field programmes in: Asia, Eastern and Southern Africa, Latin America and the Caribbean, United States
Center of Excellence in Coastal Resources Management (CECRM) http://www2.mozcom.com/~admsucrm/	Philippines, Southeast Asia
Coastal Resources Institute (CORIN) http://www.psu.ac.th/corin/	Thailand and the Asia Pacific region
International Centre for Coastal Resources Research (CIIRC) http://www.upc.es/ciirc/	Mediterranean
Coordinating Committee for Coastal and Offshore Geoscience Programmes (CCOP) http://www.ccop.or.th/	Thailand, East and Southeast Asia
Secretariat for Eastern African Coastal Area Management (SEACAM) http://www.seacam.mz/	Eastern and Southern Africa
International Centre for Living Aquatic Resources Management (ICLARM) http://www.cgiar.org/iclarm/	Bangladesh, Caribbean, Eastern Pacific, Egypt, Malawi, Solomon Islands
Center for Coastal and Marine Resources Studies (CCMRS) http://www.indomarine.or.id	Indonesia

Source: Netherlands Coastal Zone Management Centre.

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