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PROJECT PROPOSAL ON STORM SURGES DISASTER REDUCTION FOR THE NORTHERN PART OF THE INDIAN OCEAN

The Disaster Reduction for the Northern Part of the Indian Ocean was approved by the governing bodies of all international organizations and programmes concerned, namely, WMO, IOC and IHP of UNESCO (see IOC Resolution EC-XXXI.3).

This document contains the final version of the project proposal, which takes into account comments made at the Thirty-first Session of the IOC Executive Council and those of IHP and WMO. Modifications proposed by the regional meeting of parties held in New Delhi from 22-26 October 1999 are also reflected in this version. The document is recommended to be used as background material for Document IOC/EC-XXXIII/2 Annex 6 '*Progress Report on the Implementation of the Storm Surges Proposal*' under Agenda Item 4.2.2. of the Thirty-third Session of IOC Executive Council, June 2000.

PROJECT PROPOSAL

ON

STORM SURGE DISASTER REDUCTION FOR THE NORTHERN PART OF THE INDIAN OCEAN

October 1999

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EXECUTIVE SUMMARY

This proposal is a five-year programme to develop the infrastructure necessary for providing effective and timely storm surge forecasts and warnings. The primary objective is saving lives and property. In addition the project will make substantial contributions to encourage investment for sustainable coastal development, and to significantly reducing the aggravation of poverty caused by storm surge disasters in the region.

Storm surges associated with severe cyclonic storms of the coastal Northern Indian Ocean lead to frequent loss of life and damage which seriously affects the economy of the region. The countries bordering the Bay of Bengal and the Arabian Sea suffer the world's worst natural disasters. The devastation caused by a storm surge can be mitigated substantially if the height and time of peak water level at the coast and the area likely to be inundated due to storm surge can be forecast reliably.

The proposal includes improvement of the meteorological, marine and hydrological observing systems, and of the telemetry and data processing systems required. Suitable cyclone model and storm surge model (including inland inundation) developments are proposed, along with an operational oceanographic and hydrological numerical storm surge prediction facility. Procedures for strengthening of the links among the National Meteorological Services, National Hydrological Services, Marine Agencies and the counter-disaster and environmental organisations are proposed, in order to have the warning-response mechanism in place so that appropriate disaster prevention and preparedness measures be taken promptly. A key component of the proposal is capacity building and human resources development in the region through training, provision of equipment, and workshops / seminars.

ACRONYMS

UN	United Nations
UNCED	United Nations Conference on Environment and Development
IDNDR	International Decade for National Disasters Reduction
TCP	Tropical Cyclone Programme
WMO	World Meteorological Organisation
RSMC	Regional Specialised Meteorological Centre
WWW	World Weather Watch
HWRP	Hydrology and Water Resources Programme
IHP	International Hydrological Programme
UNESCO	United Nations Educational Scientific Cultural Organization
GOOS	Global Ocean Observing System
IOC	Intergovernmental Oceanographic Commission
GLOSS	Global Ocean
IOCINDO	IOC Regional Committee for the Central Indian Ocean
GDP	Gross Domestic Product
CSI	Coastal and Small Islands
TMD	Thai Meteorological Department
IMD	India Meteorological Department
DCP	Data Collection Platforms
XBT	Extended Bathy Thermography
CTD	Current Temperature Density
CES	Global Telecommunication
INMARSAT	International Maritime Satellite
NIO	National Institute of Oceanography, India
DOD	Department of Ocean Development , India
°C	Degree Celsius
NMCS	National Meteorological Centres
RCN	Regional Computer Network
AFDOS	Analysing, Forecasting and Data-processing Operational System
PMSS	Probable Maximum Storm Surge
SLR	Sea Level Risk
MSL	Mean Sea Level
CPP	Cyclone Preparedness Programme
CDMC	Cyclone Distress Mitigation Committee
TCDC	Technical Cooperation among Development Countries
DPP	Disaster Prevention and Preparedness
ESCAP	UN Economic and Social Commission for Asia and the Pacific
TSU	Technical Support Unit
VCP	Voluntary Cooperation Programme
NGO	Non-Governmental Organization
UNEP	United Nations Environmental Programme
GEF	Global Environmental Facility

1 BACKGROUND

Storm surges associated with severe tropical cyclones stand out as by far the most damaging among natural disasters. Death and destruction arise directly from the intense winds characteristics of tropical cyclones blowing over a large surface of water, bounded by a shallow basin. These winds cause the sea water to pile up on the coast, leading to sudden inundation and flooding of coastal regions.

The south Asian countries bordering the Bay of Bengal and the Arabian Sea are frequently affected by cyclonic storms originating/intensifying over these seas and moving over land areas. About 9000 km of coastal zones from Oman to Thailand and about 300 million people are exposed to cyclonic storms and associated storm surges. The economic structure and life style of the people of this region are heavily dependent on conditions during a cyclonic storm and associated storm surges, could wipe out years of economic achievement.

About 7 per cent of the world's yearly crop of tropical cyclones originate over the Bay of Bengal and the Arabian Sea. Of these most have their genesis over the Bay of Bengal, the ratio being 4:1, and usually strike either the east coast of India and the coast of Bangladesh, and less frequently on the coasts of Mynamar and Sri Lanka. The whole of the north Bay of Bengal is an area where the potential for storm surges and the range of the astronomical tide are very high. The enormity of the devastation caused by storm surges is evident: a single cyclone took toll of about 300,000 human lives in Bangladesh in November, 1970 and another 140,000 in April, 1991 and nearly 10,000 each in Orissa in 1971 and in Andhra Pradesh in 1977. There were about 40 events of severe storm surges in Bangladesh during the period 1800–1996. In many cases the observed maximum water level was 5–12 m and the death toll was 10,000 to 300,000. Fuller details of these tragic events are given in Appendix One.

In Thailand storm surges have occurred in the coastal areas of the Gulf of Thailand. In 1962 the storm surge accompanying tropical storm HARRIET that affected the Laem Taloon Pook peninsula in southern Thailand caused severe damage and more than 900 deaths. Typhoon GAY in 1989 also caused storm surge on the east coast north of Champhan and along the Rayong coast near the head of the Gulf.

Sri Lanka is affected less by storm surge compared with Bangladesh, India and Myanmar. But the cyclones of November, 1964, November, 1978 and November, 1992 have caused extensive loss of life and property. Storm surges affecting Myanmar are also to some extent less disastrous compared to Bangladesh and India. Notable storm surges affected the Myanmar area in May 1967; May 1968; May 1970 and May 1975, of which that in May 1975 was the worst. The storm surge due to the May 1975 event penetrated at least 100 km into the Irrawaddy river system and caused serious inland flooding.

The main factors contributing to disastrous surges in the Bay of Bengal, especially Bangladesh, are : (a) shallow coastal water, (b) convergence of the Bay, (c) high astronomical tides, (d) thickly populated low–lying islands, (e) favourable cyclonic track, and (f) complex coastline and innumerable number of inlets including one of the world's largest river system Ganga Brahmaputra – Meghna.

The frequency of storms and storm surges is less in the Arabian Sea than in the Bay of Bengal. However, major destructive surges can occur occasionally. There have been at least 8 major storm surges during 1782–1996 on the Arabian coast of the Indian sub–continent, when loss of life and property has been quite heavy. Surges also occurs on the Pakistan coast and along the south-west coast of the Arabian Gulf.

Tides in the Arabian Sea and the Bay of Bengal are large, with a range of several metres and are of the same order of magnitude as major storm surges. The most dangerous coastal floods occur when peak surges coincide with high tides. The surge of October 1981 in the Gulf of Kutch in the Arabian Sea, and the surge of November 1970 which affected the densely populated Meghna estuary in Banglades both occurred when peak surge and high tide coincided.

Another factor which contributes to the devastation caused by storm surges is flooding by swollen rivers. Cyclones almost always cause heavy rainfall which coincides with a storm surge propagating upstream into a river. This alone would cause flooding, but in addition, river levels far inland increase because of the blocking effect of high sea level due to a storm surge. Storm surge forecasting must include the upstream directed storm surge and a downstream directed floodwave.

While immediate loss of life is often the most dramatic result of a major surge, other effects can also be serious. Damage due to storm surges in the Bay of Bengal between 1945–1975 was estimated to be in excess of 7 billion US dollars. In the November 1970 surge, almost all the livestock in the surge-affected area were killed, and most of the fishing fleet was destroyed. It was estimated that the economic development of Bangladesh was set back by 4 to 5 years.

The coastal areas are flat and comprise natural levees and swamps, which are subjected to flooding from the sides as well as from the river channels. The blocking effect of a surge inundates vast tracts of low-lying lands for several days causing irreversible environmental damage. When the floods recede, silted river channels, salinity intrusions into the ground water and soil salination are left behind. The ground-water table is generally close to the surface and so intrusion of salt through aquifers and river channels present a persistent threat to agricultural productivity. Restoration of degraded soils and water bodies is and expensive and extremely long-term process. In addition river waters, contaminated with municipal sewage, industrial effluents and sediment severely pollute the coastal lands. Models of flooding will improve understanding of the water penetration and persistence, and so help identify impacts and anticipate remedial actions.

Another emerging factor which could have an impact on storm surges is the influence of climate change. Eventhough there is no universal agreement , the projected sea level rise and changes in storm frequency and intensity, if they occur could make things even worse. A rise of sea level by 1 metre due to global warming of 2–3^{o} C and/or melting of polar ice will have serious repercussions in South Asia. For instance, most of the Maldives, some part of Sri Lanka and substantial portions of Bangladesh would be permanently flooded. It is feared that land now occupied by 17% of the population of Bangladesh would be lost.

It is necessary that the problem of the storm surge be seriously addressed through the collective efforts and in an integrated way, by the countries of the Region and the relevant UN Agencies, and supported by the funding agencies.

The UNCED AGENDA 21 calls for co-operation among international agencies in the implementation of joint projects. This project will be a challenging and important response to this recommendation. It will also fully correspond to the recommendations of UNCED on sustainable development and to the principles and objectives of the International Decade for Natural Disasters Reduction (IDNDR, 1990-1999).

2 JUSTIFICATION and BENEFITS

It is clear from the above background that the tropical cyclones and storm surges and their associated phenomena (high winds, torrential rains, floods, etc.) cause tremendous damage to life and property in the countries bordering the Northern Indian Ocean, and particularly the Bay of Bengal. Everything possible must, therefore, be done from an economic and social point of view to minimise the disastrous effects of tropical cyclones and storm surges. With high concentration of population near the coasts, demand for quantitative estimates of vulnerability to storm surges of different coastal stretches have increased during recent years.

Progress has been made in cyclone forecasting and warning during the last two decades under regional projects on tropical cyclones. The same cannot be said about the procedure for storm surges forecasting and warning. It is still inadequate. Cyclone forecasting must be further improved, and applied to drive models for forecasting storm surges.

Several existing programmes and organisations are involved. The National Meteorological and National Hydrological Services of the countries of the region have achieved some success in provision of cyclone warnings and for implementing improvements within the existing facilities through co–operative and co–ordinated sharing of responsibilities within the framework and overall guidance and supervision of the Tropical Cyclone Programme (TCP) of the World Meteorological Organization (WMO). Amongst other things, its Technical Support Unit, in close collaboration with the Panel members, WMO and ESCAP, specifically advises and assists countries in operation and improvement of meteorological network, telecommunication systems and facilities. Within the framework of WMO's World Weather Watch Programme, New Delhi has been designated as the Regional Specialised Meteorological Centre (RSMC) with the function of providing advice and information to the Members of the Panel on Tropical Cyclones, and cyclone forecast track and intensity.

The Fourth Phase of the IHP of UNESCO (1990-1995) had a project called “Hydrology, water management and hazard reduction in low lying coastal regions and deltaic areas in particular with respect to sea level changes. In the framework of this project three workshops were held. The most relevant to the present project was held in Hamburg, Germany, in April 1991. Its title was: “Storm surges, River floods and combined effects (STORM 91). At present, IHP has other work underway in ecohydrology, groundwater contamination and impact assessment. UNESCO's CSI also has programmes in the region.

The HWRP of WMO is supporting a system of technology transfer in the field of hydrology and water resources called HOMS. At present the HWRP is implementing some components of WHYCOS (World Hydrological Cycle Observing System). This system had received the support of the World Bank, the European Union and other donors and funding institutions. The Commission for Hydrology (CHy) in its Tenth session in Koblenz, Germany, December 1996, established three Working Groups. The one in Applications is including the subject on flood forecasting. Six experts were appointed in this session to work in this particular field. These experts are at present being assisted by some fifteen associate experts. During the last quarter of 1999 a workshop on flood forecasting and an expert meeting on stream flow routing will be held. The Working Group on Hydrology of WMO Regional Association II will meet in October 1999. Among other subjects, it will be discussed one on flood forecasting, including the efficiency of flood forecasting systems for major rivers in the region.

The Intergovernmental Oceanographic Commission of UNESCO operates a Responsible Oceanographic Data Centre at the NIO in Goa, and is developing a Global Ocean Observing System (GOOS) ; several tide gauges in the region are part of the IOC global sea level network, GLOSS. India has recently deployed off-shore data buoys in the Bay of Bengal and the Arabian Sea. The IOC regional committee for the central and northern part of the Indian Ocean (IOC INDIO) co-ordinates the efforts of member states in ocean research and monitoring activities.

However, there are several aspects of the cyclone and storm surge warning systems and the disaster mitigation which require considerable improvements so as to bring about better response and minimize loss of life and property.

- The accuracy of forecasts of cyclonic storms and the lead time on warnings have to be improved and the uncertainties in landfall timing and location need to be reduced.

- Storm surge forecasting and warning systems are not adequate in the region. Particular attention is urgently needed to develop models for different coastal zones .

- The response of the public and disaster preparedness agencies must be strengthened through better scientific understanding of cyclones and storm surges, their warnings and related information. This is the area which requires great attention. In spite of some improvement in warning systems, adequate attention has not been given in the region for the development of mechanisms for public response and disaster preparedness organizations. But reliable forecasts lead to public confidence and positive responses to warnings.

The most important need is the development of robust and reliable operational technique for prediction of storm surge – based on sound hydro-dynamics in numerical models. Particular attention need be given to the coastal regions taking into account the complex coastal orientation and estuaries including the massive freshwater discharges of the Ganga – Brahmaputra – Meghna , and the Irrawaddy river systems. Attention must also given to the river systems of Arabian sea and its northward extensions.

Surge prediction demands accurate surface wind forecasts for several hours before cyclone landfall. Hence further development of a suitable regional cyclone model is equally important.

Total water level is the combined effect of storm surge and high tide, and so accurate prediction of tidal height in the model is essential.

But for driving models reliable real-time data of meterological, hydrological and oceanographic variables are fundamental. The data must be freely available to participating countries through networks including meteorological satellite data reception facilities and associated telecommunication facilities.

Another area which requires attention is the impact of climate change and a possible sea level rise and changes in the frequency and intensity of storms, on changing flooding risks from storm surges in the Bay of Bengal, especially in the low lying regions of Bangladesh and Maldives and Sri Lanka.

Detailed time histories and data dossiers of individual storm surges are needed. This will enable calibration of storm surge models and improvement of prediction techniques. This is also helpful to assess the potential and susceptibility of the coastlines. Estimates of storm surge potential from historic records are also valuable for efficient administration of cyclone mitigation plans to determine the safety and economics of coastal constructions and installations.

This project will lay strong emphasis on education for appropriate public response. The timely response to storm surge warnings of the public and the disaster prevention and preparedness organizations is most important to minimize loss of life and property. Even perfect warnings are of little use if no response organization exists. Warning and response are inter–related and one is of little effect without the other. To increase the effectiveness of the warning and response system, a co–ordinated approach by all concerned is called for.

Capacity building and development of human resources in all facets of the storm surge problem is the most important area which will be given great attention to achieve self–sufficiency by the end of the project. Development of local expertise through technology transfer will result from the inclusion of local scientists and technicians in all aspects of the programme. This will include the skills to build, repair, service and operate the many components of the systems. Many of these skills have application in other areas. The development of a knowledge base about storms in the region will aid routine local weather forecasting, and data collected as part of the continuing programme will be useful in preparing updated design criteria for coastal defences and other infrastructure.

It is difficult to estimate quantitatively the effectiveness of disaster preparedness and prevention measures, in terms of saving lives and protecting property. In documented cases cost/benefit ratios of weather warning services have been put in the range 1:55 to 1: 217. There are instances where more than $100 million of property were lost in a single storm. Disaster-related reduction in national GDP of 20-30% in a single year is not uncommon. While a warning system will not avoid all damage, at a cost of only a few million dollars the cost/benefit ratio will be very favourable.

The benefits of the project can be summarised:

- reduction in loss of life and property,
- reduction in damage to infrastructure,
- increased stability of local economy and more dependable investment ,
- improved weather forecasting,
- improved cost-effective design of local coastal defenses,
- increased scientific and technical capacity
- increased knowledge of marine and tropical storms
- strengthening of existing institutions, facilities and programmes.

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3 OUTLINE OF THE PROJECT

Main objective

The main objective is to save lives, reduce damage and encourage sustainable development of the low-lying coastal regions in the Northern Indian Ocean, with particular emphasis on the surge prone areas of the Bay of Bengal and Arabian sea.

It will enhance the national expertise and capacity in the participating countries in respect of the prediction, simulation and evaluation of storm surges associated with the occurrence of tropical cyclones in the Bay of Bengal and the Arabian Sea

Specific objectives

These are roughly in operational sequence, but are not in order of priority.

The specific objectives of the project will apply to both the Bay of Bengal and the Arabian Sea. At the beginning of implementation, coastal observations, model development and infrastructure enhancement will proceed in both areas. However, the installation of the important networks of off-shore buoys will be done first in the Bay of Bengal, which has the worst record of disasters, and for which the scientific studies are more advanced. The logistic experience of installing and operating these buoys in the Bay of Bengal will then be used to plan and execute the buoy network in the Arabian Sea.

Observations

- To expand the network of various real-time meteorological, hydrological and oceanographic observing systems for development of improved storm surge models and more accurate forecasting and warning of cyclones and attendant storm surges.
- To obtain survey information on tidal heights at coastal locations and offshore, through satellite altimetry, and assist in local coastal elevation and bathymetric surveys.

Modelling

- To develop a cyclone model for accurate information on surface winds around the cyclone field and to increase the lead time in forecasting, and to reduce uncertainties in cyclone landfall timing and location.
- To develop and/or adapt interactive storm surge models of seas and rivers to give forecasts of water levels, coastal inundation and wave conditions; and implement storm surge models appropriate for different coastal zones; develop a forecast strategy. The models of rivers that are being used in the countries that made available the information for the preparation of the present project proposal document are all based on the computer program called Mike 11. This is an interesting advantage for the future development or improvement of models. In some cases the models constructed from Mike 11 are not being used in the lower part of the river. Most probably this is because the downstream boundary condition is not sufficiently well defined. Storm surges models in different regions of the Indian Ocean will solve this problem. Good co-ordination of the time steps, accuracy of the water level predictions and the time in advance in which the prediction are to be made will be essential. Most probably a cost/benefit study will be needed for defining these aspects. (Information from Bangladesh, India and Thailand was used when preparing this paragraph.)
- To combine these models with other existing operational storm forecasting techniques into a comprehensive storm surge forecasting procedure.

Infrastructure

- To improve communication facilities both for real–time data collection and exchange and for real–time storm surge warning dissemination.
- To establish a data exchange and management system in the region.
- To collect, compile and update extensive storm surge data appropriate for use in risk evaluation and surge simulation in each of the countries of the region, and prepare data inventories and establish a data archival centre.
- To establish and strengthen warning – response mechanism amongst organizations for disaster prevention and preparedness measures.
- To develop capacity building and human resources in all aspects of the project .

- To establish an implementation mechanism based on existing regional infrastructure

Climate Change

- To study the impact of climate changes including possible sea-level rise, and changes, if any, in the frequency and intensity of tropical cyclones and in river discharge characteristics on storm surge.

4 INDIVIDUAL PROGRAM ELEMENTS

The storm surge project in the region will include the following elements:

- Improvement in various meteorological, oceanographic and hydrological observing systems
- Improvement in communication facilities
- Development and integration of storm surge inundation and cyclone forecast models
- Preparation of cyclone dossier for all historic and future cyclones
- Impact of sea level rise on storm surge, if any
- Disaster prevention and preparedness
- Capacity building and human resource development
- Establishment of a data archival centre to support regional project

These elements are described in more detail below. It is emphasised that this project is not proposed in isolation from existing activities such as the WMO's Tropical Cyclone Operations Plan, IOC's Global Ocean Observing System (GOOS), Integrated Coastal Area Management Plan and IHP and CSI (Coastal and Small Islands) Programs of UNESCO. This project is a necessary supplement to those activities. To indicate how the various elements of this proposal interlink, those elements that will be carried out from national resources are marked (*) and those requiring external assistance are marked (**).

4.1 Meteorological, Oceanographic and Hydrological Observing Systems

- ***Surface and Upper Air Coastal Stations***

a) Cyclone Season Weather Stations
The network of permanent stations adopted for regional exchange by the World Weather Watch is considered adequate. However an additional 60 coastal stations will be established that will only be operational during the cyclone season. These stations will report hourly pressure and wind speed and direction. (*).

b) Upper Air Stations
It is proposed to set up an additional eight upper air stations in the region. (*) (**). Thesestations will report pressure, humidity, wind speed and direction.

c) Automatic Weather Stations (AWS)
Four simple automatic weather stations will be established on the islands and reefs in the Bay of Bengal and the Arabian Sea to measure atmospheric pressure and wind speed & direction. Also as part of the Thai Meteorological Department (TMD) programs a drifting buoy will be deployed near Phuket (Thailand) and as part of an IMD programs anchored buoy near Mumbai (India) (*).

d) High Gust Anemometers
The very high sustained wind speeds (> 60 m/s) and gusts (>100m/s) experienced during cyclones tend to cause failures in standard anemometers, which are normally specified to operate effectively in speeds only up to 60 m/s. Thus to get some reliable measurements in the extreme conditions, it is proposed to install 17 high gust anemometers along the coastal areas of the Bay of Bengal and Arabian Sea. (*) (**).

- ***Ship Data***

Automatic meteorological stations (DCPs), and expendabe oceanographic instruments such as XBTs and CTDs will beinstalled in consultation with shipping concerns for the collection of data from the cyclone field whenever possible. These data will be transmitted by satellite to the Warning Centres through the GTS. Also arrangements will be made to improve the availability of Ships' reports at frequent intervals from the cyclone field, by using existing Coastal Earth Stations (CESs) in India and Thailand to collect data using INMARSAT and the NIO/Ocean Information Service. (*).

- ***Weather Radars***

When a tropical cyclone is within the range of one of the Cyclone Detection Radars in the region, the meteorological centre concerned will keep the system under continuous surveillance and will transmit the radar observations through GTS to RSMC, New Delhi and other countries, on a regular hourly basis. It should be noted that although the new Doppler radars have a detection range of approximately 400 km, their ability to resolve wind speed in the cyclone is limited to ranges of only 100 km. With a typical cyclone speed of advance of 19 km per hour, this converts to about 6 hours.

Out of existing 10 cyclone detection radars in India, 3 will be replaced by Doppler radars (*).

Appropriate training in Doppler radar – maintenance, operation and interpretation of data will be necessary. This is described later under "capacity building" (**).

- ***Water Level Recorders***

Major storm surges are usually so devastating that remarkably few quantitative records of flood height and landward incursion are available. Conventional tidal gauges have proven unreliable in measuring the surge height since they either go off-scale or are damaged during major events. Also, they do not measure the maximum water heights inland. For this reason a dense network of simple land-based water level recorders such as chemically treated ribbons and digital pressure recorders is recommended.

The recorders can be deployed no more than five kilometres apart in surge-prone areas, just a few days before the expected date of landfall of the cyclone, once the existence of a surge-generating cyclone has been confirmed. The recorders are deployed at pre-surveyed locations. This network of water level recorders will thus document the extent of surge depth and penetration inland of surge waters and provide a two dimensional mapping of the inundation areas for use in the development and verification of numerical models.

a) Chemically Treated Ribbons

These recorders are extremely simple and inexpensive, however they indicate only the maximum inland water height and extent of penetration of the storm surge. The ribbon is attached to poles, trees and other structures and indicates the maximum level of the flood waters by showing a marked change in colour. The sensitivity of the ribbons to sea water is at the molecular level which can not be washed away by rain water. Because this tape is relatively inexpensive it can be used widely. (**).

b) Digital Pressure Recorders

The digital recorders are miniature self-contained pressure gauges that can be deployed on land in key areas in prepared locations when a surge is predicted. They will give a very useful account of the time history of the water level rise and fall overland. Although inexpensive in themselves these instruments are still considerably more expensive than the ribbons, and so they will be used in conjunction with the ribbons. The proposal is to hold 500 gauges in preparedness for use throughout the region. (**).

- ***Tide Gauge Network***

While the general prediction of astronomical tides globally is fairly well established, the mathematical relationships used for local predictions require constants derived from local conditions. These are established through the analysis of a comprehensive set of tidal measurements. However, currently available data for the Bay of Bengal and surrounding areas are not adequate for verifying local tidal and surge models. It is therefore necessary to measure tidal heights at coastal sites. This information will be supplemented by information on offshore tidal behaviour now being derived from satellite observation of ocean surface heights.

Tidal measurements are proposed for the coastal areas of the Bay of Bengal and the Arabian Sea. It is proposed that the currently existing network of tide gauges be expanded by locating an additional 20 gauges at selected sites in the Bay of Bengal (especially in the mouths of the major estuaries such as the Hooghly, the Ganga – Brahmaputra – Meghna and the Irrawaddy), and an additional 30 gauges at selected sites in the Arabian Sea (**). This number is arrived at from theoretical consideration of the compression of the tide wave and its continuously decreasing wave length as it moves from the open ocean towards the head of the Bay.

- **Hydrological observations**

The needs for improving the models already available and for some new models that could be developed for some rivers in the region, could include the necessity of adding new stations, improving the collection of data of existing stations and the automatization of the input of data to models. The most relevant variables to be measured will be rainfall, water discharge and water level. At present , for example in the Krishna river(India) the routine water level measurements are not made down stream of the city of Vijayawada. However, it is precisely this region which is subjected to combined flooding from surges, tides and rain. In principle rainfall and water discharge would be needed for the upstream boundary condition and water levels for calibration and verification of the model. Assuming that no mathematical model for sediments will be used, A frequent calibration and verification of the models will be needed in the cases where sediment transport is important.
To define the geometry of rivers and flood plains, some additional bathymetric and topographic measurements could be needed. (**).

- **Deep Sea Meteorological Buoys**

Storm surges are caused by surface wind stresses on the ocean surface and atmospheric pressure gradients associated with strong cyclonic storms. Therefore, the accurate and timely prediction of surges requires knowledge of these forces out to several hundred kilometres from the coast and many hours prior to landfall. Numerical weather prediction models used to forecast the movement and intensity of cyclones require observations of pressure, temperature and wind speed over an area much more extensive than the region of immediate interest for the surge prediction. Ideally, a dense network of land and sea observing stations is required to provide observations for input to the forecast models. However, in areas such as the Bay of Bengal and northern Indian Ocean, only occasional ship observations and limited satellite data are currently available over the ocean. Although satellite observations are of assistance to forecasters, they are unable at present to provide the quantitative sea-level observations which are vital for accurate prediction of cyclogenesis, intensification and direction of storm motion. To improve existing forecast skills for cyclones and storm surges, an ocean data gathering network is essential.

Therefore, it is proposed that a network of meteorological buoys be installed in the Bay of Bengal and surrounding seas to complement the array of buoys already deployed and maintained by India and SeaWatch program of Thailand. An array of additional nine buoys in the Bay of Bengal and four in the Arabian Sea and three spares will provide an adequate observational network for significantly improved storm surge forecasting. This network of buoys will provide significant useful data on cyclones that may normally occur in the Bay of Bengal and the Arabian Sea. (**).

Each buoy will be instrumented to measure, at a minimum, the following parameters: atmospheric pressure, wind speed and direction, air and water temperature, wave height and period, and humidity. Tropical cyclones receive the energy needed to reach storm intensity from a water column whose average temperature from the surface to a depth of 60-80 m is in excess of 26.7 C. Therefore, in addition to the above instrumentation, a thermistor chain for measuring subsurface water temperatures is required for buoys deployed in areas of preferred storm genesis, such as the Andaman Sea. Observations recorded by all the deep-sea buoys will be transmitted hourly via satellite to the local national meteorological offices and, hence, to the global meteorological observation network.

- **Status of Equipment**

All the equipment acquired will continue to remain in the region for operational purposes after the termination of the project.

4.2 Communications

Provision of suitable telecommunication facilities is proposed at National Meteorological Centres (NMCs) for collection of all observational data from the basic network as well as from special stations to be set up for cyclone watch (Section 4.1).

Promotion of the use of SSB radio communication is suggested for communication facilities between coastal observing stations including radar stations and cyclone warning centres (CWCs) and national (or regional) data collection centres. (*)

High priority will be given for the upgrade of the following Global Telecommunication System (GTS) circuits in the region:

(i)	Karachi – New Delhi	to 2400 bps via Satellite (**)
(ii)	Bangkok – Yangon	to 2400 bps (**)
(iii)	Colombo – New Delhi	to 2400 bps via Satellite. (*)
(iv)	Dakha – New Delhi	to 9600 bps (**)

- ***Local Communication***

Within each country, consideration will be given to strengthening existing communication networks and implementing new ones. The means most appropriate to individual circumstances will be used to enable effective and efficient distribution of storm surge warnings and related information under all circumstances, particularly to organizations responsible for disaster prevention and preparedness. (*).

- ***Regional Computer Network (RCN)***

Establishment of the Regional Computer Network (RCN-II) in the area in accordance with the co–ordinated plans will represent an important contribution to the implementation of the storm surge project. This phase of the RCN will enable the widespread installation and operation of storm surge models, as well as the effective and rapid collection, processing and exchange of relevant data and products.

Under this programme the installation of the Analyzing Forecasting Data-Processing System (AFDPS) will be carried out at the National Meteorological Centres of Karachi (Pakistan) with upgrades as necessary at other centres. AFDPS is a micro–computer hardware and software system designed to assist marine forecasters (**).

Expert/Consultant Services and Fellowships will be required for maintenance of RCN and application of RCN to operational cyclone and storm surge forecasting services. These are specified separately later under "capacity building and human resource development." (**).

- ***Meteorological Satellite***

It will be necessary to establish modern satellite receiving equipment in six countries, namely, Bangladesh, Maldives, Myanmar, Pakistan, Oman and Sri Lanka, for reception of data from geostationary and polar-orbiting satellites. (**).

4.3 Development And Integration Of Storm Surge And Cyclone Forecast Models

The ultimate objective of the modelling component of this project is to develop an integrated storm surge forecast model for operational use in the forecast centres of the Bay of Bengal and the Arabian sea.. This integrated model suite, should be made available to the main forecasting centres in each of the five countries surrounding the Bay of Bengal. The three components of this integrated model suite are discussed below.

- ***Storm Forecast Models***

The first component of the storm surge prediction system is the improved accuracy of forecasting the tropical cyclones that generate the surges. The additional observing networks will improve the analysis (t=0) details of the pressure patterns and values, air and sea temperatures and wind and wave fields associated with the cyclone. An improved analysis will lead to improved predictions of the radius of maximum winds, waves, track, location and time of landfall, as well as the spatial and temporal variation of the expected precipitation. Accurate forecasts of the wind field, wave heights and storm track are essential elements in the successful forecasting of storm surges. The output data from the storm forecast models will be the key input data to the storm surge models (**). Besides the development of numerical storm forecast model existing synoptic forecasting techniques must be taken into account.

- ***Surge Prediction Models***

A surge prediction system relies heavily on the development of reliable numerical models. Some work has already been completed on the surge prediction models for the Bay of Bengal. However, accurate representation of the tidal contribution to extreme water levels has not been possible due to the lack of tidal and surge height information. Therefore, one of the first modelling tasks will be the development of accurate tidal models using the results of the tidal measurement program for model calibration and validation.

The development of models which allow for dynamic interaction of tide and surge will provide the ability to forecast surge behaviour accurately. Such models include the non-linear coupling between tide and surge which affects the time and magnitude of peak water levels. The seaward boundaries of these models must be placed well outside the shallow water regions where tide/surge interactions occur so that the tidally-driven boundary conditions are not affected by the presence or absence of surges.

Special problems that need to be addressed include land inundation by surges, penetration of surge into estuaries and rivers, and effects of precipitation on surge amplitudes in estuaries and rivers.

The Probable Maximum Storm Surge (PMSS) will be computed from the storm surge models. The PMSS gives the highest surge height along the coasts of the Bay of Bengal and the Arabian Sea and will be used to assess the vulnerability of the coastal zone.

Traditionally, finite-difference (f-d) models with rectangular or square grids have been used in storm surge models. In recent years, finite element (f-e) models based on irregular triangular grids have begun to supersede finite-difference models because of their better ability to represent coastlines and bathymetry (**).

- River models

The presence of the rivers makes it possible for the surge originating in the sea to penetrate up to greater distances inland. The interaction between the river flow and the penetrating surge would cause the river banks and deltas to be flooded in addition to the flooding due to intense rain associated with tropical cyclones. This aspect will suitably be included in the integrated model A careful assessment of all models available in the region will be made. It will be very convenient for training purposes, and for interchanging experiences at low cost that the models of the rivers would be based on the same software. Fellowship/Training will be required in river-surge interaction. This is specified separately later under “Capacity Building and Human Resources Development” (**).

- ***Surge-Wind Wave Interaction***

The total water level envelope is made up of the surge, tide and set-up due to wind waves. Cyclones that are capable of generating surges also generate large amplitude wind waves. Wave set-up and surge-wind wave interactions will be included in the integrated model (**).

4.4 Preparation Of Cyclone Dossiers For Past And the Cyclones Occurring in Future

It is proposed that a systematic collection of historical data on cyclones and storm surges with all the details and the meteorological, oceanographic and hydrographic data (including tidal and satellite observations, flood levels etc.) is implemented. About half the documented storm surge events will be used to develop and calibrate the storm surge models, while the remaining events will be used for verifying the validity of the model predictions. The collection and compilation of storm surge data into case histories along with data from pre– and post–survey mission reports for all past storm surges will be used to for hindcast studies to prepare a storm surge climatology. From this climatology the engineering design criteria can be developed. This will enable identification of susceptible areas of the coastal zones where it is necessary to plan coastal installations. The data set so created will also be of use for research studies.

It is proposed that a Data Archival Centre be established under the regional office, and that it will be linked to existing meteorological, oceanographic and hydrological data management facilities. The individual Members who are responsible for the collection and compilation of storm surge data will send all the data dossiers to the proposed Archival Centre. On a request by a country, the Data Archival Centre will make arrangements to supply these data sets to the users. (*).

Expert assistance will be required for organising and planning compilation of comprehensive case histories for future surge events and historical surge data compilation. Workshops will also be held for this programme and other aspects of the Storm Surge problem. Details are given separately under “Section 4.7” (**).

4.5 Impact Of Sea Level Rise On Storm Surge

- ***Effect of Greenhouse Warming***

It has been suggested that the greenhouse warming could affect storm surges in at least two ways; first, by raising sea levels, and, second, through intensification of tropical cyclones. Specifically, the sea level rise (SLR) will elevate the mean sea level (MSL), thereby rendering the inundation problem more serious than at present. If storms become more intense in the future, then surface wind speeds will increase. Since storm surge amplitudes are proportional to the square of wind speed, the damaging impact of storm surges will increase accordingly. The numerical models that will be developed as part of this project will have provision to enable scientists to investigate possible effects of sea level rise and intensification of storms.

- ***Effects of El-Niño***

It has been shown that during El-Niño occurrences, the total number of tropical cyclones in the Atlantic Ocean decreases compared to years without El-Niño. In the Pacific Ocean, storm tracks appear to shift. Some studies show that for the Bay of Bengal during El-Niño years, the storms landfall predominantly on the coasts of Andhra Pradesh and Tamil Nadu in South India. On the other hand, in years preceding El-Niños, storms landfall mostly on the northern coastline of the Bay of Bengal. Since some studies cast doubt on the existence of this correlation, further study is obviously required. As for the effects of the Greenhouse Warming, the numerical models that will be developed as part of this project will have provision for the effects of El-Nino.

4.6 Disaster Prevention And Preparedness

This programme of warning – response system needs considerable attention. The response of the public and disaster prevention and preparedness organizations to cyclone and storm surge warning is most important to minimise loss of life and property. National Meteorological services will issue the forecast and warning. An institutional arrangement between weather service and counter – disaster officials and administrators should be in place to take effective disaster preparedness measures relating to cyclone and storm surge warnings. While this mechanism is quite satisfactory in some countries, in others it is not so. For example, in Bangladesh, institutional arrangements have evolved over the past decades for managing and mitigating the impact of disasters. There is a National Disaster Management Council headed by the Prime Minister and an Inter–ministerial Disaster Management Co–ordination committee. There are also District, Thana (Sub–District) and Union Disaster Management Committees. A Cyclone Preparedness Programme (CPP) was established in 1972 by the Bangladesh Red Crescent Society for warning 7 million coastal inhabitants in time to save their lives in the event of cyclone and surge. CPP is primarily responsible for dissemination of cyclone warning signals at field level, assist people in sheltering after evacuation, rescuing people in distress after cyclones and storm surges have taken place etc.

In India, institutional arrangement exists at the National, State, District and Sub–District levels to deal with emergency situations relating to cyclone and storm surges.

Each maritime State in the region has a Cyclone Distress Mitigation Committee (CDMC) whose mandate is to devise measures to minimise loss of life and property by cyclones, storm surges and floods.

However, considerable efforts will be necessary in sharpening the links between the concerned organizations in most of the panel countries in DPP measures.

Following are some of the action items which will be implemented under this programme:

- ***Organizational Framework***
  Development, maintenance and strengthening appropriate organizational framework at national, state and district levels to make full use of cyclone and storm surge warning and information services for disaster prevention and preparedness measures.

- ***Warning Systems***
  Development of properly designed warning systems according to the recommendations of IDNDR and the requirements of Government Disaster Management and emergency authorities, voluntary agencies and general users.

- ***Warning Messages***
  Improvement in cyclone and storm surge warnings for :
  a) Content of message in plain language, convincing and credible.
  b) Specification of the nature, severity and imminence of the threat, expected land fall location and advice for optimum preparedness measures.
  c) Updating of warning as threat increases.

- ***Dissemination Networks***
  a) The establishment of country–wide wireless and telecommunication network in conjunction with governments and other agencies, including the media, for timely dissemination and reception of warnings. Also warning equipment like signal flags, signal lights, etc. will be desirable.
  b) Development of recommended community response actions by all sections of the community, including those living in remote areas, settlements and islands.

- ***Community Participation***
  Promotion of community participation and involvement in all phases of counter – disaster response.

- ***Community Awareness***
  Sustained community awareness of the nature and severity of cyclones and storm surges, the dangers they pose and the steps to protect life and property, through well designed educational programmes and through, videos, TV, radio, leaflets, newsletters, inclusion in school curricula, etc.

- ***Training***

  Organization of specialised seminars, workshops and training for counter–disaster officials and decision makers on all aspects of cyclones and storm surges to make them better equipped for taking effective preparedness measures and convince the public to leave the warned area as well as taking other appropriate actions.

- ***Risk Zone Mapping***

  Assessment of hazard, vulnerability and risk of coastal areas with respect to cyclone/storm surge and hazard and risk mapping of such zones.

4.7 Capacity Building and Human Resource Development

Capacity building and human resource development will involve technology transfer under exchange programme through TCDC, specialised education and training in all facets of storm surge problem through Workshops/Seminars/Roving Seminars, Training Course, Fellowships, Study Tours, attachment to Advanced Centres, Consultant Services, etc. Needless to say, consultants who would be needed for some project elements, such as , model developments/adaptation, inundation mapping programmes, RCN etc. will work in the region itself as far as possible. It is only by capacity building and human resource development that the region could achieve self–sufficiency in the storm surge problem by the end of the project. The expertise already available in the region, including those in service should also be considered in selection of consultants and accordingly member countries may encourage the participation of in-service experts.

Activities in this regard will include the following :

- ***On–the–job training in Doppler Radar (**)***
  - For maintenance, operation and interpretation of data
  - One for India for 3 months.

- ***Deep sea Meteorological Buoy Network(**)***

  (a) One consultant for installation (12 mm)

  (b) Fellowships : For operation and maintenance

  (c) 3 months for 2 persons from each participating country.

- ***Tide gauge Network(**)***

  (a) One consultant for installation(12 mm)

  (b) Fellowship : For operation and maintenance
  3 months for 2 persons from each participating country.

  (c) One Workshop : On analysis and interpretation of data.
  2 weeks for 2 persons from each participating country

- ***Surge Height Measurement(**)***

  (a) One consultant for 24 mm for installation of Ribbons and Digital Pressures Loggs

  (b) Group Training : 1 week each . 30 persons in each batch in 10 centres(3 in India and 1 each participating country(For Survey missions)

- ***Regional Computer*** Network ***(RCN) (**)***

  a) Fellowship for training in maintenance of Regional Computer Network (RCN):

  3 months for one from each country.

  b) One Consultant : 2 months for each country for Application of RCN in operational cyclone and storm surge forecasting.

- ***Storm Surge Data Dossier and Archival (**)***

  a) One Consultant for 6 months to act as a facilitator and coordinator;
    – For organizing and planning compilation of comprehensive case histories of future storm surge events.
    – For compilation of historical data.
    – For organizing data archival.

  b) One Workshop for 2 weeks (2 participants from each country).

- ***Development of Cyclone Model, Cyclone Track and Intensity (**)***

  a) One Consultant – 12 man months
     - For development of cyclone model for accurate estimate of surface wind around cyclone field.

  b) One Consultant – 18 man months
     - For improving accuracy in forecast of intensity and track, increase in lead time for warning, reduction in uncertainties in landfall timing and location.

  c) Two Workshops of 2 weeks each
     - On the above, including techniques for interpretation of Satellite Data for cyclone and storm surge prediction.

- ***Development and Implementation of Storm Surge Models (**)***

  a) Consultant – One for 3 months for each country interested.
  - For choosing and adapting some models for some countries from amongst the available models in the region.

  b) Consultant – Two for 6 months each.
  - For developments of models for Bangladesh taking Ganga–Brahmaputra– Meghna river systems and estuaries and for Myanmar incorporating Irrawaddy river and for West Bengal (India) coast including Hooghly river.

  c) Consultant – One for 6 months.
  - For development/modification of models for coastal inundation and for evolving Storm Surge Envelope and for Probable Maximum Storm Surge (PMSS).

  d) Consultant – One for 6 months.
  - For development of tide–surge models.

  e) Consultant – One for 3 months for each country interested.
  - For PC–based real–time surge prediction.

  f) Workshops – Once a year of 2 weeks duration.
  - On all aspects of storm surge problems including prediction techniques.

  g) Fellowships for training of cyclone forecasters in all aspects of the storm surge project.
  - One from each country for 3 months.

  h) Fellowship for training for river-surge interaction models (one from each country interested for three months)

  i) On–the–job training of forecasters and support staff involved in Storm Surge Forecasting, Data Collection, Information Dissemination, etc.
     Two from each country for 3 months.
     – Attachment to institutions – in the region or elsewhere.

  j) Technology transfer through exchange visits of Scientists under TCDC.

- ***Impact of possible sea level rise on Storm Surge (**)***

  Consultant – One for 6 months to study this aspect.

- ***Disaster Prevention and Preparedness (DPP) (*)***

  a) Specialised seminar for counter–disaster officials and decision makers on the nature and severity of cyclones and storm surge, their warning and limitations to enable them to take appropriate preparedness measures.
     Twice a year before cyclone season of one week each.

  b) Workshops/Educational Programme for Community to make them aware of the nature and the severity/threat of cyclones/storm surge and the significance of warning.
     Twice a year before cyclone season of one week each.

  c) Joint Workshop for cyclone forecasters and DPP officials to appreciate each others' capability, limitation and requirement.
     Twice a year before cyclone season of one week each.

- ***Proposed Workshop Schedule***

  - an initial workshop on tropical cyclones, surge modelling and forecasting procedures , and coastal hydrological processes;
  - workshops for training local personnel to carry out the regular monitoring programs;
  - annual workshops focusing on the progress of the project and the latest research and technical developments including briefings on storm surge events during the past year;
  - information workshops and materials to convey the progress of the project to the local community; and research fellowships for local researchers to travel to centres of expertise outside the region and for visiting scientists to work in local research centres.

4.8 Cost benefit ratio of the project

It has been clearly brought out in the background of the project that in almost all the countries bordering the Bay of Bengal and Arabian sea, there is enormous loss of life and property due to the severe tropical cyclonic storms and the associated storm surges. The present project aims at reducing the loss of life , loss of property and damage to coastal infrastructure by improving the storm surge warning system and strengthening warning response mechanism and the effectiveness of disaster preparedness and prevention measures. It is really difficult to estimate quantitatively the benefits resulting from this life and property protection programme.

But still one can make a qualitative assessment of the social and economic benefit that could accrue from the weather warning services. In fact, all sources agree in the clear benefits it provides. In documented cases cost/benefits ratios range from 1:55 to 1:127. The evidence suggests that every dollar spent in being prepared, can save one hundred dollars or more that would otherwise be spent to make good after the event. No where are these very favourable coast/benefit ratios more obvious than in the cyclone warning services. Where such forecasting and warning systems have been installed, as part of distaer-management programmes, the evidence shows that many lives can be saved and damage can be drastically reduced. Cost/benefit ratios of 1 to 10 or 1 to 15 are very common.

80 case studies presented in September 1997 at a WMO conference quantify the economic benefits of weather warnings. Experts estimate that the agricultural sector benefits from weather services at a cost ratio of about 15 to 1. China calculates the economic benefit to cost at 17 to 1.

The benefit of the cyclone/storm surge warning is vividly illustrated by the cyclones and storm surges of similar magnitude of November 1970 and April 1991 in Bangaldesh. In the former case 300,000 human lives were lost and in the latter case death toll was 130,000. This is in spite of the continuing increase in population. The achievement is attributed to the improvement in warning systems.

Instances are there, when more than 100 million dollars of property have benn destroyed due to a single cyclonic/storm surge. Considering that the improved service could reduce the loss drastically in each case over the coming years and that the present project would cost only few million dollars in 5 years, the cost/benefit ratio of the present project will be comparable with the figures cited earlier.

The above has not taken into account the benefits of eventual reduction of loss of life(which could be several thousands in each case) which socially exceeds any other benefit. Another recent problem has been the enormous increase of the insurance rates(300-400 per cent) in the cyclone prone regions, which could be probably reduced in the event of a good warning/response system. There is yet another issue of disaster related GDP(Gross Domestic Product) reduction of 20-30 per cent in a single year, which is not uncommon. An arrest in this reduction is possible with an improved cyclone/storm surge warning system in place.

Taking all these factors into account, there is no doubt that the cost/benefit ratio of the present project will be very significant and attractive

5 PROGRAMME MANAGEMENT

The implementation of the project will be the responsibility of the national Authorities as far as possible within existing infrastructure. However, in view of the magnitude, external resources from participating regional/international Funding Agencies will be essential. The management of the project will be carried out in accordance with the agreements among participating governments and the financing institutions. The implementation should be undertaken under the general direction of the participating member countries with the technical assistance of International Agencies (WMO, IOC, UNESCO-IHP etc.) and appointed experts/consultants. There will be arrangements for regular monitoring and reviews of progress in achieving the specific objectives of the project

It is proposed that the overall management of the program be under the joint auspices of the UNESCO/IOC, IHP and WMO with participation from other UN agencies. The monitoring and review committee will comprise of representatives of members state, UN Agencies and the funding institutions and will meet regularly, but not less than once an year. It is proposed that the project is managed from a regional Project Office to be located in the region where sufficient expertise in storm surge and infrastructure already exists. This office would include, as a minimum, the following staff positions:

Project Advisor; 25% position: Provides overall scientific advice to the Director and draws on the resources of an international team of experts. Reports to the Monitoring and Review Committee. The Project Advisor is nominated by participating countries in consultation with the heads of UN agencies concerned.

Director; full-time position : Overall responsibility of the project including managerial and scientific aspects. Reports regularly to the UN Agencies, Member Countries and Funding Institutions through the monitoring and review committee.

Technological Manager; full-time position,. Reports to the Director and in-charge of all the technical and instrumentation aspects of the project

Administrative Officer; full-time position:. Reports to the Director and is in-charge of the contracts , and financial control of the project.

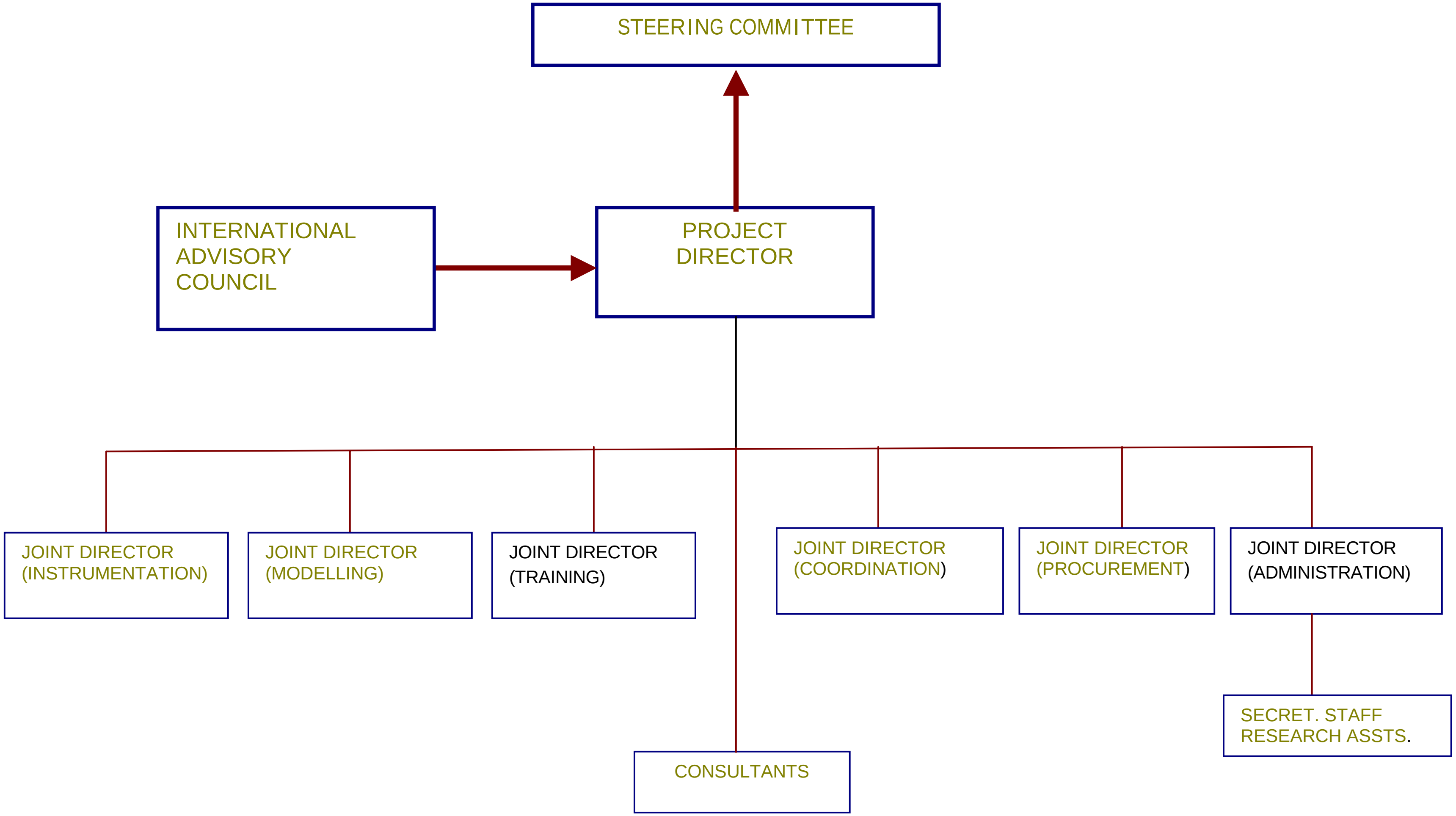
Accountant; full-time position: Reports to the Administrative Officer and in-charge of accounts for the project.

Secretaries (2); full-time positions:. Report to the Administrative Officer and help to run the project office.

Scientist-in-Charge; full-time position; Reports to the Director and in-charge of all the numerical modelling component of the projects.

Programmers/Computer Scientists (2); full-time positions.. Report to the Scientist-in-Charge and perform computer programming and systems design implementation.

The project advisor and the Director will be in United Nations scales and other staff will be at local UNDP scales.


STEERING COMMITTEE
INTERNATIONAL ADVISORY COUNCIL
PROJECT DIRECTOR
JOINT DIRECTOR (INSTRUMENTATION)
JOINT DIRECTOR (MODELLING)
JOINT DIRECTOR (TRAINING)
JOINT DIRECTOR (COORDINATION)
JOINT DIRECTOR (PROCUREMENT)
JOINT DIRECTOR (ADMINISTRATION)
SECRET. STAFF RESEARCH ASSTS.
CONSULTANTS

APPENDIX - 1

List of Storm Surges in the Bay of Bengal for the Period 1970 to 1999 based on Jayanthi and Sarma (1986), Murty et al. (1986), Katsura et al. (1992), Taluder et al. (1992) and Falther (1994). For more details see the original papers.

No.	Date	Location	Damage
1	7 May, 1970	Cox's Bazar, Bangladesh	Up to 5m surges
2	22-23 October, 1970	Chandpur, Banglsdesh	4.7m surge. 300 deaths
3	8-13 November,1970	Between Noakhali and Chittagong,Bangladesh	3-10 m surge, 300,000 deaths, 2,80,000 cattle killed, 44,00,000 houses destroyed, 18,000 boats destroyed, Unofficial estimation of deaths moe than 500,000
4	8 May, 1971	Khulna to Chittagong and offshore islands, Bangladesh	2.4-4.2 m surge. Other information not available
5	30 September, 1971	Chandpur, Bangladesh	Surge plus tide of 5m
6	30 October, 1971	Paradip, Orissa, India	Water levels up to 6m. The surge penetrated 25 km inland. 10,000 deaths
7	5-6 November, 1971	Chittagong, Bangladesh	Water levels up to 5.5m
8	28-30 November, 1971	Sunderban coast, Khulna, Bangladesh	1m surge
9	10 September, 1972	Barua, Orissa, India	3.4m surge. 0.8m tide
10	22 September, 1972	Gopalpur, Orissa, India	Inundation in Puri District
11	15-23 November, 1972	South of Nellore, Andhra Pradesh, India	Minor Surge
12	11 October, 1973	Chandbali, Orissa, India	Mild surge in river estuaries caused saline water intrusion in the coastal areas of north Orissa and West Bengal
13	16-18 November, 1973	Barisal, Bangladesh	1.0m surge. Peak water level including wind waves 3.8m
14	9 December, 1973	Patuakhali coast and offshore islands, Bangladesh	Peak water level 6.2m. Peak surge 4.5m. 183 deaths
15	13-15 August, 1974	Khulna, Bangladesh	6.7m surge
16	20 August, 1974	Contai, West Bengal, India	Inundation of low-lying areas of Digha and Juneput. 7 deaths
17	28 November, 1974	Chittagong, Bangladesh	4.9m surge. 20 deaths, 50 injured, 280 persons missing, 1,000 cattle killed, 2,300 house destroyed
18	5-7 May, 1975	Gwa (between Sandoway and Bassein), Burma	303 deaths. Damage US$78 million
19	9-12 May, 1975	Bhola, Cox's Bazar, Khulna, Bangladesh	5 deaths. 4 injured. 36 fishermen missing
20	5-7 June, 1975	Chittagong, Bangladesh	Peak surge 4.0m
21	24-28 June, 1975	Bangladesh	Tide and surge 4.8m
22	8-12 Nov, 1975	Barisal, Noakhali, Bangladesh	Maximum surge 3.1m

Appendix-1 (continued)

No.	Date	Location	Damage
23	20 April-2 May, 1976	Sandoway, Burma	Moderate surge.
24	11 September, 1976	Contai, West Bengal, India	2.5m surge. 1.4m tide. 40 deaths.
25	20 October, 1976	Meghna Estuary, Bangladesh	Tide plus surge 5.0m at Comapaniganj
26	20 November, 1976	Chittagong, Bangladesh	1.0m surge. 2.1m tide
27	12-13 May, 1977	Sunderban, Bangladesh	0.6m surge. 0.7m tide
28	19 November, 1977	Chirala, Andhra Pradesh, India	Peak surge 5.0m, Tide 0.3m. Divi and surroundings totally inundated. 10,000 deaths
29	12-17 May, 1978	Myebon (between Akyab and Kyaukpyu), Burma	90 to 95% of the city of Kyaukpyu was damaged
30	30 September – 3 October, 1978	Khulna and Sunderban coast, Bangladesh	Damage estimate not available
31	24 November, 1978	Between Kilakkarai and Rochemary Island, Tamilnadu, India	4m surges on the coasts of Tamilnadu and Sri Lanka. Extensive damage on the northeast coast of Sri Lanka. 373 deaths in Sri Lanka. 10 deaths in India
32	12 May, 1979	Kavali, Andhra Pradesh, India	3m surge. 0.6m tide. 700 deaths
33	10 December, 1981	Bangladesh	2m surge 15 deaths
34	2-5 May, 1982	South of Gwa, Burma	4m surge along the south Arakan coast. 31 deaths. US$3.8 million damage
35	1-4 June, 1982	Between Paradip and Chandbali, Orissa, India	2m surges along the Orissa and West Bengal coasts. Peak surge of 4.8m 35 km north of Dhamra harbour. 245 deaths.
36	15 October, 1983	Chittagong coast near the Feni River, Bangladesh	43 deaths. Substantial damage
37	9 November, 1983	Chittagong, Cox's Bazar, Bangladesh	300 fishermen missing. Substantial damage
38	24 May, 1985	Cox's Bazar, Chittagong, Sandwip, Bangladesh	4.3m surge. 11,069 deaths. 94,000 houses destroyed
39	29 June, 1985	Sri Lanka	8 deaths
40	20 September, 1985	Close of Puri, Orissa, India	2m surges. Inundation lasted for 3 days. Substantial damage
41	16 October, 1985	Near Balasore, Orissa, India	Up to 4m surge. Damage due to saline water inundation
42	9 November, 1986	Chittagong, Bangladesh	14 deaths. Substantial damage
43	14-19 October, 1987	North of Ongole, Andhra Pradesh, India	Moderate surge. 17 deaths. Substantial damage
44	31 October – 3 November, 1987	Nellore, Andhra Pradesh, India	50 deaths. 26,000 cattle killed. Substantial damage
45	29 November, 1988	Khulna coast near Raimangla, Bangladesh	4.4m surge. 5,708 deaths. 6,000 missing. 65,000 cattle killed. 15,000 deer killed. 9 royal Bengal tigers killed. Substantial crop damage.
46	4-7 November, 1989	Kavali, Andhra Pradesh, India	Mild surge caused destruction in Nellore and Kavali
47	4-10 May, 1990	Mouth of Krishna River, Andhra Pradesh, India	600,000 house destroyed. 21,600 cattle killed. 3,500,000 poultry killed. 42,700 goats and sheep killed. Substantial damage to agriculture

Appendix-1 (continued)

No.	Date	Location	Damage
48	7-8 October, 1990	Barisal, Bangladesh	150 fishermen missing. Substantial damage
49	29 April, 1991	Chittagong, Cox'z Bazar, Bangladesh	4 to 8m surges. 150,000 deaths. 70,000 cattle killed. Great damage
50	2 June, 1991	Bangladesh	1.2m surge
51	11-17, Nov 1992	Sri Lanka ,and Tutikorin, India	1-2 m surge at Tuticorin, 170 killed, 160 missing
52	15-21, Nov 1992	Teknoff, Myanmar, Bangladesh Coast	Damage estimation not available
53	1-4, December 1993	Near Karaikal	1-1.5 m surge, 111 killed
54	29 Apr –3 May 1994	North Myanmar coast	200 people killed
55	29-31 Oct 1994	Madras, India	1-2 m surge, 304 killed, 100 000 huts damaged, 60,000 hectares crops damaged
56	7-10 Nov 1995	Gopalpur , Orissa, India	1.5 m, 96 killed, 2,84,253 hectares crops damgaed
57	21-25 Nov 1995	Coxbazar, Bangladesh	Damage estimation not available
58	12-16 Jun 1996	Visakhapatnam, India	179 killed, 13,378 hectares of crops damaged
59	5-7 Nov 1996	Kakinada, India	2-3 m surge, 978 killed, 1375 missing , 647554 houses damaged, 1.74 lakh hectares crops damaged
60	15-20 May, 1997	Chittogong, Bangladesh	Damage estimation not available
61	4-9 Nov 1997	Bangladesh coast	Damage estimation not available
62	18-21 May 1998	Bangladesh coast	Damage estimation not available
63	17-21 Nov 1998	Visakhapatnam, India	Damage estimation not available
64	17-19 Oct 1999	Berhampur, Orissa, India	About 100 Killed, Damage estimation not available
65	25-29 Oct 1999	Paradip, Orissa, India	7-8 m surge, 10,000 killed, enormous damage to the property

List of Storm Surges in the Arabian Sea for the Period 1970 - 1999

No.	Date	Location	Damage
1	October 1975	Porbandar, Saurashtra, India	85 killed, several thousand houses damaged,
2	29May –5 June 1976	Mahua, India	87 killed, 4500 cattle died
3	November, 1977	Karwar, India	Major storm surge Karwar and environs
4	November, 1982	Veeraval, Gulf of Cambay	542 killed, 1,50,332 cattle killed, 12624 pucca houses and 54549 kutcha buildings destroyed. Storm surge – 3.5 m at Mangral, 2 m at Diu, 2 m at Veraval, 3 m at Jafarafad
5	12-15 Nov, 1993	North Gujarat and Sindh coast	50 fishermen missing
6	5-9 June, 1994	Soudi Arabian Coast	Damage estimation not available
7	15-20 Nov, 1994	Somali coast	Damage estimation not available
8	17-20 June, 1996	Between Kodiar and Diu, India	5-6 m storm surge near Bharuch. Gulf of Cambay are affected by storm surge of height 3-5 m. 47 killed. 30,000 houses destroyed
9	8-11 June, 1998	Kandla, Gulf of Kutch	550 killed, 150 kmph winds, great destruction

APPENDIX-2

SUMMARY OF ACTIVITIES

Activity	YEARS					Responsibility	Funding	Remarks
	1	2	3	4	5			
1. Improvement of observational set up							National/External	
1.1 Special Coastal Stations (60) For observations when cyclone is within 300 km						Members	National	
1.2 Establishment of Upper Air stations (10) 1 in Sri Lanka 1 in India 3 in Myanmar 2 in Thailand 2 in Maldives 1 in Pakistan						 Sri Lanka India Myanmar Thailand Maldives	 External National External External External	
1.3 Mobile Ships Installation of automatic stations and making arrangements with coastal earth stations (5)						Members	National	To be installed in consultation with Shipping concerns
1.4 Automatic Weather Stations (i) Establishment of simple automatic weather stations in Islands and reefs in the Bay of Bengal and the Arabian Sea (4) (ii) Drifting buoy near Phuket (Thailand) in Andaman Sea Anchored buoy near Mumbai (India)						 Members Thailand India	 National National National	
1.5 *Cyclone Detection Radar stations* (i) Replacement of 3 out of 10 cyclone detection radars by 3 Doppler radars in India(Chennai, Machlipatnam, Calcutta)						India	National	
(ii) One 10 cm radar at Khepupara, Bangladesh (iii) One 10 cm radar at Male' (iv) One 10 cm radar at Yangon Myanmar (v) One 10 cm radar at Colombo						Bangladesh Maldives Myanmar Sri Lanka	External External External External	Appropriate training required in maintenance, operation and interpretation of data " "

Appendix-2 (continued)

Activity	YEARS 1	2	3	4	5	Responsibility	Funding	Remarks
1.6 Meteorological Satellites: Modern facilities for reception of data from polar and geo-stationary satellites (Bangladesh,Myanmar,Maldives,Pakistan, Sri Lanka)	X	X	X	X	X	Members	External assistance	
1.7 Installation of High Gust Anemometers(17) It is planned to install:								
4 in India (Paradeep, Visakhapatnam, Machilipatnam, Karaikal)	X	X				India	National	
5 in Bangladesh (Maijdi Court, Khulna, Satkhira, Chittagong, Cox's Bazar)	X	X	X	X	X	Bangladesh	External assistance	
2 in Myanmar (Dawei, Kyaukpyu)	X	X	X	X	X	Myanmar		
1 in Pakistan (Karachi)		X	X	X	X	Pakistan	National	
5 in River mouths	X	X	X	X	X	Members	External assistance	To be replaced by Electrical Anemometer
1.8 Deep Sea meteorology buoy network (16)								
(i) Procurement of 16 buoys	X	X	X	X	X	Regional Office (RO)	External	
(ii) Buoy installation		X	X	X	X			
(iii) Buoy operational		X	X	X	X	Member/RO	Member/ External	Expert Assistance and fellowships will be required
(iv) Buoy maintenance		X	X	X	X	Member/RO Member/RO	Member/IOC Members	

Activity	**YEARS**					**Responsibility**	**Funding**	Remarks
	1	2	3	4	5			
1.9 Tide Gauge network (50)								
(i) Procurement of 50 tide gaugas (20 in the Bay of Bengal coast including all river mouths and estuaries and 30 in the Arabian Sea coast and river mouths, north of the equator.						Members	National/ External	
(ii) Selection of sites and installations						Member/RO	External	Expert assistances and workshops will be necessary
(iii) Tide gauge operations						Member/RO	External	
(iv) Maintainance						Members/RO	External	
1.10 Additional Hydrological Measurements *(i) Bathymetric measurements* *(ii) Topographic measurements* *(iii) Rainfall measurements (real time)* *(iv) River discharge measurements* *(v) Water level measurements (no real time)* *Water level measurements (real time)*						Members	National/ External	In consultation with national hydrological organisations. The exact needs will be defined after selecting the rivers in which models will be develolped or improved. The data needs of the models will define these needs.
1.11 Surge height measurement by (a) Ribbons (b) Digital pressure loggers								Experts and training will be necessary
(i) Procurement of Ribbons						RO	External	
(ii) Procurement of digital pressure loggers (500)						RO	External	
(iii) Survey and identification of tree and land-marks along surge prone areas						Members	Members	
(iv) Episodic installation and recovery of Ribbons and digital pressure loggers and measurement						Members Members/RO	External External	
1.12 Collection of Oceanographic data by DCP voluntary ships. Installation of automatic XBTs & CTD data						Members/RO	National and External	

Activity	YEARS 1	2	3	4	5	Responsibility	Funding	Remarks
2. Communication facilities								
2.1 Meteorological Telecommunication System								
2.1.1 Collection at NMCs of all observational data from basic networks as well as from special stations						Member	National	
2.1.2 Upgradation of : (a) Karachi - New Delhi to 2400 bps						India & Pakistan	External assistance	
(b) Bangkok - Yangon to 2000 bps						Thailand & Myanmar	External assistance	
(c) Colombo - New Delhi to 2400 bps						Sri Lanka & India	National	
(d) Dhaka – New Delhi from 2400 to 9600 bps						Bangladesh &India	External	
2.2 Local communication for Storm Surge warning dissemination to DPP organization						Members	National	To be strengthened jointly by NMHS and DPP organizations.
2.3 Regional Computer Network (RCN)								
(i) Application of RCN in Tropical Cyclone Forecasting and Operation of Storm Surge model						Members/ WMO	National/ External/ VCP	Training activities, Fellowships & Consusltant services will be required
(ii) Installation of micro-computer hardware & Soft ware for NMCs Six countries : Bangladesh, Maldives, Myanmar, Pakistan , Sri Lanka							External/VCP	Software to be replaced by AFDOS software

Activity	YEARS					Responsibility	Funding	Remarks
	1	2	3	4	5			
3. Storm Surge Data Dossier and Archival								
3.1 Compilation of storm data files						Members	National	
3.2 Compilation of historical surge data sets						Members/ WMO/ TSU	National	(i) One Workshop (ii) Expert Assistance
3.3 Establishment of Data Archival Centre at New Delhi						India/WMO	National/External	
4. Development of Cyclone Model								
4.1 Cyclone Model for Surface Wind estimation						Panel/WMO	External assistance	Consultant service and Workshops will required to execute the programme
4.2 Increasing accuracy in Cyclone track and intensity						Panel/WMO	External assistance	
5. Development and Implementation of Storm Surge Models								
5.1 Review of existing models and adaptation & implement-ation of suitable model(s) for some countries on operational basis						Members/TSU/ WMO	External assistance	To execute this programme Consultant Services, Workshops, Training, Fellow-ships, exchange under TCDC etc. will be required
5.2 Development of new models, particularly for Bangladesh and Myanmar						Bangladesh, Myanmar/ WMO	External assistance	
5.3 PC-based real-time surge prediction						Members	National/External assistance	
5.4 Improvement of Empirical model by parameters representing complex coastlines, river discharge, etc						Members	National/External assitance	

Appendix-2 (continued)

Activity	YEARS					Responsibility	Funding	Remarks
	1	2	3	4	5			
5.5 *Modification of existing models to study coastal inundation and storm surge envelope and to compute Probable Maximum Storm Surge*						Members/ WMO	External assistance	
5.6 *Development of Tide-Surge Models and wave surge models*						Members/ WMO	External assistance	
5.7 *Detailed bathymetry and on-shore topography for improved storm surge model*						Members	National	
6. Impact of possible sea level rise on Storm Surge						Bangladesh, Maldives/ WMO	External assistance	Expert assistance will be required
7. Disaster Prevention and Preparedness								
7.1 *Development, maintenance and strengthening organizational framework between NMHSs and DPP organizations for effective implementation of the Programme*						Members/TSU	National	To implement this programme following are necessary: (i) Active link between NMHSs and DPP organizations (ii) Specialised seminar for DPP Officials (iii Workshop/Educational programme for community awareness (iv) Joint Workshop for Forecasters and DPP offcials
7.2 *Designing warning systems according to requirements of Govt. DPP and other NGO organizations*						Member/TSU	National	
7.3 *Improvement of warnings in accuracy and lead time & to make warnings simple to be easily understood by common people*						Members	National	
7.4 *Establishment and maintenance of appropriate warning dissemination arrangement in conjunction with governments and other agencies for timely dissemination and reception of warnings and recommended response actions*						Members	National	

Appendix-2 (continued)

Activity	YEARS 1	2	3	4	5	Responsibility	Funding	Remarks
7.5 Promotion of community participation and involvement in all phases of counter disaster response	■	■	■	■	■	Members/TSU	National	
7.6 Formulation and implementation of educational programme for community awareness	■	■	■	■	■	Members/TSU	National	
7.7 Specialised seminar for counter – disaster officials & decision makers	■	■	■	■	■	Members/TSU	National	
7.8 Joint Workshop for cyclone forecasters and DPP officials	■	■	■	■	■	Members/TSU	National	
7.9 Assessment of hazard risk and vulnerability of coastal areas	■	■	■	■	■	Members/TSU	National	
8. Capacity Building and Manpower Development								
8.1 Meteorological observing system -- On-the-job training in Doppler Radar	■	■				India	External	On request
8.2 Regional Computer Network (RCN) 8.2.1 Fellowship for maintenance of RCN		■	■			Members/ WMO	External	
8.2.2 Consultant for 2 months for each country for application of RCN in operational forecasting		■	■	■		Members/ WMO	External	On request by Members
8.3 Storm Surge Dossier and Archival 8.3.1 Consultant (6 months) for organization and planning data files, historical data and archival	■	■				Members/ WMO	External	
8.3.2 Workshop (2 weeks)		■	■			Members/ WMO		
8.4 Development of Cyclone Model 8.4.1 Consultant (6 months) for Model development 8.4.2 (Consultant (6 months) for Cyclone intensity and track	■					Panel/TSU/WMO Panel/TSU/WMO	External External	

Activity	**YEARS**					**Responsibility**	**Funding**	**Remarks**
	1	2	3	4	5			
8.4.3 Workshops (2) of 2 weeks each on cyclone prediction techniques and interpretation of satellite data						Panel/TSU/ WMO	External	
8.5 Development and Interpretation of Storm Surge Models								
8.5.1 One Consultant for choosing a model from those available (3 months for each country interested)						Members	External	For countries interested
8.5.2 Two Consultants (6 months each) for development of model						Bangladesh, Myanmar/ WMO	External	
8.5.3 Consultant (6 months) for model development for coastal inundation						Members/TSU/ WMO	External	
8.5.4 Consultant (6 months) for tide-surge model and wave surge model						Panel/TSU/ WMO	External	
8.5.5 Consultant (3 months) for PC-based real-time surge prediction						Members/TSU/ WMO	External	
8.5.6 Five Workshops of 2 weeks each on Storm Surge problems and prediction techniques						Members/TSU/ WMO	External	For countries interested
8.5.7 Fellowships for training (3 months) of cyclone forecasters in all aspects of storm surge project						Members/ WMO	External	Preferably 2 from eachcountry and the instutes within the region
8.5.8 Fellowships for training (3 months) in river-surge interaction one from each interested country						Members/WMO	External	
8.5.9 On-the-job training of forecasters and support staff involved in storm surge forecasting (3 months)							External	
8.5.10 Technology transfer through exchange visits under TCDC						Members/WMO	TCDC	On request by Members
8.6 Impact of possible sea level rise on Storm Surge - Consultant for 6 months to study this aspect						Bangladesh, Maldives, Sri Lanka/WMO	External assistance	

Appendix-2 (continued)

Activity	YEARS					Responsibility	Funding	Remarks
	1	2	3	4	5			
8.7 Disaster Prevention and Preparedness (DPP)								
8.7.1 Specialised seminars for counter disaster officials and decision makers on cyclones and surge warnings						Members/TSU	National/ External assistance	Two times a year (one week each)
8.7.2 Workshop/Educational Programme for community awareness						Members	National	Two times a year (one week each)
8.7.3 Joint Workshop for cyclone forecasters and DPP officials						Members/TSU	National/External assistance	Two times a year (one week each)

APPENDIX-3

National Contributions(***)

Activity	**YEARS**					**Estimated Costs (US$)**
	1	2	3	4	5	
1. Meteorological Observing System						
1.1 Special coastal stations (60 stations)						60,000*
1.2 Upper-air stations (a) India (1)						215,000
1.3 Mobile ships Installation of Automatic stations (5 stations)						52,500*
1.4 Automatic Weather Stations (a) Establishment of simple automatic weather stations (4 stations) (islands) (b) Drifting buoy near Pukhet						80,000* 10,000 (Drifting buoy)
1.5 *Doppler Radars:* India: Replacement of 3 out of 10 cyclone detection rad by Doppler Radars at Madras, Machilipatnam and Calcutta						4,500,000

*** Equipment including its operation and maintenance

Appendix-3 (continued)

Activity	YEARS					Estimated Costs (US$)
	1	2	3	4	5	
1.6 Meteorological satellites						150,000
1.7 Installation of High Gust Anemometer India Installation of 4 stations (Paradeep, Visakhapatnam, Machilipatnam and Karaikal) Pakistan Installation of one Electrical Anemometer at Karachi						90,000
1.8. Deep Sea Meteorological buoy network (i) Installation (ii) Operation (iii) Maintenance						3,590,000
1.9. Tide gauge network (i) Procurement (50 tide-gauges) (ii) Operation (iii) Maintenacne						500,000 500,000 500,000
1.10 Additional Hydrologic measurements (i) Bathymetric measurements (ii) Topographic measurements (iii) Rainfall measurements (real time) (iv) River discharge measurements (v) Water level measurements (no real time) (iv) Water level measurements (real time)						100,000
1.11. Surge height measurements by (a) Ribbons (b) Digital pressure loggers (i) Survey and identification of tree/ landmarks along surge - prone areas						100,000
1.12 Oceanographic data. Procurring of XBTs & CTDs						200,000

Activity		YEARS					Estimated Costs (US$)
		1	2	3	4	5	
2.	**Communication facilities**						
2.1	*Meteorological Telecommunication System*						
2.1.1	Collection at NMCs of all observational data from Regional Basic Synoptic Network stations (82 stations)						410,000*
2.1.2	Upgradation of GTS Colombo - New Delhi to 2400 bps (Running cost for 5 years)						200,000
2.2	*Local communication for cyclone and storm surge warning dissemination and reception by DPP organizations and community response actions (SSB equipment at both ends in 8 countries)*						80,000*
3.	**Storm Surge Data Dossier and Archival**						
3.1	*Compilation of storm data files*						20,000*
3.2	*Compilation of historical surge data files*						
3.3	*Establishment of Surge Data Archival Centre at RSMC - New Delhi*						
4.7	**Bathymetry** Accurate bathymetry and on-shore orography for improved Storm Surge models						To be part of the routine operation of the concerned government deaprtments
7.	**Disaster Prevention & Preparedness (DPP)**						
-	All activities relating to DPP including seminar/workshops/educational programmes for DPP officials and community awareness and response						250,000*
TOTAL							**11,607,500 (11.61 million)**

- These are new costs not included in the Budgets by the Governments.
- Note: The national contribution given above does not include the costs to be charged by the shipping vessels to be involved in various instrumental observations.

APPENDIX-4
External Assistance

olo	Activity	YEARS					Estimated Costs (US$)
		1	2	3	4	5	
1.	**Meteorological Observing System**						
1.1	*Implementation of upper air observations* Myanmar (3 stations) - 48060 Kengtung - 48109 Coco Island - 48112 Kawthaung						390,000
	Maldives (2 stations) - 43555 Male' - 43599 Gan						260,000
	Sri Lanka - Wind finding radar for Colombo						300,000
	Pakistan (1 station)						130, 000
	Thailand (2 stations)						260, 000
1.2	*Cyclone Detection Radar* - One 10 cm radar at Male' - One 10 cm radar at Colombo - One 10 cm radar at Yangon, Khepupara - One 10 cm radar at Bangladesh						1,000,000 1,000,000 1,000,000 1,000,000
1.3	*Installation of High Gust Anemometer* Myanmar (2) - 48108 Dawei - 48071 Kyaukpyu Bangladesh (5) - 41593 Maijdi Court - 41947 Khulna - 41946 Satkhira - 41977 Chittagong - 41992 Cox's Bazar - 5 more in River mouths						540,000

Activity	YEARS					Estimated Costs (US$)
	1	2	3	4	5	
1.4 Meteorological Satellites Installation of modern equipment for reception of data from polar and geostationary satellites (5 countries)						150,000
1.5 Deep sea meteorological buoy network (i) Procurement of 16 buoys (ii) Installation (iii) Operational (iv) Maintenance						 8,000,000 1,500,000 400,000 500,000
1.6 Tide gauge network (i) Procurement (ii) Installation (iii) Operational (iv) Maintenance						 1,500,000 1,000,000 500,000 500,000
1.7 Surge height measurements (i) Procurement (ii) Procurement of digital pressure logger (500) (iii) Installation (iv) Post-survey missions						 100,000 250,000 250,000 200,000

Activity		**YEARS**					**Estimated Costs (US$)**
		1	2	3	4	5	
2	**Communication facilities** *Upgradation to 2400 bps of GTS* Karachi - New Delhi (Running costs for 5 years) Bangkok - Yangon (Running costs for 5 years) Upgrade Bagladesh GTS to 9600 bps						200,000 200,000 400,000
3	**Regional Computer Network (RCN)** - *Upgradation of hardware and software at National Meteorological Centres* - *(NMCs)(6 systems including MSS and Workstations)*						1,350,000
4.	**Capacity Building and Manpower Development**						
4.1 4.1.1 4,1,2	*CONSULTANTS* Consultant (16 mm) - Application of RCN in operational cyclone and storm surge forecasting (2 months for each country) Consultant (6 mm) - Organize storm surge data dossier and archival						200,000 70,000

Appendix-4 (continued)

Activity	YEARS					Estimated Costs (US$)
	1	2	3	4	5	
4.1.3 Consultant (6 mm)						70,000
- Cyclone Model Development						
4.1.4 Consultant (6 mm)						70,000
- Improve accuracy of cyclone track, intensity, landfall						
4.1.5 Consultant (3 mm for each country) (7 countries)						245,000
- Choice and adaptation of model from existing models for countries interested						
4.1.6 Consultant (6 mm)						70,000
- Model Development of Bangladesh						
4.1.7 Consultant (6 mm)						70,000
- Model Development for Myanmar						
4.1.8 Consultant (6 mm)						70,000
- Model for routing surge inland and estuarine inundation						
4.1.9 Consultant (6 mm)						70,000
- Develop Tide-Surge Model and Wave Surge Model						
4.1.10 Consultant (3 mm for each country) (7 countries						245,000
- PC-based real-time surge prediction for countries interested						
4.1.11 Consultant (6 mm)						70,000
- Impact of possible sea level rise on storm surge						

Appendix-4 (continued)

Activity	YEARS					Estimated Costs (US$)
	1	2	3	4	5	
4.2 FELLOWSHIPS 4.2.1 Maintenance of RCN - 3 months for 1 person from each country (24 mm) 4.2.2 Training of Cyclone Forecasters in all aspects of Storm Surge problem - 3 months for 1 person from each country (24 mm) 4.2.3 Rivers-surge interaction - 3 month for 1 person from each country (24 mm)						78,400 78,400 78,400
4.3 GROUP TRAINING/WORKSHOPS 4.3.1 Workshop on Storm Surge Data Dossier (2 weeks) - Two participants from each country 4.3.2 Two Workshops on Cyclone Track, Intensity forecast and interpretation of satellite data in surge forecasting (2 weeks) - Two participants from each country 4.3.3 Five Workshops (once a year) on Storm Surge problems and prediction techniques (2 weeks) - Two participants from each country						79,800 159,600 399,000
4.4 ON-THE-JOB TRAINING 4.4.1 Doppler Radar maintenance, operation and interpretation of data - Two months for four persons from India (8 m/m)						30,000

Activity	YEARS					Estimated Costs (US$)
	1	2	3	4	5	
4.4.2 For Forecasters and Support Staff involved in Storm Surge Forecasting, data collection, information dissemination - Three months for one from each country (24 mm)						78,400
4.5 TECHNOLOGY TRANSFER - Exchange visits of Scientists under TCDC (8 visits)						38,400
4.6a DEEP SEA METEOROLOGICAL BUOY NETWORK (I) Consultant for installation (12 mm) (II) Fellowships: For operational and maintenance, 3 months for 2 persons from each country, 48 mm						 140,000 157,000
4.6b FOR TIDE GAUGE NETWORK (i) Consultant for installation (12 mm) (ii) Fellowships: For operational (+ maintenance, 3 months for 2 persons from each country, 48 mm (iii) Workshop : 1 workshops on analysis of data 2 from each country (2 weeks)						 140,000 157,000 80,000
4.6c FOR SURGE HEIGHT MEASUREMENTS (I) Consultant - 1 year (1st year) - 3 months each year 24 mm (ii) Groups traning (1 week each) - 30 persons in each batch in 3 centers in India, 1 each of other 7 countries - Lectures to be given by experts responsible for Ribbon manufacture and digital pressure logger						 280,000 500,000

Appendix-4 (continued)

Activity	YEARS					Estimated Costs (US$)
	1	2	3	4	5	
9. Project Implementation and management						
Regional Office (RO) - One Director - One Administration Officer - One Technological Manager - One Accountant - Two Secretaries - One Scientists I/C - Two Programmers Monitoring and Review - Project Leader (1/4 time) - Monitoring Missions Miscellaneous Running Costs						 600,000 400,000 400,000 100,000 80,000 400,000 400,000 250,000 650,000 250,000
TOTAL						**30,134,400 (30.13 million)**
10. Overhead charges (13%) of executing agencies						3,917,472
GRAND TOTAL						**34,051,872 (34.05 million)**

Total Budget : National = 11.61 Million $

External = 34.05 Million $

Total = 45.66 Million $