Impact of Sea Level Rise on Cities and Regions

Marsilio
IMPACT OF SEA LEVEL RISE ON CITIES AND REGIONS

Proceedings of the First International Meeting ‘Cities on Water’ Venice, December 11-13 1989

edited by Roberto Frasetto

Marsilio Editori
Cover Photo: Piazzo San Marco flooded after a storm surge raised the sea level 1m above the reference level (photo by Graziano Arici)

ISBN 88-317-5449-1
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This volume represents the cornerstone for the development of the International Centre 'Cities on Water', the structure and objectives of which are listed at the end of the book. It consists of the proceedings of its First Meeting in Venice, December 1989. Under the Patronage of the President of the Italian Republic with an Honorary Committee composed of the major International Agencies and Organisations and Italian Governmental Authorities, the Meeting, through its lecturers covered the scientific, technical, socio-economic and political aspects of the topics. The resulting documentation, with general consensus, has led to a number of actions concerning the development of the Centre, planning concerted research and verifying risks connected with global environment change and cities in expansion which have a direct liaison with the water at the interface of land and sea.

RINIO BRUTTOMESSO
Director of the International Centre 'Cities on Water'
The Meeting and the Proceedings were sponsored by:

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EEC (European Economic Community) DG XII
UNEP (United Nations Environment Programme)
IOC (Intergovernmental Oceanographic Commission)

Other contributions came from:

GIUNTA REGIONALE DEL VENETO
AZIENDA DI PROMOZIONE TURISTICA DI VENEZIA
ASSOCIAZIONE VENEZIANA ABBIGLIAZIONI E ALBERGHIERI
VENZIANI
CASSA DI RISPARMIO DI VENEZIA

Acknowledgements are also due to:

The Italian Ministry of Foreign Affairs
The Ambassadors and Consuls - General of Italy in the Cities participating in the Meeting

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Mr. Minister, Madam Undersecretary, Authorities, Mayors and Representatives of cities on water, Representatives of International Organisations, Universities and Scientific Institutes: as the present Mayor of Venice, in my capacity as President of the International Centre “Cities on Water” I would like to extend a warm welcome to everyone here today. The first Venetian community dates back to the 1st century. Even that far back it was a community which lived both off and on the water, using it for the purposes of fishing and hunting, and for early trade. Venice grew to maturity and glory on the water when it played out its role of the largest Marine Republic in both economical and military terms.

It was perhaps a unique city for Europe as it used water instead of walls for defence from invaders.

For the purposes of commerce as well, elaborate techniques were developed over the centuries rerouting the course of the rivers and canals and protecting the lagoon, harbour and shipyards by means of which the city was living. It also created great works of protection from the sea, including, in the 1700s, the “Murazzi” sea walls. As a consequence of land subsidence over the last century, the city today must deal with new problems for its survival; changes which have taken place in the territory have created the problem of establishing a new equilibrium for the ecosystem of the lagoon.

Studies and projects of considerable importance and weight are under way or in the planning stages, and they may be common to other cities on water.

With the aim of renewing knowledge and furthering studies, we felt the need to meet and compare the results of research and experience, competence and knowledge of other cities with ours. Just one year ago in a meeting held here with representatives from various universities around the world, the idea of creating a Centre to group together the “cities on water” was born. The member cities, like Venice, have a continuing, important link with their marine environment, lagoons or estuaries.

We feel that it is useful to make the results of our experience and research available to others.

We are certain that continual updating of studies and results of planning and their diffusion is of great use for everybody. World experts in such important fields linked with the life and destinies of many cities will discuss common and unique problems and help less experienced decision makers.

This is the idea behind the present meeting.

My thanks to all the present participants for their contribution to a first step towards a joint effort to face problems and risks that cities on water may come up against today and in the near future.

I am convinced that our work together will produce excellent results. I wish you good work.

ANTONIO CASELLATI
The Mayor of Venice
This international meeting on the effects of the rise in sea level on cities and regions is important for different reasons:
- it encourages debate and in-depth study of an environmental problem of great international and scientific importance;
- it brings together for comparison, problems and experiences of great interest, relative to situations of "Cities on Water" in the various regions of the world;
- as well as increasing our knowledge, it will serve as a base for commitments and concrete action. This will take place through proposals of collaboration and information exchange between cities on water in relation to their respective planning solutions and adaptations to risks and threats from the rise in sea level.

The international scientific community must investigate the many hypotheses and assertions that have been put forward regarding the greenhouse effect. Despite the categorical statements of newspaper headlines, we do know that there are still many uncertainties and unresolved problems. For this reason serious effort in organising data collection and interpretation is necessary on a worldwide level. Development of research on the greenhouse effect and the consequences of the rise in sea level, necessarily involves governmental responsibility alongside international organisations: information and research are, in fact, an integral part of participant policies.

This does not mean however that we need to wait for incontrovertible information (never the case) before acting. Uncertainty cannot be an excuse for lack of action. In a situation that involves risk, even in conditions of uncertainty the political response cannot be to wait. A decision is necessary, and the process of decision-making takes place by evaluating and balancing costs and potential benefits in relation to possible outcomes. This calculation must leave no room for the possibility of a catastrophe.

When we move on to consider the implications on the regions and cities on water of changes in temperature and sea levels on a world scale, we must not forget that these processes have had an impact on local realities that have, generally, been made more fragile by different types of changes in the local ecosystems. The case of Venice, from this point of view, is a good example.

The last century and the last forty years in particular, saw changes of enormous dimensions and gravity in the lagoon: a high level of pollution caused by increased organic discharge and dumped nutrients and the disappearance of approximately half the tidal flats ("barene") have caused the degradation of the biotic system and the disappearance of numerous species. The lagoon bed has deepened (from 30 to 40cm since the start of the century), and this is particularly striking at the lagoon mouths (at Malamocco, from 4-5 metres to 15 metres on average).
The coastal strips that separate the lagoon from the sea are subject to erosion processes that would require critical protection in some points in the case of serious meteorological events. The water level has risen by 23 cm over the last fifty years, compared with an average of 4 cm per century in the past. The high tide flooding (‘acqua alta’) phenomenon has become six times more frequent since 1930. Compared to the attention and care that the Republic of Venice dedicated to the maintenance of the lagoon, we have had decades of neglect and negligence, at the same time as disorderly growth exercising a deadly pressure on this delicate environment.

The 1966 flood, and the dramatic high water (1 m 94 cm), were the shock that brought the problem of safeguarding Venice to the forefront. The President, Dr. Zanda will be illustrating the history of the various proposals, decisions and norms that led, in November 1984 (law no. 171) to the present policy line, and he will be describing the features of the new project of the Consorzio Venezia Nuova.

I would like to emphasise that this project has taken into consideration the possible rise in sea level as a consequence of the greenhouse effect. On all sides the Consorzio’s project responds to the directives assigned it. The work the Consorzio has carried out so far, in the face of difficulties and obstacles not always of a technical nature, is a guarantee of the success of this extraordinary operation. We cannot rest on our laurels though. There is a further worrying aspect of the problem on which I would like to make a brief comment.

It is one of the central themes of this meeting: the unique nature of the problems involved in re-establishing the equilibrium, pollution control in the lagoon and protection from flooding. The feasible environmental effects consequential to climatic changes involve the ecosystem of the Venetian lagoon from both a hydraulic and quality of the environment point of view. It is obvious that a rise in sea level could determine important changes in the systems of regulation and sea-lagoon exchange: from the hydraulic point of view, the mobile closure system for the lagoon mouths designed by the Consorzio Venezia Nuova will have to be activated frequently, in order to avoid or limit flooding; from the qualitative point of view, an increase in the frequency of closure of the mouths could bring about important changes in the ecosystem, as a consequence of sea-lagoon exchange reduction and interruption of the "physiological" tide cycles.

This situation confirms that the scenarios concerned with climate modification reinforce the concept that the hydrodynamic models used in designing the mobile closures system, must be closely integrated a priori with "trophic" models of the lagoon’s ecosystem, to correlate the hydraulic and environmental effects.

The lagoon’s ecosystem and the drainage basin must be considered as a unitary whole of hydraulic and biological phenomena. These are the fundamental "coordinates" of "Progetto Venezia" ("Project Venice") of November of last year. One of the basic necessities singled out by Project Venice consists in working toward closer coordination between the interventions for pollution control on the mainland and the interventions finalised for the safeguard of the lagoon. Four precise implications and needs are derived from this statement:

1) the measures foreseen for the Special Law for Venice must be extended to the whole of the permanent drainage basin (from 8 to 99 communes, going over and above the present distinction between waters that directly or indirectly drain into the lagoon;
2) the financial dimension and the type of works necessary for such an operation are much more far-reaching. To involve the whole of the territory the Venetian lagoon subtends, in an action of infrastructures and environmental restoration, means starting up a Lambrora-type operation;
3) this means giving life to a financing mechanism that is not dependent on public spending only, but foresees finance from private sectors as well;
4) in order to develop an initiative of these dimensions and complexity, suitable technical-managerial structures will be necessary.

In its report last September, the “Comitato Tecnico Permanente per l’Ambiente Lagunare” (Permanent Technical Committee for the Lagoon Environment) proposed that “the design, execution and working of the works and interventions be entrusted to one single body, capable of guaranteeing the realisation of the plan within the programmed time, even resorting to financial advances with respect to the flow of public financing”.

Our progress along this road is so slow that we are virtually at a standstill. Various solutions are available, ranging from the most obvious one of activating an operative organism in which both the Regione and the Consorzio operate together using the guide lines of the Lombardy experience, to other possibilities. What is absolutely unacceptable is that the problem, stagnates with these long time lapses that would have been inconceivable at the time of the Repubblica di San Marco, that uniting designer and constructor of colossal works.

The situation must be re-examined in the context of the Committee responsible for the project direction, and in which the presence of the Minister for the Environment, should the delay be protracted, would become completely superfluous.

On the other hand, it is not only in this region that environmental policies are hampered by obstacles and delays and by initiatives that risk contradicting it. However, this is not a suitable place for raising problems that will shortly require the attention of the Government.
This is a technical sitting, for meeting and comparing experiences of great import and significance.
As the century comes to its exciting close, the close web of interdependence that makes our planet not only a unique, delicate and vulnerable ecological system but a sole political world, becomes more and more obvious. The rise in sea level belongs to the kind of challenge that demands real answers on their level. And I am sure that this meeting of yours will make a valuable contribution to the efficiency of this answer.

GIORGIO RUFFOLO
The Minister of Environment
Minister, Mayors, Ladies and Gentlemen, I was very enthusiastic to receive the invitation to open the works of this international meeting. I feel that we are not only dealing with endangered structures palaces and monuments - symbols of this splendid Venice and of other cities represented here - but also, and perhaps more importantly, with the form of social community itself: the city that in our case, has grown and developed on and with water. This inevitably brings into play a series of problems at the very base of our civilisation.

Man and his civilisation have, in fact, reached such a level of development that we now have the power to influence, for better or for worse, the present and future state of our planet.

The coming decade will be decisive; questions such as that of the destruction of entire habitats will either be resolved before the millennium is over, or these processes, which for the most part have been triggered off by human activity, will take that road of no-return.

In fact, together with the growing vulnerability and impotence of the nation state when faced with events such as an international recession, AIDS, or an ecological catastrophe, these mutations have given credence to the concept of "interdependence", that is to say, the idea that we are all in the same boat and that, either we solve these problems all together or not at all.

Sound multilateral and international structures are then necessary, as the causes and effects of any of these problems are on a global scale; the greenhouse effect is a case in question, as it requires both an effort from the North of the planet to reduce carbon dioxide, and an effort from the South to put a stop to uncontrolled deforestation (even though, on the theme of the ozonosphere irrational attitudes could best be avoided on both the catastrophic side and the optimistic one: the scientific community recently informed us that the hole is closing at present due to seasonal oscillations).

In conclusion, however, the most important ingredient is political will, because even the international organisms, such as the newly conceived European Agency for the Environment, can only be effective if the member states really want it.

The Italian Government, for its part, is well aware of the global nature of the problem and, as a consequence, the Minister for Foreign Affairs has introduced projects concerned with environmental impact into his policies of Cooperation for Development, as for example can be seen in the recent agreements with Brazil.

Initiatives such as this of the "Cities on Water" are welcome. They should not limit themselves however to collecting material, but should also supply imaginative and effective information to national governments, local administrators and other competent bodies.
In conclusion then, I would like to remind you how several problems such as the smog in London or the lead emissions in the USA were solved, or nearly. Having said that, let us hope that the future generations can credit us with having at least tried to reverse the tendency. Thank you for having given me the opportunity to deliver this address, and I wish you a successful working session!

SUSANNA AGNELLI
The Undersecretary of
Foreign Affairs Department
In this international meeting on the effects of sea level rise on cities and regions, cities, international bodies, universities and research centres from all over the world are gathered here in Venice for three days to discuss a concrete problem of great import. This meeting itself is one of those miracles of commitment and international collaboration that gives one hope for the future.

It is the first public initiative of a very young institution, and has attracted considerable attention and success. The organiser, the International Centre "Cities on Water" came into being only a few months ago stimulated by the operations Venice is carrying out to defend its environment and historical heritage. This represents an experiment in innovation, a mobilisation of economic, technical, intellectual resources to construct a different future.

Reactions and appraisal of the experiment are expressed through approval, but also criticism and contrasting ideas as well as operative proposals, from the Venetian community. This too is of great importance, because we cannot conceive of our societies and cities successfully dealing with serious environmental and urban planning problems in the future, unless their inhabitants are directly and coherently involved.

Whatever takes place in a city so deeply linked to the water in all aspects of its economic, social, technical, artistic life could be of use to other cities, regions and institutions in the world that could also have close ties with the water.

The International Centre "Cities on Water" was the result of an initiative of the City of Venice, its two universities and a consortium of private companies. It is in itself a model for relationships and collaboration between the protagonists in economic and social processes.

The response to the Centre's first public initiative has been overwhelmingly positive.

This reinforces the idea to make Venice a permanent reference point for cities and large urbanised regions, where it is possible to exchange information, check strategies and projects, and collect documentation in a systematic way.

Through a series of work meetings making use of results of specially planned research projects, an international meeting like this will be held yearly. This will serve to take stock of the situation with respect to a variety of specific problems of cities on water. An international research group is already working on next year's meeting which will deal with the waterfronts of the world's large cities: the transformation of their use due to changes in technology and transport and production and the possible rise in sea level, the great opportunity this represents for making changes in the cities' functional structures, the complex public works that these transformations bring about and the new environmental problems that they generate.

They are projects on an enormous scale, economically speaking. Many cities are counting on these for their future, but they have not always been planned as they
should be, nor are they giving or will give desirable results.

In two years’ time the meeting will cover another theme of far-reaching importance: water pollution in the harbours and bays of the big cities on the sea or large lakes, and the serious problems involved. Appropriate technical solutions adapted to different cases will be examined, together with the necessary financial and legal mechanisms, and the legal aspects the projects pose.

The international meeting will thus become a set appointment for all those who operate in this field. Thanks to the presence of many experts and representatives of cities on water in Venice, more precise hypotheses on the contents and organisational structures to be given to the centre will emerge. They will be integrated with those already drawn up over recent months by an international work group.

As well as these meetings, a permanent centre of international documentation will be set up. Furthermore, publications will be put out so that the institutions that adhere to the International Centre “Cities on Water” can be kept updated on new projects, technical innovations and new policies in a variety of fields connected with the relationship between city and water: from defence from the sea, to the quality of water; from the re-use of port areas, to the re-introduction of water transport in urban areas; from the productive use of water to the governmental organs for managing large-scale water systems.

In this way the Centre will become a valuable organ for meeting exchanging information and developing ideas, and will serve as a reference point for all the cities in the world, whether they be rich or poor, highly developed or less so, and other interested bodies. The International Centre “Cities on Water” has the legal structure of an association.

Cities, research institutions, government organisations, technical agencies will all be able to adhere. Every year, at about the same time as the international meeting, a meeting of members will be held, to set out the general line of the Centre’s activities to follow. An international scientific committee will propose the themes for documentation and research work, as well as the nature and type of initiatives to be undertaken.

I would like to underline two aspects that I find particularly interesting. The first concerns the Centre’s contents. They are not limited to scientific or technical, economic or legal problems, but also to that more complex set of aspects and relationships concerning nature and the works of man.

The cities on water with their complex and relative fragility represent a field for study and reflection of far-reaching import: an opportunity for reflecting on many aspects of the future of mankind.

The second concerns the participants at the activities of the Centre “Cities on Water” and thus concerns the special enthusiasm with which the problems are being dealt. The protagonists are the city, or the large urban areas, rather than the national or subnational government organs. This enables us to give the appropriate weight to a series of problems and to deal with them in the right light.

The cities are becoming important role-players once again in the economic, social and political life. This fact must be underlined and considered a new.

One last consideration, one that is nevertheless important for the Centre.

Over recent months there has been a series of initiatives promoted by various institutions including the University, which has played an important role. These have led to the consolidation, here in Venice, of other new important possibilities for research and innovative production in the field of marine technology.

The most recent of this series is the project to set up a focal point for research on marine technology, marine engineering, offshore engineering, coastline protection, marine biology, aquaculture, biomanipulation, special marine equipment and marine technology in numerous laboratories for research and experimentation.

One group of Italian companies and multinationals has already decided to set up an executive committee, to have the focal point operational by 1990. The focal point has already been supplied with equipment worth 60 thousand million lire, and will employ 200 people.

It will draw up agreements and contracts for research on national and international levels.

The Venice Universities are working towards expansion in the field of studies of the lagoon and marine environment. Work is under way regarding the possibility of reinforcing the area of research on the problems of the sea that have been the concern of the Laboratorio Grandi Masse of the CNR.

Development of the university studies in Venice in the field of Hard Oceanography and Marine physics could be a logical extension and integration of what already exists.

In the light of the large research laboratory and interventions of Project Venice, the CNR laboratory, the university activities in the field of marine environments, the establishment of a focal point for applied research in the field of marine technology, the existence of the International Centre “Cities on Water”, Venice becomes a focal point par excellence on an international level in the field of study and marine technology.

We feel that this is the best prospect for the future of this water city, which is somehow representative of the cities on water in the whole world.

PAOLO CECCARELLI
The Vice-President of
International Centre
Cities on Water
Three introductory lectures review the general topics and the common problems and roles of cities on water.

Prof. Wiin Nielsen reviews the state of the art in modelling and predicting atmospheric and ocean warming as an effect of evidenced trends of greenhouse gas concentration on the planetary atmosphere and specifies the proper way to interpret the results. 40 years of data in the archives wait to be cleaned of noise and analysed to feed simulation models and reduce their uncertainties.

All present models predict temperature increase, are imperfect, improperly describe ocean-atmosphere heat transfer and time constants but cannot be disregarded. Research needs strong support but decision-makers must now deal with the possible impacts of Global Change to the best of their ability.

Prof. Tunney Lee gives a tale of the year 2050 describing the cases of one city prepared and a second city unprepared for future hazards, such as severe storm floods, and emphasises the economic and human advantages of the prevention policies. Prevention is unpopular but more effective and less costly. Earthquake prevention in vulnerable areas, has been and still is a convincing strategy but so seldom confronted with either the impossibilities or incapacity of policy makers.

The first role of city officials is the assessment and management of risks.

In the face of the possible new threats of greenhouse warming and sea level rise there is a need to rethink and reinvent our cities management, governance and planning systems. For each site intrinsic problems must be defined.

Cities have become major economic engines. They cannot fade away; too many people now rely on them. The 7 cities of the world with more than 5 million people in 1950, will be 93 in 2075. Traditional plans are no longer sufficient and new versions of wisdom are needed.

Roads, water and several services, public safety building, broadcast and telecommunication facilities must be updated to face the predictable adversities and hazards.

With an intelligent analysis of preventive measures, cities will learn more about their own ecosystem, their own economy, politics and environment. They can construct a model of models.

Dr. Frassetto demonstrates that there are reasons to be confident with the worldwide scientific effort of the coming decades to understand and demonstrate the processes and the effects of global change and its impacts on human life, activity and structures.
While the scientific assessment of the causes and effects of the alteration of the global environment will progress, the present uncertainties in the prediction models should not prevent the responsible policy makers from analysing the physical and socio-economic impacts and consequences of present human behaviour and disrespect of the natural environment, and planning institutional measures. Think global and act local—should be the slogan of cities, where populations are growing most, particularly in the cities on water which are vulnerable to the multiple consequences of a rise of global Sea Level.

A primary responsibility of scientists and technologists of those cities is to establish the reference level for a continuous long-term measurement and high accuracy verification of local land and sea level variations in time. The values of tectonic subsidence, isostatism, soil compaction and eustatism components can be identified in the spectra of level variabilities if these are referred to a global reference system. This is possible today with a well-organised network of benchmarks and the use of space technology.

CASE STUDIES

The introductory lectures were followed by 23 presentations of significant city or regional cases. Seven of them were sent by the authors who could not be present (Eng. Guo Hsia-Chuang, Shanghai; Prof. Chidi Ibe, Lagos; Prof. Miek Kelly, Norwich; Prof. Ren Mei-e, Nanjing; Prof. Yang Hsairen and Prof. Xie Zhiren, Nanjing; Prof. Enrique J. Schnack and Prof. Jorge L. Fasano, Mar del Plata - Prof. Nuruddin Mahmood, Chittagong).

Dr. Zanda illustrates the case of Venice, the unique urbanised lagoon exposed for more than a thousand years to natural and artificial modifications at the interface between the Adriatic Sea and the large alluvial basin extending from the Alpine slopes to the coast. Following the needs of industrial development, subsoil water table exploitation accelerated the natural subsidence of the city creating serious problems for its survival. The degradation of the historical buildings and monuments has severely accelerated as an effect of exposure to more frequent and ample storm surge floods. A project of defence by means of tide gates at three openings of the land barrier separating the lagoon from the sea is well under way after 25 years of planning, but needs political will to be completed as expected in about 10 years. This long time interval between alertness, planning and action is a demonstration of the need for timely studies of preventive measures and risk analysis. The proposed flood gates have a margin of safety to face up to the effects of a 60cm rise in sea level in a century, which is also the expected life of the gates. The paper gives some statistical and historical information of the Venice storm floods and collateral effects. It demonstrates the importance of analysing all interconnected physical, morphological, environmental and socio-economic aspects of a delicate city and lagoon system with the risks posed by the sea and the drainage basin.

Prof. Jelgersma illustrates in detail the mechanism of soil compaction in reclaimed lands of the vast deltaic lowlands of Holland and the experience acquired to deal with this problem which is common to all urbanised lowlands of the world.

Dr. Waterman presents a new plan to protect the expanding city of Rotterdam and its growing Europort by means of the soft technique of “building with nature”. Rotterdam, at the outlets of the rivers Rhine, Meuse and Scheldt, is a typical case of a city on a delta. After a review of historical floods and the following projects and of the failure of hard defence systems, he describes the more effective soft approach of flexible integration of land in sea and water in land, making use of material and forces present in nature. This is the first advanced engineering project and urbanistic analysis of using nature and human wastes to reclaim land from the sea and build defences.

Dr. Ascher illustrates the history, problems and interventions of the city of Hamburg, a typical case of a large marine city built inland, about 120km from the estuary of a river (the Elbe). The 1976 and 1985 flood damage, created by storm surges to the city and the surrounding agricultural areas, despite the existing embankments on the river sides and the coastline defences, forced the city officials to provide a new protection program (1989). Its cost was over 180 millions marks, raising 60km of banks 50 to 80cm to the 100-year event. The long-term programme of defence contemplates the use of flood gates near the estuary and planning discharge areas. This introduces legislative problems and agreements with the neighbouring nations. 25 years will be needed to complete the programme.

Dr. Shennan emphasises the need for accurate assessment of potential impacts of Sea Level Rise following the identification of areas at risk such as urban areas, industries, transports, agriculture, wetlands, habitats. New developments and costs and benefits of measures should be analysed on a national scale and improved local monitoring is needed to identify trends of changes. He then describes the geography and history of the UK Tees Estuary. The 5-metre level has been used in the evaluation of the areas at risk for SLR in the Cleveland region with potential impacts by the year 2050. The economic modelling is facilitated by the use of the Geographic Information System (GIS).
The major problem is the “quality” of data. Mr. Kelly illustrates the case of London and the Thames Barrier, built with a 40cm margin to face the 1000-year return period flood (and a mean SLR to 2030). If global warming were to create a 60cm MSLR, the 1000-year flood case become a 190-year case.

An additional 100cm protection margin should then be considered and fortunately this appears possible without substantial redesign of the Barrier System.

Prof. Sevenard illustrates the floods generated by the front of long waves on the Neva delta, invading Leningrad. Its forecast is today only 4-6 hours. A 25km defence with 6 flood gates, 2 of which will be navigable, is under construction on the sea side of the delta. The problem of pollution may emerge for insufficient flushing.

Dr. Leatherman reviews the Atlantic coast of the US with the problems of Boston, New York, Atlantic City, Washington DC and Galveston where, on average the Relative Sea Level increased about 30cm over the last century.

Different defence strategies are described, as well as damage to and nourishment of beaches and dunes. Galveston, a typical city on a beach, was flooded at a 2m level by the 1900 hurricane which killed 6000. The problems of defence are illustrated.

Dr. James Titus illustrates the land loss in Louisiana, in the area of the Mississippi delta, the river course displacements in the last 1000 years and the effects of human defences (hard method) over recent decades. In the 1940-50 decade the oil industry has accelerated land subsidence (about 1cm/year).

The consequent erosion of the land barriers is a typical example of what would happen with the erosion of a deltaic coast line exposed to SLR and not replenished by river transports of sediment.

Prof. Morioka and Dr. Tamai talk about the 1959 typhoon, which destroyed the Nagoya defence system which had cost 3 billion US dollars, and killed 5000. Since then Osaka has had 2 billion US dollars a year expenses for disaster prevention and mitigation, including tides, storm surges and tsunamis.

The responsibilities are divided between the Japanese Environment Agency, the Ministry of Transports and the Ministry of Construction.

The soil is subject to compaction; an experiment of rising downtown Osaka with 2m of sand appeared successful but too expensive. Subsidence on the coastal side reached 280cm in 52 years (1855-87). Since the institutional measures were enforced, the anthropogenic subsidence due to water exploitation has stopped.

Osaka’s advanced safety services against storm surges and floods have reached a high grade of reliability. Adaptation technologies and hazards mitigation options are available and in continuous reassessment. 1700km² with 3.8 million inhabitants and properties worth 370 billion US dollars would be submerged with a 0.5m MSLR. New flood control would cost about 400 billion US dollars.

Planning criteria were reviewed in 1965 after the typhoons of 1934-44-45-50 and 61. 85km of dykes, 8 tide gates, 14 drainage facilities were built and 29 bridges upgraded. Raising embankments about 2m would disfigure the landscape and would be an obstacle to cargo handling. The reasonable solution is the use of tide gates on the sea side of the city.

Dr. Gerstle presents the case of Sydney. The Warringah Council has adopted the SLR of 40cm in 50 years as a margin of safety, for long term protection against floods of vulnerable coastal fringe where 80% of the Australian population lives.

SLR in the last century in Australia was about 1/3 the Global Value because this is a tectonically stable area. Urban areas in lowlands are however subject to effects of soil compaction for structural loads. A Coastal Branch of the Environmental Protection Authority has been created.

A regulation prohibits developments in areas where flood occurrence is more than 1% possible (average return period of 100 years). Engineering “design life” of structures is an useful index for realistic assessment of time of redevelopment of a site.

Dr. Yim presents the case of Hong Kong, of which the majority of the population (6 million) lives in the Pearl River estuary with the largest port of the world. 5% of this area is reclaimed land.

Soil compaction and subsidence is therefore the major problem exacerbating the risk of SLR.

Dr. C. Lohe-Ming presents the case of Singapore, with its population explosion. Singapore is an island surrounded by 60 more islands and reefs that are mostly flat and reclaimed from wetlands.

Dr. Guo Hsia-Chuang. Shanghai’s district is 3 to 3.5m above MSL, lower than high spring tides and subject to tropical typhoons in the July-September season. Storm Surge Floods above MSL were 4.77m in 1949; 4.98m in 1974 and 5.22m in 1981 (defences held on this occasion).

Land subsidence for water pumping from the subsoil water tables was 1.77m in 59 years (1921-80).

The Yellow River, where salt and oil are important resources, is a deltaic region of continuous land variation, expansion, subsidence, accretion and erosion, subject to storm surge floods and earthquake effects. In Tanggu, floods reached 4.6m in 1939 and 7m in 1985. Some areas had to be abandoned.

A new sea port, Huanghe, is in development and new systems of protection must be conceived.

Dr. Pernetta presents the cases of reef islands and atolls and the case of Male, in the Maldives region. Built on reclaimed land by pumping in sand from the
lagoon. Male lies about 1m above MSL. SLR risks are very serious as 85% of the artificial land is below this level.

Most islands of the Maldives are ill-equipped to handle new Sea Level Rise problems. Medium and long-term natural defences need to be studied, including coral reefs build-up.

Dr. El Sayed describes the problems of Alexandria (Egypt) with 3.5 million people placed on an elevation but surrounded by lowlands and wetlands where harbour developments, amenity resources and city expansion are under way, facing MSL Rise risks. Lake Maryut particularly needs protection.

Prof. Mahmood describes the Chittagong case in the Bangladesh deltaic area, where up to 24 million people live. The monsoon floods with unpredictable typhoons bring repeated disastrous damage in summer seasons but the population is reluctant to abandon the fertile soil and their unique source of living. Unable to build up adequate defences, Bangladesh faces frequent losses of human lives.

Dr. O. Johannessen illustrates the vulnerability of Bergen and Oslo to severe storm surges of Atlantic origin and emphasises the impact of SLR to navigation, harbour amenities and sewage disposal use, regardless of the isostatic trend of the area soil lifting.

Dr. C. Ibe points out in an abstract the severe problems of coastal erosion in the growing cities of Lagos, Boujul, Dar-Es-Salaam in. act today. SLR will force defence which is unlikely to be made for its coast with anticipatory planning and actions. A second major risk is the salination of the already poor aquifers. The population of Lagos today is already 8 million.

The case studies were discussed in a Round Table session the summary of which is at pg. 193-195. Following this session the delegates of participating International Organisations presented their point of view (which are also summarised here).

INTERNATIONAL ORGANISATIONS
Interest and Activities

"The World Bank with its 150 members is dealing with the environmental challenge by promoting research and education", says Dr. Guarda. Calculations show that with a world economic growth of 2.3%/yr, the rate of increase of greenhouse CO₂ will double its present concentration by 2040-2070, gradually creating an increase of temperature of 1.5 to 5.5°C and a SLR of 20 to 140cm in about half a century (Villach). Arrhenius predicted effects of doubling atmospheric concentration of CO₂ in 1896, nearly one hundred years ago and was ignored for more than half a century. Had he been listened to, we would be better prepared today. Dr. Guarda gives an overview of the variety of costly damages to human activity and properties and to the coastal oriented economies affected by SRL.

How can global warming be stalled with our lifestyle? One figure has to be admitted: that 8% of the world population of advanced countries account for 75% of dangerous emissions.

Key positions of the World Bank in limitation policies, in the preparation for research, in training and in regional studies are described with the ongoing Bank operational activities.

The OECD Secretary Jones illustrates effective methods for the assessment of the socio-economic impacts of SLR, and of the cost and benefits of policy responses, and indicates gaps in the present analysis and in the available literature as a contribution to IPCC Groups II and III.

The function of growth-versus-time is not easy to estimate. Indirect impacts, such as loss of life, unemployment and others must be included in the analysis. The approach based on market and non-market impact is the most appropriate for modelling at national and international levels. A framework for economic approach to impacts of SLR is given as a catalyst for local or regional studies.

The GIS (Geographic Info. System) offers some potential for assisting in quantification and integration of processes and impacts.

Dr. Koehes, Director of OCA/PAC, presented UNEP views on Global Changes. Adopting temperature increases of 1.5°C by 2025 and 1.5 to 4.5°C by the end of 2100 with SLR of 20 and 20-140cm respectively, OCA is proceeding to case analysis.

The potential impacts are assessed by task teams for six regions (mostly developing countries) with the objective to assist their governments in early planning.

Dr. Ramachandran, Director of HABITAT (UNEP), emphasises the fact that about 50 million people will be driven from their coastal dwellings by the Rising Sea in the next century if no action is taken since now. Complacency greatly increases the cost of future action. Resources should be allocated now to mitigate threat costs. He also expresses the necessity of scientific credibility of predictions, in view of the severity of their consequences.

The cities on water need full support in HABITAT as it could bring a very realistic contribution to the analysis of single and common problems as a centre of excellence.

WMO, established in 1873, has today 160 members. "Its present major role is to provide authoritative scientific information and understanding of the climate change mechanisms and acquire the ability to predict", says Dr. Olsson.
The resolution of climate change was adopted in 1975 and the World Climate Program with UNEP, ICUS approved in 1980. The objective is to provide the information for the benefit of economic and social activities, to develop climate projection scenarios, to determine the causes and the extent of human influence on climate, to monitor climate variations and develop the capability to warn governments.

The European Community, Directorate General XII has, since 1979, solicited research programmes on climatology.

Dr. R. Fantechi illustrates the 3 major programs of DG XII: the first for a duration of 5 years (1979-1984) was supported with 8 million ECU. The second was its renewal for the period 1986-1990. The third program (1989-1992) included Climatology and Natural Hazards with 40 million ECU support. EEC publishes its tenders in the Official Gazette in all languages.

The research proposals from European Institutes are carefully analysed and, when accepted, a contract is made, the EEC financing on the basis of 50% of the research costs. The DG XII organises yearly schools in Institutes of excellence and has created, with its support, important and productive international collaboration among scientists.

The final objective is to provide, with advanced scientific and technical research, a new light on industrial, agricultural, environmental and internal market policies. An other important objective is to promote uniform test and measurement procedures. The Greenhouse effect, ozone depletion, acid rain, deforestation, desertification, etc. have been the motive for cooperation at Community level to contribute to prenormative aspects with work on atmospheric chemistry, modelling and the application of Remote Sensing.

Dr. Pugh, representing IOC, dealt with MSL measurements and GLOSS, the Global Sea Level Observing System and its network of 1300 permanent stations. Local variations from tide data analysis and averaging are best understood in the context of long-term global variations and tendencies. More detailed and precise studies at local levels are needed with unified procedures.

Dr. Goldsmith, DEO of ESA, illustrates the potentials of new satellite systems including GPS, Altimeters, Lasers, Prarie to map the Geoid as a gravitational equipotential surface stable enough to represent the reference surface for heights. The Sea Surface Topography is however disturbed by tides, currents, wind stress, salinity and temperature variations while the MSL is the average of all instantaneous sea surfaces over a sufficiently long period of time. Absolute SLR should be determined when it is measured relative to a stable

Reference point, with high accuracy, at the millimeter range.

The meeting concluded with the comments of the participating city officials resumed at pg. 227-229 and with the compiling and presentation of a conclusive report and recommendation document (pg. 230).

ROBERTO FRASSETTO
1. INTRODUCTION

The general greenhouse effect, i.e. the fact that the atmosphere of the earth has a pronounced effect on the temperature climate in the atmosphere in general and particularly at the surface of the earth, where we live, has been known for a long time. Now almost a century has passed since Svante Arrhenius, a Swedish scientist, introduced what may be called the special greenhouse effect. By this he meant that changes in the composition of the atmosphere for some gases which have a marked influence on the radiation budget of the climate system, could also change the climate. This happened in 1896, when Arrhenius was the first to estimate the temperature effect of \( \mathrm{CO}_2 \), if the concentration of that gas were to increase. Two years later he spoke about his results in the Royal Swedish Academy of Sciences.

The issue lay dormant for at least half a century, but it became a very lively issue, when it was discovered in the 1960’s and 1970’s, particularly from measurements at Mauna Loa in Hawaii, that the concentration of \( \mathrm{CO}_2 \) was steadily increasing.

Using the old arguments of the Swedish scientist it was then quite easy to come to the conclusion that the temperature of the atmosphere should be increasing. The only question seems to have been: How much?

The global warming issue has now become an international scientific issue of huge dimensions. We are constantly seeing it and hearing about it in the newspapers, in magazines, on television, and numerous scientific conferences and symposia have been arranged to study the more quantitative aspects of the issue. But it has also become a political issue. Atmospheric scientists have raised the issue, talked much about it, and their advice is now being sought by politicians all over the world.

There are no borders, and the issue has not divided the East from the West. On the contrary! General Secretary Gorbachev, Prime Ministers Thatcher of the U.K., Bruntland of Norway, Mulroney of Canada, and President Bush of the U.S. are all aware of the global warming issue, and the international calls for action from many fields are steadily increasing.

The scientific academies from various parts of the world have not been silent either, but have issued statements to be used by the policy makers in their own countries or elsewhere.

The scientific community or at least a part of it has indeed raised an issue that lends itself to support by leaders everywhere: The mission of saving the inhabitability of Planet Earth!

The main purpose of this paper is to examine the questions: How good and true is the scientific foundation of the many statements which have been made? What is the defendable action which can and should be taken in view of the certainties and uncertainties of our knowledge?
What is the best advice to be given to the participants of this conference which is concerned with the side issue of sea level rises that may result from the global warming, if it comes? The greenhouse effect has been investigated in two rather different ways:
1) Model simulations and
2) Data studies.
In the following we shall review both of these groups separately.

2. MODEL STUDIES

The main effect of an increased concentration of CO₂ is normally incorporated in a model in the calculation of the outgoing radiation, because CO₂ absorbs the long wave outgoing radiation at certain wave lengths. The primary effect is therefore a heating of the part of the atmosphere where the absorption takes place. Since the trace gases are well mixed in the lower atmosphere (the troposphere) it should give an in situ heating everywhere, but the resulting temperature change will depend on pressure, and it is for this reason that one would expect a larger temperature change in the lower part close to the surface of the earth. However, here we have spoken about the primary effect only.

Several important secondary effects should also be considered. We mention the most important ones. If the temperature increases in the lower part of the atmosphere, there will be changes in the interaction processes across the interface between the atmosphere and the surface of the earth, which may be ocean, continent or ice.

Since the turbulent transfer of sensible heat and evaporation depends on the temperature difference between atmosphere and ocean, we should expect a decrease in the temperature close to the ground. This process is what we call a negative feedback mechanism, because it counteracts the temperature increase due to the primary effect.

On the other hand, we also get a different effect. The increased temperature at the bottom of the atmosphere will increase the convection. But convection creates clouds, and we can thus expect an increase in the cloudiness. Clouds shield the air below them from the incoming short wave solar radiation, and the whole process will therefore result in a cooling effect, or, if you will, another negative feedback process.

But that decrease in the temperature will enhance the transfer of heat and moisture to the lower atmosphere and so on. One will understand from these examples, that the greenhouse effect is extremely complicated, and that one has to use a most sophisticated model to simulate all these processes correctly.

Unfortunately, not all models used to study the greenhouse effect can pass the test of sophistication. A weakness in all atmospheric models is the description of turbulent transfer mechanisms, which are described in a simplified way by empirical formulas. All models suffer from our inability to describe the convection in the atmosphere in a realistic way, and this inability is probably the most serious weakness in all model studies.

If we do not describe the negative feedback mechanisms correctly (or at all) we will get a too large greenhouse effect, while it will be too small in the opposite case. You will consequently understand that the results of model studies contain an uncertainty. We cannot necessarily believe them, at least not in detail. Purists would say that under these rather pessimistic considerations we should not do model studies at all, but if we always followed this advice, we would never be able to advance our science. It should, however, be a requirement that we use our best models for these sensitive studies.

What has come out of all the studies? All model studies seem to agree that an increase in CO₂ will result in warming close to the surface of the earth. The warming is predicted to be larger in the high latitudes close to the poles and smaller in the low latitudes close to the equator.

If this is correct, there will be smaller temperature differences between equator and pole than without the greenhouse effect, and this will in turn decrease the amplitude of the waves in the atmosphere and thereby change the paths of the cyclone systems at the surface.

So far we can find agreement in the model studies, but it is also generally agreed that regional and local changes due to the greenhouse effect cannot be predicted in a reliable fashion.

It is most important to stress that most, but not all studies have been carried out using atmospheric models, where the oceans have been considered as a reservoir without motion and with sea surface temperatures kept constant locally.

This too is unrealistic, and it is therefore encouraging that coupled ocean-atmosphere models are arriving on the scene. In reality, the oceans will at least have a delaying effect because of the very large heat capacity of even a rather shallow ocean layer (say 75m). The delay coming from this factor is of the order of 10 to 20 years.

The most recent major model study was carried out by Dr. James Hansen and his co-workers at the Goddard Institute for Space Studies in the U.S. This experiment has become particularly well known because Dr. Hansen gave a testimony to a subcommittee of the U.S. Congress on his results. They have also been widely reported in the newspapers. Since many of you may have your information about the results of the greenhouse effect from this study, it may be important to mention it here in a brief fashion.
The models looks like this:
A) The model, called GISS II, has a horizontal resolution of 8x10 degrees in each surface, and it has 9 vertical levels. This very low resolution is unsatisfactory, because it is impossible to model the small scale effects mentioned above in a correct way.
B) The heat transport in the oceans is considered, but it is fixed at its present level.
C) The observed and approximated changes in CO₂, CH₄, NOX, CFC and atmospheric aerosols are included from 1958 to present.
D) An integration, simulating 100 years is done first as a control experiment.

Thereafter, the following integrations were made:
Scenario A: Continued exponential increase in the concentration of all trace gases.
Scenario B: Reduced linear increase in the concentration of the trace gases.
Scenario C: No change in the concentration of the trace gases after year 2000.

The group came to the following conclusions:
1) The atmosphere will under all three scenarios obtain a temperature increase at least as large as the temperature under previous interglacial periods.
2) One should be able to observe these temperature changes during the decade 1990-2000.
3) The regions which will experience the temperature changes first, are the oceans in low latitudes, China, other interior regions in Asia, and the oceans close to the poles.
4) The temperature changes will be so large that they will influence the biosphere in a significant way.

It is a model result which has created rather intense discussion on the other side of the Atlantic Ocean. Not unexpectedly, the criticism has been severe because the investigators have drawn rather firm conclusions from experiments made with a model with very low resolution, which in turn prevents a realistic representation of all the important processes which have been mentioned in this discussion.

In summary, all models have predicted increases in the temperature.

All models have larger temperature increases in the higher latitudes than in the lower latitudes. All models are imperfect, particularly with respect to the description of rather subtle feedback mechanisms (positive and negative). All model results are therefore uncertain, but they can not be disregarded.

3. THE VOLCANO EFFECT

It has often been mentioned that an eruption of a volcano may have an impact on the temperature conditions in the atmosphere. The reasoning is that the eruption will put a lot of particles into the atmosphere. If it is a weak eruption, the particles will be mainly in the troposphere, but more violent eruptions will get the particles all the way into the stratosphere.

The particles, being fluid or solids, will of course have a tendency to fall out of the atmosphere again, but as we shall see, they may reside in it for quite some time.

Here, there is a major difference between the troposphere and the stratosphere. If a particle is in the troposphere, it may be carried by the winds, get into regions of precipitation and thus be washed out of the atmosphere.

On average, it is expected that particles in the troposphere may stay there for about 1 week. If the particles have arrived in the stratosphere, it is a different story.

This upper part of the atmosphere is much more stable, there is little or no convection, and no precipitation processes. The particles will thus stay in the stratosphere for a much longer time.

It is, for example, well known that the optical effects from the many particles in the stratosphere put there by the very large eruption of the volcano Krakatoa in 1883 stayed in the stratosphere for the better part of two years.

The particles in the atmosphere will influence the radiation budget mainly on the incoming side, because they will scatter the short wave radiation coming from the sun. Since the scattered radiation goes back to space and thus never participates in the atmospheric heat budget, the main result ought to be a cooling effect. We should also expect that the effect will be temporary, because it should disappear with the particles.

The volcano effect was investigated by Bradley last year (1988). The investigation was carried out using case studies, which means that Bradley grouped similar events together to obtain a characteristic picture. One way of grouping them was to consider separately, eruptions in high latitudes.

One sees quite clearly the cooling effect which, close to the volcano, may amount to a couple of degrees, and about half of that far away from the site of the eruption. It is, however, also quite clear from these analyses that a lasting effect is not found.

The temperature has a strong tendency to return to normal after 18 to 24 months.

We may therefore say that the volcano effect is important, but not significant since it does not have a net effect on the climatic timescale.

4. STUDIES OF CLIMATOLOGICAL SURFACE DATA

It would be excellent if we were able to verify the results of the various model studies which have been carried out in the past decade or two.

It is of course much more work to conduct a data study than to do a model study, simply because the data are very cumbersome to work with. They have to get out of the archives, be arranged properly, and computations have to be made.

But there is much more to it than that.
Meteorological data are notoriously 'noisy'. This is especially true for climatic data, which generally speaking are obtained by low grade instruments, carried out just a few times a day, and they should of course be available for a reasonably long period. In addition, and this is the major scientific problem, the data are of course influenced by all kind of processes. Our main goal is to locate the greenhouse effect, if it is possible.

But this means that all other effects will have to be removed from the data. A series of publications by P.D. Jones et al. has appeared. The group did a large amount of work to 'clean' the data. The following questions were considered for each station:

1) Have there been changes in the location of the station in the time period under consideration?
2) What changes, if any, have taken place in the instruments at the station?
3) Have changes occurred in the observation time?
4) Have changes taken place in the computational procedures used on the data?
5) What changes have taken place in the surroundings of the station (construction, concrete replacing grass, trees which have grown up during the period)? All such effects are grouped together in the so-called 'urban effect'.

The most serious concern is no. 5, because a station is almost never in an unchanging environment for many years. A typical example is an old airport station. It may very well have been established at a time when the airport was no more than a landing strip covered with grass. Today the same station may be surrounded by large buildings, domestic housing and concrete runways. If this is so, the station will have experienced a real temperature increase, but it is the urban effect, not the greenhouse effect.

Similar examples are the old stations from communities, which have grown much larger during the years, but the immediate environment changes due to the growth of trees, new houses, etc. All these factors have to be taken into account. The investigators used a scheme of intercomparisons to locate those stations, which were infested with the 'urban illness', but this system does not work, if the two stations are influenced in the same way.

The main result of all these studies were two major papers:
1) Variations in the surface air temperature in the Northern Hemisphere.
2) Variations in the surface air temperature in the Southern Hemisphere.

The authors concluded from these studies that the surface temperature has increased by about half a degree in the last 100 years.

Wood (1988) has been very critical of the whole investigation, especially the way in which the authors removed the urban effect.

He pointed out that it was not done correctly, so that stations influenced by the urban effect were left in the data set. As a result the conclusion of a temperature increase of half a degree is too large. Still another astonishing result which differs from the one obtained by Jones and collaborators has been published by Kirby Hansen et al. (1989).

They restricted themselves to data from the contiguous United States, and contrary to Jones they used area-averaged data.

One may assume that the urban effect is effectively removed in the averaging procedure. Using statistical tests, especially the Spearman Rank Test of the constancy of the mean and so-called two way correlations, they come to the conclusion that statistically significant changes have not taken place in the surface air temperature in the last 100 years (1886-1987).

In a paper from this year (1989) Karl and Jones have compared the area averaged temperature data for the U.S. with the global data set and found that the criticism of the removal of the urban effect was justified.

Thus, the conclusion from the studies of the climatological surface data for the last 100 years must be that only insignificant changes in the surface temperature can be found. The greenhouse effect, put into the scientific literature in 1896, can thus be characterised as the oldest unverified theory, which exists in the atmospheric sciences.

This does not mean that it can be forgotten or that is is wrong. It can only mean that the increase in the concentration of CO₂ in the atmosphere so far is too small to result in significant changes or that counteracting processes are at work destroying the primary effect.

5. A NEW STUDY OF GLOBAL DATA

As pointed out in the previous section, it is extremely cumbersome to use the standard climatological data. Are there other data sources? It occurred to me and to others that the operating prognostic centers in the world routinely make global analyses every day as a preparation for the production of the forecasts. Could these conveniently arranged data be used?

A discussion with old co-workers at the European Centre for Medium-Range Weather Forecasts (ECMWF) was not too encouraging, because they pointed out that analysis procedures were changed from time to time, and such discontinuities could lead to systematic changes.

Nevertheless, after some hesitation and discussions with other people, who pointed out that these data were actually the best available from a global point of view, that they would give information also from other levels than the surface, and that, right or wrong, the data were at least consistent, we decided to go ahead with a preliminary investigation.
Globally averaged temperatures as a function of time from 1962 to 1988, incl. for the isobaric surfaces 1000, 850, 700, 500 and 100 hPa. The straight lines appearing for all surfaces except 850 hPa are linear regression lines fitted to the data.
Still, in order to avoid the concerns of ECMWF we restricted the investigation to the period 1982-1988 and to global mean temperatures for the following levels: 1000, 850, 700, 500, 400, 300, 250, 200, 150, 100, and 50 hPa. ECMWF provided monthly mean temperatures for each of these levels. The data provide a series which is much shorter than required for real climatological significance. They should therefore be considered as a test of the most recent development. The data are based on global analyses carried out with all available data four times a day. Let us look at some of the results. For each level we used the data to calculate annual mean values for each of the years. Some examples for 1000, 850, 700 and 500 hPa are shown in the figure.

To each curve we have fitted a linear regression line, where such a procedure makes sense. Obviously it does not do so at 850 hPa. We see immediately that the slope is negative at 1000 hPa and positive at 700 and 500 hPa. At each level we have applied the test for the constancy of the mean as developed by Spearman. The data passes the test at all three levels. The same is true for the data at 100 hPa, which indicate a decrease in the lower stratospheric temperature as seen in the next figure. There was no significant trend at any of the other levels, which were investigated. This is our main result. For each year we also calculated the grand mean for the whole atmosphere by averaging the data for each year in the vertical direction using weighted averages due to the inhomogeneous arrangement of the levels. For these seven temperatures there were no significant changes.

In other words, no significant changes have been found for the mean taken over the whole mass of the atmosphere.

We have, furthermore made a number of calculations to test the validity of the data, since some suspicion existed in our mind of our application of the data for the greenhouse effect.

If the continents and the oceans were arranged in a symmetric fashion around the equator, we would not expect any seasonal variation of the mean temperature for each level. Due to the fact that the actual distribution is asymmetric with more continents in the Northern Hemisphere than in the Southern Hemisphere, we should expect a small seasonal variation. It should have the smaller temperatures in the Northern Hemisphere winter and the larger temperatures in the summer of the same hemisphere. Our calculation of the seasonal variation for each of the pressure levels indicated that this expectation holds. Furthermore, the amplitude of the seasonal variation is largest at the surface of the earth and decreases upward.

The fact that the data pass such a test helps to increase the confidence in them.

6. Sea Levels

It should be quite clear from the preceding discussion that we are dealing with a field containing large uncertainties. This is true for the estimates of sea level changes as well. But these changes are of course the main interest of this conference, so they should be at least be mentioned in this presentation. Global sea level has never remained constant. It will change as ice shelves and glaciers freeze or melt, and as air temperatures increase (causing thermal expansion) or decrease (causing contraction), and as ocean ridges change their rate of expansion. Local sea levels are determined not only by fluctuations in the sea, but also by changes in the geological stability of the coastal region itself.

At a place where the rise of the land goes on at the same rate as the rise in sea level, there would of course be no relative change in sea level. At this conference it would seem safe to restrict the discussion to the changes in sea level, which may or may not result from a global warming.

Glacier ice, of course, made of water coming from precipitation in the form of rain or snow, but this water comes into the atmosphere by evaporation from the oceans, so the sea supplies in the end, the water of which glaciers are built.
Thus, during a glacial period, under which much water is frozen down, we should expect a fall in sea level, and geological investigations also find changes ranging from 50 to 150 metres. The evaporation from the ocean will also, under such extreme conditions cause increases in salinity, which may change by some percents. Corresponding sea level rises occur when the glacial period is replaced by an interglacial warmer period. The changes in sea level during the last 5,000 years have been small, less than 1 m, and at many places in the world these changes are due more to variations in the coastal regions than to absolute changes in the sea level. Modern uses of tide gauges indicate that the sea level has risen 10 to 15 cm over the last 100 years. There are at present no indications that the rise is accelerating due to global warming. Thus, if the present trend were to continue for the next 100 years we would experience no more than these amounts. While such small amounts may create problems for people living in very low lying coastal zones, it is far removed from those changes which have been predicted by the catastrophic scenarios. The largest sea level rise seems to be forecast by Stephen Schneider and Stephen Olsen, who, as late as 1980, put up the possibility that sea level could rise as much as 2.6 m (sic!), but it is comforting to know that the authors later modified the estimate (which now seems a low probability) to between 10 and 150 cm over the next 100 years. With all these uncertainties it would appear reasonable to select some few areas of great interest for various reasons and monitor sea level changes over the future with the best possible modern equipment. Needless to say, the data should be analysed immediately, and the information passed on to interested parties. One could also use satellite based geodesy, where the accuracy in absolute terms is such that one can detect changes of 1 cm or a little less. A further advantage of the use of satellites would be that a dramatic change could be detected immediately, while tide gauges would be sure of the changes much later. For the immediate future, all but the people living in very low areas would seem to have little to fear from sea level rises.

7. DISCUSSION

The picture which emerges from the model and data studies, is far from clear. While the models are in general agreement in obtaining a warming as a consequence of the increasing concentration of CO_2, we know at the same time, that the models are far from complete in describing the development. We know that the model prescriptions for such processes as air-sea interaction, convection, evaporation and precipitation are, at best, a rough approximation of the real processes. We know that the models so far do not describe the whole of the climate system, but are mainly atmospheric models, occasionally with crude ocean models attached to them. We know that the models are inadequate in describing some, perhaps important, feedback processes. But with all these uncertainties about the models, should we neglect the outcome of them altogether? The answer is no, because the models are certainly not totally inadequate. We know also that, in spite of their shortcomings, they do provide a reasonably correct simulation of the present climate. In addition, they do respond to changes in the parameters in a reasonable way as has been shown in numerous sensitivity experiments. Since the models so far applied in climate studies vary greatly in resolution and parametrisations, and since some of them clearly could be improved, we should require that we take the results from the most reliable models as more certain than those obtained from less complete models. However, we should always remember that in the study of climate as in almost all studies in applied science, we shall never have all the information we desire when the time comes for decision making. It is our task to make decisions based on incomplete and uncertain information.

The data studies are also uncertain. Some results could be taken as indications of a weak signal through the noisy data of a first indication of a warming. Other studies seem to indicate that the warming has not yet started. Still other data studies seem to paint a picture somewhat different from the classical perceptions, because they show a cooling at the surface of the earth and the warming in the middle of the troposphere, but these studies cover a relatively short period only. Perhaps the best outcome of all the data studies is that no study so far has given a strong indication of a warming of the magnitude predicted by some model studies. In the present situation it is a good result, because it may give us time to continue the studies and at the same time to ask the politicians to take action in reducing the input of all the trace gases (CO_2, CH_4, NOX, CPC, etc) into the climate system. It may, in that way, be possible to reduce or to amend the worst scenarios. The community of atmospheric scientists is responsible for raising the global warming issue. It has been with us for a long time, at least a few decades, but the debate has increased in intensity in the last few years. Needless to say, it is the responsibility of the scientific community to warn society if it believes that actions in society may result in major changes in the climate system, which is shared by all of us, and in which we live and function. While the scientific community should be willing to
accept its responsibilities, it is the politicians and the lawmakers who should take action, and they should take the responsibility for introducing the necessary modifications in the behaviour of society to counteract the undesirable effects.

In the end it comes down to the energy policies of the world societies. The majority of the CO₂ introduced in the atmosphere has come from the burning of fossil fuels. If we are to reduce the input of this gas in the climate system, it will be necessary to change to other alternative energy sources.

It is beyond my allotted time to go into a detailed discussion of the whole energy issue, but it is probably the central problem. In this regard I shall refer to a paper by Dr. Robert M. White, the President of the U.S. Academy of Engineering, published in the Bulletin of the American Meteorological Society (September 1989, 1123-1127).

However, the best action may very well be not to select a static 'best policy', but to think in terms of strategies and sets of options leading to a continuous policy process where it is possible to reassess the political responses considering new information and new findings.

8. CONCLUDING REMARKS ON POLICY MAKING

In the question of global warming we are dealing with a global issue, and it calls, needless to say, for international action.

As mentioned in the introduction the international scene has already accepted the global warming as an issue to be dealt with.

But how can we make policy with all the various uncertainties, which we have described?

One must first of all exercise caution in making policy about climate change.

Certain scientists, however, are convinced that the very concept of uncertainty and its introduction into the discussion will make policy making a purely subjective exercise. Although there is an element of subjectivity in all policy making just as there is uncertainty in the process of making laws), a well-developed methodology exists for incorporating uncertainty in a rational and systematic way in to the policy-making process. The name of the game is to strike a balance among potential benefits, potential costs, and the probabilities of the different outcomes.

To follow Dr. Robert Lind and Dr. Robert M. White the best action may be to adopt a continuous policy process, where we periodically reassess our earlier responses in the light of new findings and new information.

In such a scheme, research and information gathering become an integral part of the policy development. So what we might do is to establish a process of continuing or better periodic reviews charging the reviewers with the responsibility of performing an evaluation of the state of our knowledge about science and information and the implications on the policy options. If this scheme were adopted, we would always be in harmony between our knowledge on the one side and the policy on the other.

In dealing with the media and with the politicians, it is important that we get the level of uncertainty across to them. It is naturally in our power under the present circumstances to excite the science writers at any time, but it is time that we control the desire to make headlines, that we should tell them about our level of uncertainty, and that we should explain to them that there are risks in action as well as in inaction. We are asked as always, to be honest in our judgements and to serve to the best of our ability.

And a final remark, selected observations are not representative samples, scenarios are not predictions, short-term fluctuations do not imply long-term implications.

All these things we should have in mind as we proceed to advise the people, who do not necessarily understand the words which we use.

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Wood, F.B., (1988), 'Comments on the need for validation of the Jones et al. temperature trends with respect to urban warming', Climate Change, 12, 297-311.
1. INTRODUCTION

Thank you Mr. Mayor and the City of Venice, the Centre, the various sponsors, the Palazzo Grassi for this wonderful setting and also, Prof. Brussetto, Prof. Bruttomesso and the wonderful staff for putting together this important conference. It is really fitting that this worldwide problem should be symbolised by Venice. Though the city was founded in crisis a thousand years ago, it went on to become a major power, solved problems of living on the water brilliantly and gave to the world a heritage that it can always cherish. Having lost its original purpose however, Venice, by its very nature is the symbol of cities on the water. If we must deal with the problems of some smaller cities, it becomes important that these problems are linked with Venice. The establishment of the Centre in Venice for problems of cities on water is very important for dealing with this very large problem.

We have again a new crisis, brought upon by our very growth. That is, the growth of the world and the growth of economic development has brought the crisis upon us in a way we can no longer ignore. Professor Wiin-Nielsen has brilliantly put forth a very balanced view of the difficulties of predicting and forecasting exactly what will happen, but his analysis nevertheless presents severe problems for cities. Cities are where the problems will eventually arrive. That is, we are not interested in this problem in its abstract sense. We are interested in this problem because it will make our lives and our growth more difficult and potentially disastrous. The year 2050 has been used often as a marker for predictions and we have to remember that it is not so far away. Many of the women and men who will live in, manage and govern our world and our cities in 2050 have already been born or will soon be born. They will be educated and reach their own maturity in the next decades. These are people that we must begin to influence.

As we gather here, the task of awakening the public and political leaders should not be one of creating panic about global warming and its consequent sea level rise. Rather, it is the task of understanding the additional problems created by sea level rise in a world already beset by the population explosion and growth of cities. The difficulty of balancing economic opportunity for the Third World with the need to reduce fossil fuel use and environmental pollution seems insurmountable. However difficult that is, we must make an attempt and it is our responsibility to start the process.
2. A TALE OF TWO CITIES

In order to illustrate the problems facing cities and what it takes to manage them I have created a fable. Imagine the year 2050. Global warming has raised water level by half a metre. A strong hurricane coinciding with the high tide has struck two cities. They are now dealing with the aftermath of this natural disaster and the clean-up has begun.

2.1. City A

The unprepared city is under martial law. Looting and rioting is taking place in the streets because food and water supplies cannot be maintained. The police and emergency workers are hampered because of a breakdown in telecommunications mainly because of the inability to broadcast from the crippled TV stations.

The computer records, which by 2050 are the most important in City Hall, have been damaged by water. The major roads are under water. Tunnels have been flooded and sewers are blocked by high water so that they cannot drain. Thousands of homes, factories, offices and schools have been destroyed or severely damaged or destroyed. The attempts to relocate residents from flooded areas to other areas in this time of crisis have met with armed resistance from the suburban areas. People who must provide the shelters can not see how to cope with this mass of people coming into their communities.

The city's economy has been crippled and chronic unemployment will become even worse. The city's political structure has been unable to deal with the slow but inexorable impacts of the rise in sea level and is now in severe crisis.

2.2. City B

It has also suffered significant damage and is facing a very difficult period of adjustment, but it has prepared itself. It had paid more, but not much.

It has built its major roads, water and sewer lines, telecommunication channels, protected its public records and public safety buildings and broadcast facilities by designing them to be above high water levels. The cost of these was not great but nevertheless significant in any city budget.

As many of the mayors and public officials know, the extra two or five percent seem very difficult in times of budget crisis. After a very long and bitter debate and opposition from the business community and builders and people who want to live along the waterfront, the city has banned building on land vulnerable to flooding and has severely limited landfill. These were very difficult decisions because the potential linear growth of the city and the powerful interest of those who live in the desirable parts along the water.

In those areas where they had limited building, the city has invested in a series of parks and natural preserves and wildlife areas on prime waterfront land both for recreation and as a buffer for storms and flooding.

At the same time, they had looked very carefully at their historic centre and their major economic assets and built a series of small but limited number barriers to protect public safety, vital institutions and the economic base.

More importantly, the city, as a community, had begun to deal with problems of how to manage itself. Public safety forces, from police to health workers had planned and rehearsed. Citizen volunteers were meshed into the public effort.

Residents from areas that were likely to be damaged were paired, assigned shelters and introduced to their host communities long before the disaster struck. The city's citizens and leaders had for decades supported non-partisan institutions to deal with the particular problems of protection.

Now these are obviously exaggerated scenarios, but it is a way of illustrating the problem and trying to analyse what we need to do in order to prepare for crisis.

3. BACKGROUND

First let me talk a little bit about the background. It is nothing new that cities in the world have been faced with natural disasters and have been destroyed or completely altered in their relation to the environment. We are all familiar with Mont-Saint-Michel. It was once inland and, by a series of natural changes, gradually became surrounded by water (Fig. 1, 2).

Other cities like Suzhou, Caesaris, Hilo in Hawaii, and the Adriatic coast itself have been importantly affected by sedimentation, volcanoes, earthquakes, tidal waves and other kinds of natural events. The question is then, what is different about today?

4. GLOBAL URBAN GROWTH

Now let us talk about global urban growth. In 1950, there were just seven urban centres in the world with a population of more than five million: New York, London, Paris, the Rhine-Ruhr complex, Tokyo-Yokohama, Shanghai and Buenos Aires. By 1984, there were thirty four. By the year 2025, there are expected to be ninety three, eighty of those in developing countries.

The growth is exponential and startling. Further, a significant number are coastal cities - Jakarta, Bangkok, Calcutta, Bombay, Cairo, Istanbul, Lagos. Fueling this growth are two factors. One is the continuing explosive population growth of developing countries while developed countries have stabilised their populations.
Fig. 1. Mont St. Michel surrounded by land and vegetation in historical times

Fig. 2. Mont St. Michel surrounded today by sea in tidal floods

The second is the shift of population from the countryside to the city. The problems of cities created by rapid growth itself, with or without global warming, are quite evident. Housing, transportation, food, water, public health are all severely strained and over stressed. Sea level rise and natural disasters become tragedies for millions of people.

When cities were few and far between, the population displaced by natural disasters was re-absorbed into the countryside. However, as the countryside itself has become fully developed and cities have become the major engines for economic development, the possibility of re-absorption no longer exists.

5. RETHINKING PLANNING

What we have to do is to rethink planning. I come from a profession in which we have always thought of ourselves as making plans to be carried out by other people. But that is no longer viable. Because when the prospect of a rise in the sea level or changes in the storm patterns around sea coasts are added to the list of the difficulties that cities already face, you can see that it is not a separate problem. Sea level rise is part of a series of problems created by our neglect of both the local ecosystems and of the global environment.

Solutions to these problems must have both international and local contexts. The international context, as Professor Wiin-Nielsen has already pointed out, needs to consider the reduction in the worldwide use of fossil fuels, preservation of forests and very importantly, the need for aid from the developed countries to the developing ones. But that is in a larger policy context which concerns the rest of the conference. My focus is mainly at the local level. In order to deal with such threats to the survival of cities, it is necessary to rethink our present methods of planning, management and governance of urban areas. I also want to emphasise the integration of planning, management and governance rather than the present separation of or lack of these functions.

The traditional master plans which direct the physical growth of the city are no longer sufficient. Nor will the construction of sea-walls, dykes or barriers of various kinds be effective by themselves. City administrations must begin to look at the full set of actions that would be required.

The actions undertaken by the cities in the table that I referred to can be classified into three categories:

- CONSTRUCTION
- PREVENTION
- ADAPTATION

5.1. Construction

Construction of course refers to the traditional dykes, seawalls, groynes or the new movable gates of Venice, London and others. They are by far the most visible, the most costly and, in a strange way, the most satisfying from a political viewpoint because a politician can point to them and even name them. However, I think in terms of their effects on the environment they tend to have very large effects, many of them unintended and unforeseeable.

They are also, in Professor Wiin-Nielsen’s terms, the least flexible.

5.2. Prevention

This is really in many ways the most important. It is the less costly from a total point of view. But it is also the most politically unpopular. It is clear that for City B, one of the most important things they had to do was to prohibit building and then to gradually remove existing uses from vulnerable areas.
I come from an area in which many buildings are built on barrier beaches in the southern part of our state. As the ocean in the natural course of events, even without sea level rise, has eroded these buildings and destroyed them, there has been tremendous political pressure to rebuild them in the same areas. After Hurricane Hugo in South Carolina, the homeowners whose houses were destroyed along the barrier beaches mounted a fierce political campaign to have the right to rebuild on those beaches.

It is easy to say that we should not build in vulnerable areas but it is very difficult to implement. Even more difficult is the gradual removal of uses from such vulnerable areas. The limitations on landfill is also very difficult. For airports and other economic uses, the filling-in of land is much easier to deal with than to facing the problems of building in already developed urban areas.

Another part of prevention is the promulgation of strict standards for buildings, roads, infrastructure, communications, etc. This requires the very difficult task of adding extra cost to buildings and projects already in progress. Since scientists are really not clear and can not predict absolutely whether sea level rise will happen or not, it is difficult to justify the additional small amounts for stricter standards. But a perfect example of where this makes sense is in the preparation for earthquakes.

The aftermath of the San Francisco earthquake clearly shows that the buildings built after the strict codes were put in, survived much better than those built before. For San Francisco and California which face a higher certainty, that kind of action seems clearer. For other areas in which the timetable is much further away it is much more difficult but necessary.

5.3. Adaptation

Adaptation is a much neglected area of planning. This is the really traditional way for cities on water to deal with the problems of tides and storms. The adaptations are both physical and behavioural. In Thailand, the central plain is only a few metres
above sea level. Flooding has always been a way of life. The houses are built in such a way to accommodate changes in water levels. They are either built on stilts or they float. (Fig. 3, 4). The other example of course, is Venice, where the whole way of life and the celebration of the sea has been a factor in the development of the Venetian economy and culture. Ground floors of palazzi that have never been used for habitation but for storage is an example of how to deal with extreme high tides. Cities and cultures that deal with water on a seasonal and daily basis have developed sets of behaviours and buildings that change accordingly to the season, time of month, or time of day. Traditional architectural forms in Venice, Thailand and many other parts of the world, both embrace and celebrate water, its power and its danger. Therefore cities have to learn new versions of traditional wisdom. We must develop designs of buildings that recognise the variability of water levels and preserve natural areas that absorb tides and storms. Very importantly new institutions and rituals need to be invented to prepare for periodic and unexpected changes and to provide for public safety.

6. DIMENSIONS OF PLANNING

Lastly, I am going to discuss the dimensions of planning that will be necessary to carry out actions required to cope with the new complexities of growth and survival. These are:
- UNDERSTAND AND FORECAST
- ASSESSMENT AND MANAGEMENT OF RISKS
- NEW INSTITUTIONS AND TIME HORIZONS

6.1. Understand and forecast

This conference is a very important step in that direction. The Centre will become an important part of how cities can learn about their own ecosystems, but it must also see itself as a part of global regional and local modelling and data gathering efforts. The data is scarce and imprecise. But it is crucial, as Venice has done with the lagoon, for cities to develop models of their own ecosystem so they can understand what would happen when global changes and regional changes take place. Equally importantly, the cities must understand their own built environments in relationship to their social, economic and political environments. They must then model and understand the changes in those environments, their population and their own political systems.
These dynamic and complex systems have to be understood. We are right at the beginning of this and the Centre again can play a very important part in defining and constructing prototype models.

6.2. Risk assessment and management

We will hear over and over again in these next few days that scientific certainty can not be achieved when such complex systems are studied. This is especially so when you have to make expensive political and sensitive decisions in such a short time. The science of risk assessment and risk management is something that city planners and city officials have not yet begun to grasp.

The need to understand when there is a probability of x happening (eg water rise) versus the necessity to invest y dollars to promulgate strict standards is something that we all have to learn how to do. Without that understanding, we are faced with either of two unhappy alternatives: one of which is to react in panic to build more expensive than necessary or to promulgate standards way out of proportion with the risk; or a throwing up of hands which says since we can’t deal with it anyway, let’s not do anything.

6.3. New Institutions and Time Horizons

The central factor in risk assessment is the time period and the probabilities of the event being studied. We think of cities and our political systems as having existed for a long time but they are actually very recent. Most city governments have only come into place in the last hundred years or so. In that time, the modern management of cities have either been elected or totalitarian systems of governance.

Totalitarian systems can last anywhere from hours or days to decades but in completely unpredictable ways. The changes in Eastern Europe and the changes elsewhere indicate that.

However, the facts of long term environmental changes and the measures needed to deal without them are on a completely different schedule. The measures take many decades and political stability and continuity to carry out. There is a real need again for research and invention. Each city is different in its own situation and its own political culture. Each city will have to develop according institutions, political, voluntary or others, which can begin to equal the time span of the problem and the implementation of the needed solutions.

These institutions will have to have a time horizon that stretches to match the problem. Environmental groups begin to do that.

But so far, they have been much too concerned with preservation and not enough with thinking of how to solve the conflict between preservation, or reduction in uses of energy and the resultant effects on people and economic development. The institutions must be flexible, because the changes are very great and uncertain. Finally, the development of democracy is very important.

We tend to think of being accountable to the public as being incompatible with the implementation of very drastic measures. But if we are not able to be accountable to the public and accommodate their needs in these solutions, we will not be very far in solving them.

7. SUMMARY

It is clear that the problems posed by the rise in sea level are not isolated from other problems caused by the neglect of the natural environment. However, the inexorable impacts are more palpable and vivid than pollution and holes in the ozone layer. That is, every hurricane and every flood are cataclysmic events that the public and the politicians can experience directly.

Therefore, rise in sea level as a topic, even though by itself may not be the most important factor, will contribute to the eventual solutions for our cities. The need to rethink and reinvent our cities management, governance and planning systems to deal with the very difficult urban problems everywhere, especially in the Third World, could be one of the outcomes of this conference.

Thank You.
INTRODUCTION

It is recognised worldwide that society must prepare itself to reduce, prevent or face the consequences of future population growth, demand for energy, economic development and of the related alterations to the natural environment. Awareness of these alterations and of the greenhouse effect has been created over the last decade by the media, speculating intentionally, at times, on the catastrophic extremes of the far-reaching scientific elaborations which begin with simplified and well defined hypotheses and models in order to obtain a wide range of predictions.

Prof. Wiin-Nielsen has clearly illustrated the problems involved in modelling the climatological and environmental processes and future tendencies and in interpreting the results.

The major difficulty in the elaboration of realistic models has been the lack of time series of appropriate measurements and the analysis of the full spectra of variability of the significant parameters; a deficiency that technology should be able to considerably reduce with long-term observations of the earth from new generation satellites, in the decades 1990 and 2000.

The development of clear national and international policy options to deal with energy and climate changes has become a general concern and the time is ripe to analyse the full range of possible socio-economic and political responses, to educate the international community on potential environmental and economic trade-offs and initiate an active dialogue between national environmental agencies and the industrial community on how to respond best to future climate change.

The issues of the global climate change can be divided into three categories of scientific and technical nature:
- The science of climate and environment changes,
- The policy of limitation of the causes,
- The policy of dealing with the effects.

1. THE SCIENCE OF CLIMATE AND ENVIRONMENT

Scientific research on the full range of variations in climate and environment and the interaction between the geophysical and biogeochemical spheres has rapidly developed over the last thirty years along with the advanced techniques of computation and earth observation from satellites.

An orderly international program of scientific assessment studies is underway, created and promoted by the various agencies of the United Nations and of national and international scientific unions.

It would take too long to describe the objectives and activities of even one single international program at this moment in time. A perspective of the interlaced activities of the principal agencies and international institutes per topic is given in Annex 1, prepared for the IGBP (International Geosphere Biosphere Program).

One can feel confident that with such efforts involving scientists from all over the world, progress will be fast and reliable and that the major United Nations organisations with the WMO programs, will produce accurate information on the trends of global changes needed for the analysis of regional and local future impacts, and for the preparation of a range of sound strategies of interventions.
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World Ocean Circulation Experiment (WOCE) | 1990-95          | Oceanography; Meteorology; Circulation; Air-Sea Interaction; Sea ice | WCRP; CCCO; IOC; SCOR |
| 4.  
International Hydrological Programme (IHP) | Ongoing 1975-    | Hydrology                                               | UNESCO; WMO; UNEP; IAHS; IUGG |
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| 6.  
Joint Global Ocean Flux Study (JGOFS) | Proposed         | Air-Sea Interaction                                    | SCOR                   |
| 7.  
International Satellite Cloud Climatology Project (ISCCP) | Ongoing 1983-    | Cloud Cover; Solar Radiation Fluxes                   | IAMAP; COSPAR; SCAR; JSC |
| 8.  
International Global Atmospheric Chemistry Programme (IGAC) | Proposed         | Atmospheric Trace Constituents; Atmospheric Photochemistry; Aerosols | IAMAP; IUGG |
| 9.  
Integrated Management of Coastal Systems (COMAR) | Ongoing          | Coastal/Marine Ecological Processes                    | Unesco; IABO; IUBS    |

**D. Solar-Terrestrial**

<table>
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<tr>
<th>Programme</th>
<th>Status</th>
<th>Subject</th>
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| 1.  
Middle Atmosphere Programme (MAP) | Ongoing (continuation proposed) | Solar-Terrestrial Physics  
Atmospheric Physics          | SCOSTEP                  |
| 2.  
Polar and Auroral Dynamics (PAD) | 1985-90          | Auroral Particles; Particle Physics; Physics of         | SCOSTEP; SCAR   |
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<tr>
<td>4. World Ionosphere-Thermosphere Study (WITS)</td>
<td>1987-89</td>
<td>Global Dynamics of Ionosphere-Thermosphere</td>
<td>SCOSTEP</td>
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<tr>
<td>5. Solar Interplanetary Variability (SIV)</td>
<td>1988-90</td>
<td>Transition of Sun and Interplanetary Medium</td>
<td>SCOSTEP</td>
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### E. Monitoring and Data

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<tr>
<td>2. World Digital Data-base for Environmental Science (WDDES)</td>
<td>Proposed</td>
<td>Hydrology, Bathymetry, Terrain, Coastline, etc.</td>
<td>ICA, IGU</td>
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<td>3. World Soils and Terrain Database (SOTER)</td>
<td>Proposed</td>
<td>Soils Terrain</td>
<td>ISSS, UNEP</td>
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<tr>
<td>5. World Data Centers (WDC)</td>
<td>Ongoing</td>
<td>Solar and Geophysical Information</td>
<td>ICSU</td>
</tr>
<tr>
<td>6. Federation of Astronomical and Geophysical Services</td>
<td>Ongoing</td>
<td>Astronomical and Geophysical Observations</td>
<td>ICSU</td>
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<tr>
<td>7. Monitoring of the Sun Earth Environment (MONSEE)</td>
<td>Ongoing</td>
<td>Solar-Terrestrial Interaction Data</td>
<td>SCOSTEP</td>
</tr>
<tr>
<td>8. World Climate Data Programme (WCDP)</td>
<td>Ongoing</td>
<td>Atmosphere - Ocean - Cryosphere Terrestrial Earth Science Climate Data</td>
<td>WMO, ICSU UNEP</td>
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Policy makers are generally reluctant to incorporate scientific matters in policies for possible medium and long-term future events, until the threats are clear and well-known, or are under way. It is in their interest to invest now on extended scientific activities to reach a sufficient level of knowledge and obtain the reliable evidence of facts needed for responsible planning.

2. THE POLICY OF LIMITATION OF THE CAUSES

This category regards the assessment of future global impacts and of strategies for curbing the anthropogenic causes of global climate and environment change. These include an increase of emission of heat-trapping gases such as CO₂, ozone, CFC, methane, etc.

It is a problem of a planetary scale, which involves intergovernmental, political, economical, juridical, long term actions, which may generate conflicts of interests and which will need wide educational activity in developed as well as in developing countries.

Perhaps the most promising initial strategy is the one leading to a rapid improvement of the efficiency of energy production and to a reduced trend of the present economy of waste initiated about 50 years ago with the onset of the industrial era.

Following recommendation of the Secretary General of the UN, the UNEP established a Task Force on Global Climate to operate on a continuing basis under the Advisory Councils made up of the heads of agencies including WMO, FAO, UN Development Program, International Bank of Reconstruction and Development (IBRD) and the United Nations Industrial Development (UNID).

The purpose is to develop initiatives contributing to the stabilisation of climate in a global sense, including multilateral negotiations as appropriate, and preparation of a series of protocols dealing with specific aspects of the issue.

A few weeks ago, seventy nations in Noordwijk agreed to reduce CO₂ emission, the timing and quantity of which is to be defined in November 1990 at the conclusion of the research requested by the UN to the IPCC (Intergovernmental Program of Climate Change) (Table 1). It is hoped that, in the year 2000 a stabilisation of the emission will be reached and thereafter a program of limitation or reduction can start without penalising economic and welfare growth in the developing countries. The US and Japan waived their consensus and methods for reduction, pending the adoption of new, safer sources of energy.

A battle for the reduction of CO₂ is estimated to cost one hundred times the battle against ozone depletion, which is about 400 billion dollars in 10 years.

This issue was the subject of a previous intergovernmental meeting in 1988.

New detailed analysis show however, that a limited reduction in CO₂ to the order of 20%, is feasible within a reasonable time limit (year 2005?) and with acceptable costs.

3. THE POLICY OF DEALING WITH THE EFFECTS

This category concerns the elaboration of strategies to deal with the effects of global issues in a specific area. Nature, in the battle for survival learned to adapt itself to changes in environment, climate and habitats that occurred naturally over the span of thousands and millions of years, but will find itself in a crisis when faced with significant short-term changes generated by man.

Time scales of natural adaptation cover a wide range: for agriculture it is about ten years, for green lands a few decades, for forests a few centuries; and for humans perhaps several generations.

Turnover times of marine phytoplankton is a few weeks, while the cycle of dissolved carbon lasts a few centuries to several millennia.

Highly populated ocean cities may be subject to significant changes over periods ranging from a few decades to half a century, as a hindcast analysis can demonstrate, but it is difficult to estimate the nature of future changes that depend on human factors.

The objectives of the Cities on Water Association fall into the category of adaptation or prevention.

In the process of population growth which involves increasing migration from developing to advanced countries in the search for better life styles, the largest human flux is towards the cities and especially towards ocean cities as easier landing grounds.

Regional and national strategies must be developed to face this human and socio-economic urbanistic problem, taking into account the other set of problems imposed by the local impacts of climate and environment changes.

The major cities of the world are overwhelmed with the complexity of these problems but marine cities with adjacent coastal areas have one more problem to face: their vulnerability to sea level rise and wave forcing due to the likely intensification and frequency of storms predicted in all climate change models.

The coasts will be increasingly menaced by erosion, floods and salt-water intrusion.

A detailed analysis of the possible increase of these events and of their socio-economic impacts is needed region by region, following the experience of the historically exposed coastal areas.

It is for this reason that the International Centre “Cities on Water” has organised this first meeting of scientists, engineers and policy makers to initiate an exchange of information on experiences, know-how, unsolved problems, propose a common program of research and education, and provide a forum for the discussion of ideas and plans.

The impact and the consequences of RSLR (Relative
Table 1. Adaptive options and policy implications of Sea Level Rise and other impacts of Global Climate Change. Interactions of IPCC subgroup.
Sea Level Rise) was selected as priority topic, to be followed by the problem of re-assessment of the quality and value of water, too often, over the last half century considered a vehicle for waste disposal instead of a precious landscaping element for aesthetics, health, recreation, communications, city traffic, marine and inland trade. The re-evaluation and proper use of the waterfront is the main scope of the Cities on Water Association.

4. THE RELATIVE SEA LEVEL RISE AND WAVE CLIMATE

According to P. Morel (WMO, 1988), the greenhouse forcing is paced by the dynamics and thermodynamics of the slow components of the climate system: the global ocean and land-ice. The problem is to understand how the two components of the climate system, fast and slow, work together, conditioned by a series of feedback mechanisms which require a great deal of research to be understood.

Present modelling of these processes will continue to have limitations until a large set of geophysical validated observations in time and space is available, and data assimilation in models is a well acquired technique.

The present models however constitute the only reasonable diagnostic tool for simulating atmosphere-ocean-land interactive processes and predicting future trends.

Sea level rise is the most evident and unavoidable effect of global warming. Fig. 1 and 2 from J. Titus of EPA (1989) give a general view of the nonlinear trends of sea level. The nonlinearity is due to the slow response of the ocean water masses to heating from the atmosphere. How the biogeochemical changes of the ocean occur under heating is only hypothesised, and their effects have not yet been properly introduced into modelling ocean warming and SLR.

A great deal of interdisciplinary research is needed to reproduce the significant interactive mechanisms. On the basis of common assumptions however, the trends of SLR have been calculated by several independent authors and associations.

The trends of SLR in Fig. 1 and 2 are based on a linear atmospheric warming of 3°C in the next 50 years, after which it is assumed that the temperature change will remain constant.

**Fig. 1.** Estimates of eustatic sea level rise during the next century. This fourpart figure depicts sea level rise due to: a) thermal expansion; b) melting of glaciers and small ice caps; c) melting from the Greenland ice sheet; and d) increased ice discharge from Antarctica.

**Fig. 2.** Total sea level rise during the next century. The dark shading indicates the most probable response to the climate scenario described in the caption to Figure 1. The broken line depicts the response to a warming trend delayed 100 years by thermal inertia of the ocean. A global warming of 6°C by 2100, which represents an extreme upper limit, would result in a sea level rise of about 3.3m, but errors in this estimate are very large.
Fig. 3. Simplified ISOS system diagram
will remain constant (hopefully an effect of
limitation!).

Following the alteration of the temperature gradients
from equatorial to polar regions, the atmospheric
and ocean dynamics in due time would change their
present climatic character.
Storms, wind, precipitation and currents should
increase in intensity and frequency and change latitudinal zones.
As an expected effect, storm surges and wind and
wave forcings would be exacerbated and must be
evaluated for defence planning. Several preliminary
analyses of these effects are available for further
analysis and regional verifications.
Numerous case studies on the Impacts of Sea Level
rise have been done around the world and this
meeting is presenting a few. They give a preliminary
set of information important for further
developments.
Among the most exhaustive studies published is
ISOS (the Impact of Sea Level Rise on Society) done
by a group of Netherland institutes sponsored by
UNEP. It presents a series of very valuable reports
with final recommendations and a framework of
methodologies to be followed in the analysis of case
areas, including static and dynamic coupled human-
environment models.
One of these models simulates a 100-year period of
impacts and socio-economic evolutions in short time
steps of five years.
Its components are shown in Fig. 3, and start with
four scenarios of Sea Level Rise: economic/capital
growth, population growths, and social discount rate,
ending through the measures and the impact areas,
with the effects, such as populations exposed to risk,
losses of land in area and capital, damage to water
resources, ports and shipping.
The preparation of this program involves the
development of a model and data collection.
Fig. 4 shows the steps in Carrying Out the Analysis
(COTA) after the completion of a preliminary phase
of Setting Up the Analysis (SUTA).
Several detailed models on regional impact processes
studied in the US are in an advanced stage of progress.
Of particular interest is the SLAMM (Sea Level
Affecting Marshes Model) which simulates the
long-term changes in coastal areas due to SLR
involving wetlands and barrier islands and the
processes of erosion (Park et al., 1986). The model
has been applied to the case of Charleston.

5. THE ROLE OF CITIES ON WATER

Analysis of future impacts and the consequences of
SLR given the uncertain nature of the trends, can be
made for the next 50 or 100 years, depending on
the choice of decision makers dealing with urbanistic
problems and city structures with lifetimes of 50 or
100 years. Obviously the many uncertainties of the

Fig. 4. Steps in carrying out the analysis (COTA)
factors increase with time as it is very difficult to predict them.
A pilot case study could start, for example, with an
hypothesis of a 30cm global SLR in the next 50 years.
Local subsidence/ uplift would have to be added.
On this basis one could estimate reasonable times for
the development of the various phases, to conclude
with the execution of the interventions.
1) A first phase could take 10 to 15 years for:
a) the development of flexible strategies with dynamic
models based on environment, engineering and
human factors;
b) local measurements to define the spectra of
variation and calculate the trends with the highest
possible accuracy;
c) contributing with regional data, to the Global
Change Research and setting up education courses
in local universities.
2) A second phase, probably 5 years, could be needed for:
   a) fine tuning of strategies on the basis of new evidence;
   b) investments in defence or resettlements;
   c) adoption of new trends of global SLR with reduced uncertainties.
3) The third phase, probably 20 years, would concern the execution of plans and projects.
The total time is about 40 years. By this time, the risks of SLR may turn out to have been under or overestimated. A risk that can only be prevented with a strategy in excess when economy is not a critical factor or a flexible strategy when possible. Another possible scenario is the passive attitude of “wait and see” which may be forced by economic impotence or by decisions to see the results of the more accurate scientific information of the next decades.
With this scenario the century scale is the most appropriate.
The first unprepared-for catastrophic storm surge may generate disorderly evacuations from flooded areas with loss of lives as in the case of Bangladesh in 1970.
The role of the “Cities on Water” Association is to join efforts, to analyse problems and solutions to help decision makers to act to the best of their ability.
A core group of experienced cities could lead the activity of the Association, create a reference information service on technical and scientific urbanistic issues, create educational university programs for visitors particularly from developing countries and convene workshops of experts to discuss on specific topics. Furthermore it could define, promote and realise networks of regional measurements and verifications such as soil and water level variations and air-water climatic temperature variations, contributing with local and regional data to the global climate and environment research. It could improve specific measures for coastal disaster prevention, follow up actions, and assist engineers and managers.
This activity is possible making practical use of the recommendations and guidance of the large UN organizations following up the IPCC.
CASE STUDIES
1. INTRODUCTION

The history of Venice has been characterised by a successful alliance between land and water. Man has always attempted to alter the natural processes of environmental transformation by modifying and adapting them as the case required. In some cases his actions were effective, in others they proved to be counterproductive. But only through this continual trial and error has it been possible in the past, to maintain an environmental equilibrium that has enabled this historic city to exist. Today that very equilibrium is at risk. The action of auto-regulating processes in the ecosystem seems to be insufficient for checking the consequences of the socio-economic activity of the growing population around the Venetian lagoon. The city's environmental equilibrium is threatened by a series of risk factors such as industrialisation, urbanisation and in agriculture in the territory surrounding Venice. One can see the gradual decline of what used to be one of the commercial capitals in the West, now in the condition of having to rely on a nearby chemical industry, itself in crisis for its future, and on a culture of mono-tourism. Furthermore, along with the other coastal cities in the world, Venice is exposed to the impacts of a possible global climate change. An increase in mean sea level, the intensification of atmospheric disturbances, and all the phenomena connected with the greenhouse effect constitute a problem that needs to be dealt with seriously and well in advance for safeguarding the delicate structure of this city. Venice can then be taken as a test area for the cities that live on water, and become a useful experimental model for other cities and regions of the world in need of interventions that may alter the city/environment relationship.

2. SUBSIDENCE, EUSTACY AND STORM FLOODS

From the beginning of the century the difference in level between land and water in Venice has changed for the worse by about 23cm. The level of the sea has risen by approximately 11cm while that of the land has sunk by 12cm because of a process of subsidence accelerated by the extraction of water from underground water tables. In the very first decades of this century, St. Mark's Square was invaded by water 7 times per year. Today flooding occurs on average more than 40 times (with even higher peaks: in 1967 there were 67 floodings). At the beginning of the century very high tides (such as the one that occurred in 1966) had a repetition period of about 800 years. Now, only a few decades later, that same repetition period would be about 200 years.
The processes of subsidence due to draining of water beds for industrial and urban use, is now under control, but the new risk of a climatological rise in sea level is very serious. Eustacy is the most threatening impact of the global greenhouse warming. The international scientific community is now in almost unanimous agreement about the development of this phenomenon, whilst opinions concerning timing and extent of sea level rise need to be verified accurately on both local and global levels.

In fact, the process of greenhouse atmospheric warming that causes the sea level to rise has still not been simulated with sufficient precision, as Prof. Wiin Nielsen showed. Planning defences to possible scenarios of sea level rise can however make use of the available information; this allows for a range of effective solutions to be studied suitably in advance.

One certain fact that must be taken into account, is that even if the emission of greenhouse gases were to stop today, the effects of the present concentrations would continue to be felt long after the end of the operational life of a defence structure. It is for this reason that several coastal defence works that are being finalised in various parts of the world, take into account both a mean sea level rise between 30cm and 50cm for the coming century as a safety factor.

In Venice, without defence, a 30cm change in sea level would flood St. Mark's Square 360 times a year, and the 1966 storm flood would be repeated every 30 years, a period which would be reduced to 5 years with a 60cm S.I.R.

3. HIGH TIDES AND THE DEGRADATION OF URBAN STRUCTURE

The normal tidal range nowadays goes from 50 to 80cm. Storm surges, and most certainly the exceptional ones, strongly accelerate the general process of degradation of Venice's structures that is already very advanced. The present dangerous situation is due to worsen unless urgent action is taken. The stability of the buildings in Venice is threatened by problems which can be attributed in varying degrees to the nature of the terrain, to the character of the old structures, to the hostile environment and to wave action.

The palaces have numerous cracks and remain standing thanks to successive emergency repairs. But their state is ever more precarious.

Subsidence and eustacy have brought the water into close contact with the brick and masonry with increasing frequency, wetting the brick walls over the strip of semi-impermeable Istrian stone base which has protected the palaces of Venice for many centuries. Unlike the stone, bricks are very porous and permit the capillary rise of salts and acids, which trigger off the decay of the mortar and the scaling-off of the masonry.

All this has led, and continues to lead today, to a slow but continual deterioration of the buildings' general resistance, aggravated by the fact that the load-bearing cross sections tend to become progressively weaker for age and environment aggression.

The deterioration of the historic centre of Venice is however not due to physical factors and processes alone. Some socio-economic causes are equally important. In 1989 the population of Venice dropped to under the 80,000 mark, the lowest point ever on a depopulation trend which saw the city go from 175,000 inhabitants in 1951 to 137,000 in 1961, then 108,000 inhabitants in 1971 to 92,000 in 1981.

From the point of view of urban decline, such a massive exodus means a radical transformation in the use of the city. It furthermore signifies that the upkeep of buildings and houses is virtually at a standstill. There is thus an acceleration in chemical-physical deterioration and an increase in risk factors.

4. EFFECTS AND RISKS OF THE TRANSFORMATION OF LAGOON MORPHOLOGY

The Venetian lagoon has a surface area of 550 sq.kms, 60 of which is wetland. As a result of natural and anthropogenic adaptations over time, the many streams that run into the lagoon connected to the regional drainage basin create a complicated hydrological system. The lagoon itself is run through by a dense network of canals and beds of ancient watercourses that branch out from the port mouths on the sea side through the lagoon to the mainland.

The canals constitute the main route of tidal currents; as a result, the tide wave takes on markedly unidimensional characteristics.

Over the centuries the dimensions, forms and character of the lagoon's natural morphology have been altered by the intervention of man. Three periods of important interventions can be distinguished in the recent historic period: 1) 1300-1800. During this period work was carried out on the diversion of the main watercourses (Brenta, Bacchiglione, Piave, Sile) that once flowed into the lagoon. The results of these engineering feats is still visible today: they were successful in putting a stop to the tendency of silting due to sediment transport by rivers. As well as providing the basis of the naval, commercial and military power, water was the city's necessary natural defence against enemy attack. The Venetians kept regular checks on the depth and on the dynamics of the water, changing the lagoon's configuration and morphology for the needs of the city. A regular and thorough flushing of the lagoon with the tides was also the means for preventing illnesses and infections, malaria above all.

The projects to divert the rivers turned out to be indispensable for the city’s survival. They were successfully completed over the centuries with the only possible method of trial and error.
2) 1880 to 1920 saw the construction of the protective dykes at the three mouths of the lagoon, first at Malamocco (1839-1872) then at the Lido (1882-1925) and lastly at Chioggia (1911-1934). The construction of the dykes was intended as the solution to one of Venice's oldest and most important problems, access to the port. The ships last century were already much larger than those of the past and necessitated much deeper channels and easier access to the lagoon. The protective dykes ensured perfect conditions for navigation, but altered the process of sand transport along the coast and in the lagoon, creating new erosion and accretion effects.

3) From 1920 to the present day, other significant works have been carried out: dredging of the Lido-Marghera canals (1919-1930) and of the Malamocco-Marghera ones (1960-1969). Three areas of the lagoon were to be reclaimed for industrial use but only two were actually allowed to be filled.

There has also been an increase in the surface areas used for fish farming along the mainland edge of the lagoon reducing the area of tidal expansion. The interaction between these interventions and the natural responses have transformed the lagoon and the movement of its waters which in some areas have assumed a bi-dimensional character.

While the tendency to silting was checked last century, the recent dynamic processes of erosion tend to deepen and flatten the lagoon bed. According to recent estimates, the depth of the water in the lagoon this century has increased by an average of 30-40cm, and about 50% of the "barene", which still existed at the start of the 20th century, have been lost. If action is not taken to stop and reverse the deterioration, the lagoon will continue to lose about one million cubic metres of sediment per year, resulting in an average increase in depth of 10cm in 50 years and a further decrease in "barene".

The lagoon could, in the future, gradually become a branch of the sea, unprotected from marine movements. This would also be helped by a rise in mean sea level due to the greenhouse effect that would accelerate erosion of sandy barriers such as the Lido barrier.

5. DEGRADATION OF THE QUALITY OF THE LAGOON WATER AND THE BIOTIC SYSTEM

Pollution of the water and sediments in the lagoon has exceeded the accepted level over the last decades. Striking phenomena such as the intense algae growth that explodes every summer, and less obvious processes such as the decreasing variety of biospecies are all symptoms of ecological transformations and are due, for the most part, to the enormous quantities of nutrients that are poured into the lagoon daily from a variety of sources.

Many studies have been done on the pollution, but none have provided decisive figures as yet, though the available data speak clearly.

Since the beginning of the century pollution of an organic nature has tripled, and the nutrient load is five times higher. Each year between 10,000 and 12,000 tons of phosphorus and nitrogen are poured into the lagoon. The overall figures are however less meaningful than the different spatial concentration.

Urban pollution accounts for 15-20% of the total. The percentage of nutrients has been reduced over recent years, thanks to numerous new water treatment plants along the mainland edge of the lagoon.

However the situation in the old centre of Venice itself is very serious - there is no sewage system, and it would be extremely expensive and difficult to plan one. Most industrial plants of Marghera have not been discharging their waste water into the lagoon for several years now; despite this fact the discharges from small industries along the lagoon's edge and, to a lesser degree, those of the various port activities, represent a more important part (20-25% of the total).

The lagoon also receives waste from agricultural and livestock activities from the vast (184,000 hectares) and densely populated (approx. 1,000,000 inhabitants) drainage basin surrounding Venice (Fig. 1). Over the last two decades the nutrients conveyed by the waterways from the basin into the lagoon have become the most important source of pollution (40-60%) of the lagoon's waters.

Fig. 1. The water drainage basin.
The complex drainage system of rivers and artificial canals leading into and around the lagoon has been modified over the last decades to prevent silting of the lagoon and to allow for efficient navigation waterways.

Two main rivers were diverted around the lagoon before 1900 and dykes were made at three entrances to the lagoon at the beginning of this century. The present tendency of the lagoon is to erode and become deeper and flatter. Plans are being made to contain this undesirable process within appropriate limits.

The drainage system is the key for the water pollution to flow into the lagoon from agricultural, industrial and urban areas. A sea level rise may create more problems to be dealt with in time.
Some 10% of the water pollution can be attributed to the sinking of particles and gases emitted by industries into the local atmosphere. More difficult is the estimate of the organic and chemical substances that the sediments assimilate and emit, and of the effect of sea and lagoon water mixing. The presence of nutrients in the water and sediments in high concentrations (above the level of tolerance) has many damaging effects. To give one example, the introduction of 1 kg of nitrogen into the lagoon can lead to the growth about 250 kg of algae; extrapolating, we would have an overall annual production of about 1 million tons of macroalgae. The damage to the biotic system is a direct consequence of the pollution concentration in the lagoon, and it particularly affects the resident species that become extinct or drastically reduced. The lagoon's biotic system is also damaged by the natural reduction of the "bare" surface areas and by land reclamation such as that of the airport, which contributes to the alteration of habitats. A rise in sea level due to the greenhouse effect with the lagoon being closed more often, would mean a reduction in water exchange. Immediate decisions and interventions are therefore necessary to regulate input of pollution into the lagoon and improve the quality of the water and of the sediments regaining the condition of half a century ago.

6. PROBLEMS OF THE PORT AND OF SHIP TRAFFIC THROUGH THE LAGOON

Navigation, shipyard operations and in general all activities linked to the lagoon and to port traffic have always been at the heart of the Venetian economy. The first human interventions in the lagoon were connected with the port, including quay construction and canal dredging. At the beginning of this century the shipyard at the Venice's Arsenale was still operating but came to a standstill with the war in 1916. The Port of Venice instead is still very important today: it serves the city and its industrial and commercial hinterland. Its usefulness however ranges far beyond regional borders. During the last 20 years the port activity followed the decline of commercial activity and industrial restructuring (employment has lowered, 50% in commerce and 20% in industry). The future of the industrial port is uncertain at present. For some time there has been talk of relocating refineries and chemical industries and constructing a large container port in the southern part of the industrial zone. None of these projects would seem to alter the present conditions of navigation in a short or medium term. Today the Port of Venice, the fifth in national importance, handles just under 5,000 ships per year, a figure which corresponds to a volume of traffic of 25 million tons. The port of Chioggia on the other hand, is equipped for small commercial activities and fishing, and handles a volume of traffic equivalent to about 1 million tons per year. 40% of the ships enter and leave the lagoon through the Malamocco port mouth; 60% use the Lido mouth. This means that no less than 3,000 ships each year enter and leave through the Giudecca canal, passing just a few hundred metres from St. Mark's Square. A little more than 20% of the ships arriving in Venice (about 1,100 ships per year) transport oil products and about 200 of these vessels are large (that is, over 40,000 tons). If we add to these the 1,000 lighters which transport oil products from Marghera to the waterways, and calculate in and out-going journeys, we find that each year the Venice lagoon is crossed more than four times by ships carrying cargoes of oil or its by-products. The level of risk to which the lagoon is exposed with this traffic is the subject of great concern and discussion that aims to find a solution. A possible rise in sea level would worsen the situation in that the gates at the mouths would have to be closed, thus reducing the in- and out-flow of lagoon water the ship traffic would be maintained by way of locks foreseen as an element of the gates system.

7. SAFEGUARDING THE HISTORIC CENTRE OF VENICE

On November 4th, 1966 there was an exceptional storm tide which rose to 1m 94cm a.s.l. submerging Venice. Both the historic centre and the inhabited islands in the lagoon were seriously damaged. The storm surge had invaded Venice at 10pm on November 3rd. After 6 hours the level had not gone down, and at 5 o'clock in the morning on November 4th the height was 1m 16cm. A further tidal influx at 12 o'clock on November 4th raised the level to 1m 76cm in just two hours. At 6pm the water level reached 1m 94 cm (Fig. 2). It was only at 9pm that it suddenly started to go down. The flood laid bare the fragility of the urban structures and the sea defences which had been constructed over the centuries and brought the problem of how to protect Venice and its lagoon to the attention of international public opinion. The events of those three days, twenty-three years ago gave a new impetus to research that was already planned since the high and medium-high tides had occurred more frequently from the beginning of the century, following the R.S.I.R. trends (Fig. 3). The analyses that had been carried out until then were reassessed in contents, method and depth. Two main objectives of research were selected: a) the physical defence of Venice and its lagoon which contemplates a system of flood control, b) the re-establishment of the environmental equilibrium of the lagoon. It was in the '60s that the importance of
this objective began to be realised, even though little was really known about the lagoon ecosystem. In view of the heterogeneous nature of the objectives, there were great differences between the solutions. They ranged from narrowing the lagoon entrances to closing them off completely, from reopening the fish farm zones to artificially raising the level of the land, from making a "cut" in the reclaimed land, to reducing the depth of the mouths of the lagoon. Leaving aside the value of each individual idea the apparent incompatibility between the two objectives: physical defence and renewed environmental equilibrium, remained. Many people felt that through the study of flood protections it would be possible to slow down, or stop the overall environmental deterioration, or, vice versa, that some plans for environmental protection could be effective to defend the area from the floods. From 1966 on, in any case, on the wave of emotion caused by the threats to the safety of Venice, it was the city's physical defence that received most of the attention of the population and of the politicians. In 1973 the Italian government proclaimed a law that clearly set out the range of problems to be dealt with, leaving to later considerations some aspects which today are considered crucial, such as the harbour's activity and environmental protection. In 1981 a group of experts appointed by the Ministry for Public Works drew up a project (the so-called "Feasibility Study" or "Progettino") which included the installation of mobile structures to regulate tidal flow at the three mouths of the Venetian lagoon. The project as a whole was approved by the governmental technical control bodies who requested further studies on the impact of the project on the ecosystem and on the ratio of the fixed structures to the mobile ones. On November 29th 1984, a second and more complete law for Venice saw the light, and a Consortium of firms was put together: the Consorzio Venezia Nuova. On the basis of a series of complex guidelines, it was entrusted by the State with designing a preliminary project for the flood defence structures. Project REA (Riequilibrio e Ambiente) was completed by the Consorzio in October 1989. It is the result of multifaceted studies to reach a system meeting all requirements concerning defence, activity, environment.

6. PROJECT REA: OBJECTIVES, FORMAL CRITERIA, PROJECT DIRECTIONS

The law required the adoption of four basic criteria: the project was to be experiment, development in
phases and be reversible and flexible. The studies and structures in Project REA are therefore experimental.

The study is preceded by theoretical analyses, the outcomes of which are then verified using mathematical and physical models capable of simulating the behaviour and responses of the ecosystem. When a solution was considered sufficiently refined, the project design and the successive construction plans were carried out. The project however proceeds with successive tests and corrections; solutions which did not prove their effectiveness were removed.

Flexibility of the system was assured by the realisation of structures which could operate in a variety of different scenarios: of harbour activity, evolving ecosystem, sea level rise, urban development. This led to the adoption of a special type of gate which respected the imposed conditions, to:
1) safeguard the inhabited areas and the monuments;
2) control variations in sea level;
3) improve the quality of the lagoon ecosystem.

Furthermore, the mobile structures should not alter the following:
a) the volume of water exchanged between the sea and the lagoon;
b) the flow pattern between the mouths and the lagoon's canals;
c) the landscaping by means of structures above water.

As far as the morphology of the lagoon was concerned, the following were to remain unchanged:
a) the cross-sections of the mouths of the lagoon;
b) the transport of sediments along the littorals.

As far as the ship traffic was concerned, it was essential that access to the industrial, commercial, fishing harbours and marines be guaranteed.

9. PROJECT VARIABLES: FREQUENCY OF CLOSURES, SEA LEVEL RISE, USE OF LOCKS FOR SHIP TRAFFIC

As Project REA progressed, three interconnected factors proved to play an important role:
1) the frequency of the gates closure;
2) the increase in sea level;
3) the use of locks.

Because of subsidence the threshold of the lagoon water level could vary over time. This has prompted the design of structures effective over a very wide range of water levels from +80cm to +140cm above the level of reference. These are today the two extreme levels: in fact all the inhabited areas lie above +80cm but are entirely flooded with a water level of +140cm.

These two extremes coincide with two opposing 'political' debates:
- very frequent closures, which would ensure virtual total protection for the inhabitants, but would partly compromise the environmental equilibrium reducing sea-lagoon exchange and limiting port traffic;
- less frequent closures which would ensure better conditions for the ecosystem and the port, but would flood more frequently the residential and monumental zones.

A possible future rise in sea level has been evaluated with three different scenarios:
a) eustacy of 0cm;
b) eustacy of 30cm;
c) eustacy of 60cm.

These figures are similar to those adopted in other parts of the world for projects of similar social and economic importance. The new project for the port of Rotterdam, for instance, assumes a 50cm rise in sea level. The effects of S.L.R. on the frequency of gate closures has been carefully analysed to foresee their impacts on shipping.

Since the preliminary stages of the work it appeared necessary that both projects of the gates and of the environmental protection were to be conducted in parallel. The closure level was selected between +95cm and +110cm a.s.l.

Within this range the equilibrium of the ecosystem will suffer no significant consequences, even if some zones of the city will partly be invaded by water (with +110cm, about 10% of Venice is flooded today).

The adoption of locks to grant ship traffic during total closures is linked to developments in world shipping trends, as well as to the rise in sea level and the management of the gates system.

These locks, which allow naval traffic to pass when the gates are closed, today are not essential. Restricted traffic imposed by closures at +95cm W.L. for example, could be avoided by providing means to keep the traffic going at night or in fog conditions. Project REA therefore provides for the projects of locks, following the same criteria as far the other works, but for realisation when needed, at a later stage.

10. SOME ALTERNATIVES TO THE GATES SYSTEM

The first step the project designers took was an evaluation of possible alternatives to the selected gates system. One of these was a return to the past to recover several of the original characteristics of the lagoon opening the fish farm areas, opening the reclaimed areas, reducing the depth of the mouths and of the "canale dei Petrilli". Measurements and mathematical models have shown that the effect of such actions would bring variations of no more than 2cm in water levels in the centre of Venice during high tides, an insignificant and useless value, in terms of cost and benefit.

Another alternative, the reduction of the cross sections of the lagoon's mouths could have more significant results. In order to obtain a useful S.L. reduction, (some 10cm), it would be necessary to reduce the cross sections by 60-70%.

This would only be effective for tides of a large range but short duration, which is unrealistic. Such substantial reductions in the cross sections of the mouths would,
instead, penalise the flushing of the lagoon permanently, with negative effects on the ecosystem.
Another idea reduces the gate closure frequency by creating defences around the low parts of the city, granting a protection from the minor and most common tides (up to 100 or 110cm).
There are many problems for this option which is called the "insulae" option. In a historic centre the sewerage and waste water network directly connected to the lagoon is ancient and eroded and would cause flooding through its channels.
All of these alternatives create new problems with a rise in sea level due to climatic factors; they have therefore been discarded with the exception of the "insulae" which deserve further analysis.

11. A SERIES OF FEASIBLE INTERVENTIONS

While the gates system project was progressing along with the simulation of the dynamics of the lagoon's waters, the solutions of other problems were studied such as:
1) the re-establishment of the lagoon's morphology: the interventions consist in the experimental reconstruction of the semi-submerged areas (Fig. 4), the "velme" and "barene". These are typical elements of the lagoon's ecosystem and play a determining role in maintaining its equilibrium. Seconding nature, four "velme", a total of 20 hectares and six "barene", 62 hectares were reconstructed.
b) the interruption and reversal of environmental degradation: the study carried out shows that pollution in the lagoon can be reversed over a 10-12 year time period, enabling the lagoon to re-acquire its own auto-purifying capacities within 6-7 years.
c) the restoration of the littorals and defence from erosion: studies are under way for possible intervention before the end of 1990. The narrow land barrier that separates the lagoon from the sea is in a critical state, and already today in certain points no longer provides adequate protection. The defence works constructed by the "Repubblica" 200 years ago are likewise inadequate.
d) the "insulae" alternative: the feasibility study is under way. It is already obvious that there are inherent construction difficulties, very high costs and a negative impact on aesthetics: furthermore, it would be necessary to reconstruct techniques for a sewerage and rain water drainage system.
e) the exclusion of oil tankers from the lagoon: there are difficulties posed by this problem, such as the effects it would have on employment, and the cost of constructing a network of pipelines. Time may show this solution worthwhile.
f) re-opening the fish farm and reclaimed areas to tidal expansion: the advantages and difficulties balance of this intervention is not favourable. A study is under

Fig. 4. Morphology of the lagoon.
An effort is being made to re-establish a morphological equilibrium of the lagoon. One of the actions under way is the restoration of submerged "velme", once above water, to re-establish their function in the dynamics and ecology of the lagoon. These areas are filled in with material also using natural water dynamic processes, protected by nets and will be repopulated with the original flora.
way for the creation of a nature park for local bird and animal life.
g) the management of the ecosystem: a study will begin after the completion of the interventions. The conditions and constraints that govern the project emerge from the data collected on the behaviour of the lagoon ecosystem, and on the experience acquired through past actions. The Consorzio Venezia Nuova meanwhile is developing an Information Office with a computerised archive.

12. THE FINAL GATE SYSTEM

The lagoon closure system adopted by the Feasibility Project in 1981 is, in essence, the one that has been taken on today. It envisaged tide control by means of a modular series of independent floating flap gates hinged to a bottom base (Fig. 5). The solution is radically innovatory and has never before been used for works of this importance.

Compared to more traditional systems, the floating flap gates offer considerable advantages. First of all they do not need intermediate piers or overhead structures. Furthermore, they oscillate freely under the action of the waves and this entails far less stress and less complicated support structures.

A life-size gate module was built (MOSE) (Fig. 6) and tested in real conditions near the Lido mouth for more than one year. It was shown that the system satisfies the requirements. Three different positions were studied for each canal entrance of the lagoon; on the lagoon side, on the sea side and in the middle of the channels.

Each position shows a different impact on the environment.

Fig. 6. The caisson module
The prototype of the caisson, a module of the gate system for the closure of the three mouths of the lagoon when storm surges occur, is shown in its support structure made to test it at the Lido channel over several months. Results were successful.
The first interacts with the physical character of the lagoon, the second with the littoral system. The middle one represents a compromise and has been devised to reduce the overall effects on the environment to a minimum.

Each scheme has variations, so as to meet the needs of the particular area involved and the solutions with locks. This explains the number of designs made (16 for Malamocco, 8 for Lido, 7 for Chioggia).

13. THE GATES AT THE MALAMOCCHI MOUTH

Malamocco is taken as example because it is considered as the main future entrance to the lagoon harbours. Tests, mathematical elaborations and physical models have been used to evaluate the variations in the water heads and flow distribution, in the height and motion of the waves in the areas of access, in the lock operation and navigation through the openings. The impact the new works would have on the coastal and lagoon morphology were evaluated. As the width of the opening of Malamocco varies between 300m and 420m, the position of the barrier was optimised.

Two other aspects must be mentioned: the depth of the canal and the locks.

To respect the water exchange between the sea and the lagoon and the morphological equilibrium as far as possible, the depth of the canal was fixed at 14m in the area of the berm of the mobile structures, and at 15m at the gates base structure.

The lock is 400m long and 50m wide and permits the transit of ships of present-day size and draught entering the port of Venice today.

If oil tanker traffic were to be eliminated from the lagoon, the lock could be smaller (330m by 40m), allowing the passage of container ships.

Similar problems have been faced in the study of the flap gates for the two mouths of Lido and Chioggia. The solutions are sufficiently flexible so as to allow for adaptation or developments that could become necessary in a near future.

14. CONCLUSIONS

The impact of a possible rise in sea level due to the greenhouse effect is not an unsurmountable problem for Venice. It can be taken into account in the present project design for the defence and environmental recovery of Venice, its littoral strip and mainland. The most difficult problem is most probably the human element, that is concerning the behaviour and evolution of the population in the historic centre of Venice and in that part of the city that lies on the hinterland (Mestre-Marghera). Solutions do exist, but political will is slow-moving and safeguarding delayed.
1. INTRODUCTION

In October 1987 the European Workshop on interrelated bioclimatic and land use changes took place in the Netherlands.

During one of the parallel sessions: "Impact of a future rise in sea level on the European coastal lowlands", 12 papers were presented and discussed.

The conclusions and recommendations of this session and the various articles presented will be published by Blackwell in 1990; the book is edited by Saskia Jelgersma and Michael J. Tooley.

This paper presented in the proceedings of the First International Meeting on Impact of Sea Level Rise on Cities and Regions is an abstract of the article about the Netherlands that will be published in the Blackwell book.

For this reason the text figures given in this abstract cannot be used without consulting the author.

2. GEOLOGICAL SETTING

More than half of the Netherlands consist of the deltaic and the tidal plain of the rivers Rhine, Meuse and Scheldt.

In geological terms the delta and coastal plains are very young; they were formed by post glacial sea level rise. In response to this sea level rise, a wedge of recent water-saturated sediments could have been formed on top of the seawards sloping Pleistocene surface.

These deposits consist of alternating peat, clay silts and fine grained sands; their maximum thickness (25 m) can be found in the present shoreline area.

It must be mentioned that the observed sea level rise and the related sedimentation are the combined effect of eustatic sea level changes, controlled by changes in the ice volume on earth; and tectonic movements.

In the Netherlands slow tectonic downwarping must be present due to its position on the edge of the subsiding North Sea basin. Subsidence is thought to be a few cm/century. A simplified geological map is given in Fig. 1.

3. LAND RECLAMATION AND COMPACTION

From the twelfth century onwards land was reclaimed from the sea by making dykes and embankments. Land drainage took place during low tide by opening the gates. Due to compaction of the soft clay soils this natural drainage system had to be replaced by pump lift enforced by windmills.

Many times during storm surges the sea flooded the reclaimed land but soon after that reclamation started again. The invention of the use of windmills as pump lift made it possible to reclaim lakes in the 17th century. The bottom of these lakes was between 2 and 5 metres below sea level. In the 19th and 20th centuries steam and electrical energy made it possible to reclaim bigger lakes.
Fig. 1. Generalised geological map of the Netherlands
An important side effect of reclamation is compaction causing important surface lowering. When water-saturated fine grained sediments happen to be irrigated and/or reclaimed, the lowering of the water table stimulates compaction of the sediments with accompanying subsidence of the surface. In the Netherlands, Bennema et al. (1954) have done extensive research on compaction of reclaimed land. Clays with 35% finer than 2 have porosity of more than 80% and they will be compressed to about half of their original thickness after reclamation over a 100-year period. Peats will be compressed much more: to about one-ninth of their original thickness.

Holocene sands are not subject to much compaction because of their lower porosity. Striking compaction differences can be found in land that was reclaimed centuries ago where peat layers have been eroded by creeks. The latter have been filled up by sand and silt and now emerge up to 2 metres above the adjacent part of the landscape due to compaction of the adjacent peat and clay. Important compaction was found in some land reclaimed at the end of the nineteenth century. In an old creek filled up with peat-mud a compaction of 2.5m was measured over 75 years.

Outside this creek the surface lowering in these polders amounts to 1.5m over the same time period. After World War II new polders were reclaimed in the Netherlands in the former Zuidzee area. To predict subsidence of the surface after reclamation consolidation, constants were derived from the pore space and the thickness of the sediment (de Groot, 1959, 1973, and 1986) before reclamation.

Before the polder was pumped dry, permanent measure sites were installed to observe the regional pattern of subsidence after reclamation. In 25 years the observed subsidence varied between 10 and 100cm; it is related to the thickness of the Holocene layer and its composition. Due to poor drainage conditions compaction during the first 10 years is much lower than in the following 15 years.

Another problem related to human activities is saltwater intrusion. Saltwater intrusion in the river occurs during high tide. This process can be stimulated by human activity. An example is the salt-water intrusion through the waterway giving access to the harbour of Rotterdam which moved landwards over 35km in a period of 60 years due to dredging in connection with port development.

A future sea level rise will cause the salt-water intrusion to move further inwards. Saltwater intrusion also takes place in the subsurface layers. The reclaiming of former lakes has caused horizontal and vertical saltwater intrusion. The latter is the result from rising of fossil saltwater due to pumplift in order to keep the water table in place. A rise in sea level will result in more pumping and accordingly, the salt-water intrusion will increase.

4. EFFECTS OF A FUTURE SEA LEVEL RISE ON THE COASTAL LOWLANDS

More than half of the Netherlands consists of "coastal lowlands" mainly situated below mean sea level and protected by dykes and coastal dune against the sea. This part of the country is densely populated, and 8 of the 14 million people living there are housed in big city agglomerates like Rotterdam, The Hague and Amsterdam.

It is also of high economic value as the most important industries, the harbour of Rotterdam, the Schiphol Airport and the most important agricultural land are found in this area.

A future rise in sea level will strongly influence the defence system against the sea (dunes and dykes), the drainage system, the rivers and lake dyke system and salt-water intrusion into the rivers and by seepage into the polders.

It is calculated that this new situation can be technically and financially dealt with.

In Fig. 2, the defence system against flooding is represented. The dunes are the natural defence against the sea, and in addition the sea dykes are indicated, a total of about 400km.

The river dykes protect the land from flooding during high river discharge.

It must be mentioned that the entrance channels to the harbours of Rotterdam and Amsterdam are also protected by dykes.

Fig. 2. Defence system against flooding
In the lowland itself, there are thousands of kilometres of inland and polders dykes which are not indicated in Figure 2.
The infrastructure of the Dutch water management system is found in Fig. 3.

It is clear that a future sea level rise will upset this whole water management system.

Some cost calculations, in relation to coastal defence, are included in reports prepared by the Ministry of Transport and Public Works (1989) for the Government of The Netherlands.

Several scenarios, different in time and sea level rise are calculated and translated into costs.

These are restricted to sea dyke reconstruction and sandy shoreline erosion protection. For the dune coast and sandy shoreline there are 4 possibilities:
1) retreat
2) selectively maintain,
3) maintain and
4) build seawards.

One of the sea level rise scenarios is 85 cm in the coming 100 years. It is calculated that the total costs of coastal defences: raising of dykes and maintaining the position of the sandy shoreline by means of supplementary sand, will be about 90 million florins a year for the coming 100 years with a sea level rise of 85 cm.

The building costs of a storm surge barrier in the entrance channel to the harbour of Rotterdam, to protect against high water and to slow down salt-water intrusion, is calculated at 1 billion florins.

5. CONCLUSION

In the last decades all over the world the increasing population has been responsible for extensive urban, agricultural and industrial development in the coastal lowlands.

Strong interference in the natural environment is one of the negative side effects of these activities. These include interference in the hydrodynamic systems of shorelines and river valleys and in the geological process of land subsidence.
The latter in particular has been triggered and enlarged by these human activities: withdrawal of oil, gas and groundwater and reclamation of land.

Natural subsidence in sedimentary basins amounts to a few centimetres a century, whereas man-induced subsidence can reach metres in a few decades.

Most times the negative effects become noticeable when the process is already in progress and there are no countermeasures available due to a lack of knowledge of the geological and hydrological processes involved.

A serious problem is that most of the man-induced processes are irreversible. In the coming decades human activities in the coastal lowlands will continue to increase.

If a future sea level rise does occur, more lowlying land has to be protected by dykes and their groundwater level controlled by pumping.

This process will cause land subsidence and salt-water intrusion. At the present time much more knowledge is available about the man-induced process of land subsidence, and it is possible to predict and control the process.

It is advisable that the known methods for controlling or arresting subsidence become part of integrated coastal lowland management.
1. INTRODUCTION

Many civilisations had their origins in deltas and coastal regions. In the year 2000 approximately eighty percent of the cities (regions) with the largest populations will be found in those areas. There we have to deal with many existing and forthcoming problems that require solutions. Integrated coastal policy, based on careful analysis of these regions and their subsoil, gives an answer to the question of how we can solve these problems in relation to each other, and in relation to the hinterland on one hand, and the bordering sea on the other. An important element of integrated coastal policy is land reclamation, using the principle of building with nature. Existing and forthcoming problems in coastal zones and hinterland can be solved, and new opportunities can be found. By learning from mistakes and using the achievements of the past, can the challenge of the future be met. Two aspects are essential:

1) An integrated approach to coastal zone and hinterland, including old/new land-sea.

Many functions have to be considered carefully, using many different disciplines.

2) Possible realisation of new land, where nature allows us to do so, using the principle of building with nature. The essence of this principle is: flexible integration of land in sea and of water in land, making use of materials and forces present in nature. (See Fig. 1)

2. A PARTLY NEW COASTLINE FOR THE NETHERLANDS

2.1. A third step in delta and coastal zone management and development

The present coastline of The Netherlands is the result of natural forces and the action of Man. The country is situated in the delta of the rivers Rhine, Meuse and Scheldt. Its subsoil consists mainly of sand and clay deposited by the rivers and the sea in the past millenia.

Its present coastline is the uneasy border between the North Sea and the alluvial deposits and, through the ages, it has been subjected to slow growth and sudden catastrophic set-backs. Storms at high tide in the sea and floods from the rivers caused breakthrouths in the sand barriers which had formed naturally along the beaches. From the earliest times, the inhabitants of these low-lying lands have struggled to save the land from the onslaught of the sea.

In 1953, the unfortunate coincidence of an extreme high tide and strong north-west-westerly gales caused the uneasy equilibrium to be disturbed: the dykes were breached in many places, large areas were inundated and more than 1,800 people were drowned.
To the north, the plan would reach as far as The Hague, including Scheveningen and its harbour. The area to be created between the future and present coastline, filled up to above sea level with dunes, will provide new spaces for many purposes. One of the most interesting aspects of the new plan is the method of construction. Another significant factor is its requirement for integrated planning of the many developments in the new coastal zone, in which the relations with the hinterland and the bordering sea play an important role.

2.2. Water control and land reclamation

More than half of The Netherlands lies below the level of the sea and rivers, so an effective system of water control is needed to keep the land dry and habitable. This is particularly important since 60% of the population live in the low-lying parts. Natural defences like sand dunes and man-made defences like (reinforced) dykes and strong solid seawall elements are used for the protection of the low-lying part of The Netherlands. Protection against sea water which would flood it via estuaries and inlets and against infiltration by river water, ground-water and rain. Modern pumping stations work day and night to drain off excess water.

The Netherlands used to be threatened by two "sea claws". One reaching in from the north via the former Zuyder Zee (now Ijssel Lake) aimed at the heart of The Netherlands. One, multi-pronged, reaching in from the south via the estuaries of South Holland and Zeeland, also aimed at the same heart.

As an answer to these two threats and for additional reasons (like land reclamation, and the creation of fresh water reservoirs) the Zuyder Zee Project and the Delta Project were designed and implemented.

2.3. The Zuyder Zee Project

In the early 1930s the Zuyder Zee was closed off from the sea. This entailed the construction of the 30 kilometre Barrier Dam connecting the Provinces of Friesland and North Holland. The dam with sluices, transformed the Zuyder Zee into an inland lake which gradually became a fresh water lake (the Ijssel Lake). Once the Ijssel Lake had been closed, work began on draining enormous polders, four of which have now been completed. They represent a total gain of 165,000 hectares of new land. The two oldest the Wieringermeer Folder and the North East Folder - are used for agriculture. The newest, South Flevoland, is also being used for housing, various types of employment and recreation to relieve some of the congestion in the Randstad conurbation.
The Eastern Flevoland Polder is a combination of the two. The result of these plans has been to create space within the old Zuyder Zee for several hundred thousand people. In 1984, it was decided not to proceed with the plans to create a fifth polder, the Markerwaard Polder, for financial and environmental reasons. The Dutch were no strangers to land reclamation before all these major projects were undertaken. They had acquired a great deal of experience and know-how of draining lakes and bogs in the course of the previous seven centuries.

2.4. The Delta Project

The last occasion on which the sea made major inroads into the land was on February 1, 1953 when large areas in the southwestern part of the country were flooded. The disaster cost 1,835 lives and brought home the need to carry out the Delta Project to close off the estuaries as quickly as possible. All the estuaries have now been closed with the exception of the New Waterway and the Western Scheldt which remain open to allow shipping access to the ports of Rotterdam and Antwerp. The Eastern Scheldt has been closed by means of a storm-surge barrier which is 3,200 meters long, made up of 65 concrete piers between which 62 steel gates are suspended. Under normal conditions, the gates remain open and permit the sea to flow in and out the Eastern Scheldt; in stormy weather they are lowered to protect the estuary from high water levels. The design and method of closure was chosen to conserve the shellfish and other marine organisms in the Eastern Scheldt which depend on tidal movement to survive. The Delta Project was completed in 1987. An added project will be a barrier in the New Waterway, consisting of two circle-sector doors which can each revolve around an axis (positioned on each side of the New Waterway). This additional project will be completed well before the year 2000.

2.5. The Province of South Holland

The Province of South Holland is remarkable in many ways. The largest harbour of the world, Rotterdam, is situated within its borders as is the largest uninterrupted greenhouse area, the so-called Westland District. Of all Dutch provinces, South Holland has by far the highest industrial and agricultural production. The Central Government and the Houses of Parliament are situated in The Hague. In many ways South Holland is the motor of the Dutch economy. In addition, it houses important institutions of education and research, has fascinating old and new towns and extensive areas of rich scenic beauty for recreation and leisure. However, the province of South Holland also has the highest population density, the highest refuse production and energy use both per capita and in total. The absolute environmental friendly collection, transport, storage and processing of various types of waste is causing problems. There is a serious lack of space for urban expansion, new industrial and office development, and recreation facilities. And, very importantly, there is the need to preserve and expand valuable nature. The unemployment figures are too high. Thinking of South Holland, it could be stated that there is only little space available for living, working, travelling and recreation, and there is the need to preserve or expand valuable nature, specifically in the vicinity of the metropolitan area. The plan to enlarge available coastal areas would provide possibilities to solve many of these existing and forthcoming problems, and it can create opportunities for specific new developments.

![Fig. 2. Defence system against flooding](image-url)
2.6. Coastal extension plans

The idea of pushing outwards the coastline of this most intensively utilised part of The Netherlands was published in several earlier plans (1975-1978). Briefly summarising the most important of these plans, the following are mentioned in geographical order, from north to south:

- the Polyzathe “Village in the Sea” plan, comprising 45 hectares of new land north of the northern mole of Scheveningen harbour;
- the plan for the fourth Scheveningen harbour extension, commissioned by the Municipality of The Hague and designed by Nedeco Group member Haskoning;
- Cadel’s and Ten Velden’s “West Dunes” plan, comprising 240 hectares between the southern mole of Scheveningen harbour and Kijkduin;
- the Volker Stevin “New Dunes” plan, comprising 1,300 hectares to be reclaimed along the coast between Kijkduin and ’s-Gravenzande;
- the Ballast Nedam plan “Voorne Dam” south of Hook of Holland and the New Waterway. This plan envisaged the construction of a new peninsula with an area of 1,250 hectares, connected to the Meuse Plain (Maasvlakte) off the coast of the Island Voorne. The peninsula would have been available for landing, storage, treatment and transit of natural gas or the handling of petroleum gas and other hazardous substances.

All these plans were creative. However, they all had as a basis, from a constructional point of view, the application of solid sea-wall elements to protect the new land.

2.7. The Principle of “Building with Nature”

In 1979, the hydraulic engineer J.N. Svasek, a recognised authority in the field of coast morphology and harbour construction, launched a new concept for coastal extension. This new method, based on morphological theories and practice, has been suitably and aptly named “Building with Nature.” Solid stone or concrete bulkwalls against the sea are no longer considered of prime importance, but instead, use is made of the various forces acting on the mobile loose sand material, while creating a flexible new dynamic equilibrium coast.

Utilising and taking into account the effects of tides, currents, river outflow, waves, wind and gravity on the mobile loose material (sand, clay particles, etc.) is essential. Use is also made of coastal flora types. In this case, the plan is based on utilising the effects of tides, currents, river outflow, waves, wind and gravity on the sand in the estuarine reaches to restore a coastline which, between the years 1500 and 1600, existed between Scheveningen and Hook of Holland.

The Dutch coastline underwent changes over the centuries. This part of the West European continent, including the North Sea floor, is still gradually sinking, whereas the sea level is rising.

In the past the coastline was breached by the action of the sea during periods of springtide and heavy storms. The position of the various rivers shifted and caused also breakthroughs in the coastal defence systems.

To all this must be added the action of the Dutch engineers in the western part of The Netherlands. All these and other factors combined made the present coastline.

Now we have the interesting possibility of creating a new, fairly stable coastline via a step by step approach using to the utmost, materials and forces present in nature, and utilising the geographical position. Thus we reach a new phase in creating an optimum coastline position through coastal zone management and development.

2.8. The new overall coastal extension plan

The present plan, based on Svasek’s concept differs in the alignment of the harbour moles of Scheveningen and Hook of Holland and in the curvature and location of the new coastline in between, and in the design and planning of the new land. Furthermore, an analogically designed extension of land south of Hook of Holland has been included in the new plan. This new overall plan can be divided
into a northern (Plan 1) and a southern part (Plan 2). In addition, three newer plans have been developed (Plan 3, 4 & 5), all fitting in the master concept of the new overall coastal extension plan.

Plan 1 reaches from Scheveningen to Hook of Holland, and is a wedge-shaped addition of new land to the present coastline. It is designed for improved safety from flooding (including the effects of sea level rise) and for increasing the fresh water reservoir under the new dune area.

It is multifunctional in design. The functions include recreation and tourism in various forms, a new harbour and harbour related activities, housing and facilities, modern offices and industrial development, infrastructure, aquaculture, horticulture, and a nature reserve area. A net gain for the environment can be realised, while it strengthens the economy and increases employment.

Plan 2 is situated south of the New Waterway. It is a multifunctional peninsula attached to the greater Europoort/Meuse Plain area of Rotterdam.

Plan 2 is primarily designed for the absolute environmental friendly storage and processing of various types of wastes. In addition, areas are included for industrial and harbour development, for recreation near the new seashore, and provisions are made for infrastructure, and a nature reserve area is created.

Plan 3a is a land reclamation area south of the southern harbour mole of Ijmuiden, with a yachting harbour, a recreation centre and a nature reserve area with a lake.

Plan 3b is a land reclamation area north of the northern harbour mole of Ijmuiden, primarily designed for the storage and processing of various types of wastes, and several other functions.

Plan 4 concerns the alteration and linkage of the island Noorderhaks to the island of Texel mainly for coastal morphology reasons.

Plan 5 has the shape of a peninsula connected to the Brouwersdam, between Goeree and Schouwen-Duiveland. This new peninsula is a so-called “Lievense-basin” for pumped storage of energy.

In addition it offers possibilities for recreation. All these coastal extension plans are multifunctional in character, and are based on the principle of building with nature. They all stress the importance of environmental aspects. Most of them can be executed in phases, segment after segment.

3. PLAN 1

Beginning at Scheveningen-North, the area to be reclaimed between the new and the old coastline is wedge-shaped. In the north it is only a few metres wide and its width gradually increases to 3,500 metres near Hook of Holland.

From the top at Scheveningen to the base at Hook of Holland the length is 21 kilometres. The new land has an area of approximately 3,000 hectares and the volume of sand required amounts to 360 million cubic metres. This amount of sand can either be obtained by widening and deepening the Euro-Meuse Channel and/or by dredging from the sea-floor of the North Sea parallel to the new coastline, at a minimum distance of 3 to 10km.

The plan includes the establishment of a primary range of sand dunes parallel to the new coastline with the beach in front, and a secondary range of dunes at an angle to the coast parallel to old dune ridges in the hinterland (which we still can recognise in the orientation of the basic street-pattern of The Hague).

The southern boundary of the new wedge-shaped land area will be formed by the existing northern harbour mole of Hook of Holland. This harbour mole with a length of 4.7km was originally constructed to protect the entrance to the New Waterway leading to Rotterdam and to provide calm waters for the ships entering and leaving the New Waterway and the Euro-Meuse Channel.

The orientation of the new hollow coastline in relation to existing currents, waves, etc. and the movement of sand along the coast could prove to be an improvement on the original situation.

Although it is taken into account that, once every five years, a certain amount of beach replenishment will be necessary because of the net loss of sand by coastal drift to the north, coastal protection by groynes will most probably not be needed anymore.

North of Scheveningen, groynes have not proved to be necessary and in future this may also be the case along the new beach. Another interesting aspect of this plan is that the new land area, being composed mainly of sand, may increase the fresh water reservoir underneath the dunes. This would improve the protection of the low-lying Westland district with its large greenhouse area and important horticultural activities, against salt-water intrusion.

3.1. Plan 1: Physical Planning

The essential objective is to reach an integrated coastal policy which can solve many existing and forthcoming problems in relation to each other and in relation to the hinterland on one hand and the North Sea on the other.

Planning plays an important part in this. The new area that will become available behind the new coastline will be needed for many different purposes. Some of the details of the physical planning in various sections going from north to south could be as follows:

Scheveningen-North to Scheveningen harbour entrance
- most northern part to von Wied Pavilion: widening the beach in front of the Scheveningen boulevard.
Thereby increasing the beach capacity and improving the safety conditions for the beach pavilions during storms and high tide;
- von Wied Pavilion to northern harbour mole of Scheveningen: primary dunes with the beach in front and behind the dunes an area for a new model camping site or an educational park and a limited number of houses and apartment-buildings; facilities for sailing, surfing and other sports.
Scheveningen harbour entrance to Kijkduin
- 4th Scheveningen harbour (900m quay length) and 32 to 55 hectares of land for non polluting harbour-related activities;
- there will also be room for sections of a modern sewage treatment plant, based on bio-technological methods in order to replace the existing plant which serves thirteen municipalities in the province.
These developments must be carefully planned so as not to disturb the present Bosjes van Poot (woodland park and its bird sanctuary);
- provisions for public transport and an access road, linked with the horseshoe road system around The Hague, serving the extended harbour and the adjacent area. The road with a limited but adequate capacity can be built at a lower level. Parking areas under the ranges of new dunes;
- an attractive building site for housing and facilities on The Hague municipal territory. The existing dune area between the already existing built-up area and the new area (Westduinpark) will be left intact, and will be extended to the new beach.
Kijkduin
- a fresh-water dune lake of approximately 120 hectares with three lobes and south-oriented beaches. A good micro-climate because of the beach orientation and the protection against the prevailing western winds by the primary range of dunes.
This will cause lengthening of the tourist season and more recreational variety, because one can always choose between the lake and the new seashore, which is easily accessible.
The layout of the lake (with curved meandering beaches, special depth profile, bridges, tunnels, water supply and hygiene) deserves special care.
The area between the lake and the new coast can also be used for recreation and tourism. Another building site for an attractive housing area is also possible.
Municipality of Monster
- a golf course and other facilities for non-intensive recreation would form a transition zone for aquaculture and a large nature reserve area adjoining Westland Drinking Water Company's terrain;
- in this nature reserve provisions are made to create and preserve living conditions for the various species of flora and fauna specific to the region.
Differentiation moist-dry, high-low chalk content, high-low nutrition values, varied height of dunes, differences in micro-climate, are essential for creating conditions which will induce a large variety of species;
- near Ter Heijde and Monster there will be space for housing.
Municipality of 's-Gravenzande
- urban expansion could be realised near the town centre on the old land, whereas an area between the old and the new coastline could be assigned for horticultural activities (greenhouses), based on modern energy-productive methods like hydroculture and substratum-culture;
- a fresh-water dune lake coupled with a woodland park for tourism and recreation, serving Slag Vluchtenburg and the northern part of Hook of Holland.
Hook of Holland (Municipality of Rotterdam)
- Hook of Holland has a unique position, being situated at the mouth of the rivers Rhine and Meuse (Maas), via the New Waterway, and being situated on the North Sea;
- it deserves very special development in stages, complete with a salt-water tidal lagoon, a yachting marina, and a hotel with rotating top restaurant, a conference centre; housing and facilities, a bungalow park; and, furthermore offices and industry as one of the stepping stones in the European market for Great Britain;
- infrastructure: connections will be realised for public and private traffic, including extension of the Rotterdam - Hook of Holland railway (with a railway station) and an extension of the A20 motorway Rotterdam - Hook of Holland.
The total surface area of the new land (excluding the area occupied by the primary range of dunes) would amount to at least 2,500 hectares.
This area will be distributed among the four municipalities of The Hague, Monster, 's-Gravenzande and Rotterdam. The present municipal boundaries will be extended perpendicular to the original coastline.
The new territory will come into being by using sand from the sea. K.P. Vollmer, director of Nedeco Group-member OD 205, consultants for urban and rural planning, had an interesting suggestion, which could be defined as the three coastlines principle. Instead of creating the new land, using sand from the sea, starting from the shore outwards, we first create the new dynamic equilibrium coast consisting of the new primary range of dunes with the new beach in front and on the other side keeping the original beach intact.
Then we plant special Marram grass (Ammophila Arenaria) and pioneer plants and let nature take hold in the new dunes. After that, we either connect the old beach and dune area with the new territory, or leave the space in between open, depending on future functions.
Finally, considering integrating land in sea and water in land, using forces and materials present in nature, we want to stress the following.
Fig. 4. The Van Dishoorn Triangle. Land accretion of approximately 100 hectares - already created according to the principle "building with nature". Note the correct orientation of the coast and the disappearance of the original Delfland groynes under the sand. Photo 16th March 1981 - high water.

Fig. 5. Narrowest part of the present South Holland coastline off Ter Heijde. Better protection of the hinterland is needed here. Note the existing dune wedge between Ter Heijde and Kijkduin. Photo 16th March 1981 - high water.

Taking into account all functions, the necessary operations must be carried out in such a way that in the end nature, landscape and the environment will benefit from it.

4. PLAN 2

Plan 2 is a multifunctional peninsula attached to the greater Europort/Meuse Plain area of Rotterdam. Its ultimate shape resembles the panhandle peninsulas of Goeree and Schouwen-Duiveland, and to a certain extent Walcheren, with dominating southwestern coast orientations, typical for the estuarine coast between Hook of Holland and Belgium.

Two designs were made. Plan 2a with the longitudinal axis parallel to the coast of Voorne and Plan 2b with the longitudinal axis parallel to the coast of Goeree. Both Plan 2a and 2b can be realised in phases, segment after segment.

Plan 2 is primarily designed for the absolute environment-friendly controlled storage and processing of various types of wastes. In addition areas are included for industrial and harbour development, for recreation near the seashore; provisions are made for infrastructure and a new nature reserve area is created.

Plan 2a, with the longitudinal axis in SW-NE direction parallel to the coast of Voorne, has the advantage that it can be completely realised by using
Towards an Integrated Coastal Policy for South Holland

- Safety (including coastal protection and protection from salt-water intrusion)
- Building locations (houses/factories, offices/industries)
- Public utilities (energy and water supply, sewer system, waste water purification)
- Tourism and harbour related activities
- Landscape, nature and environmental values
- Recreation and tourism
- Aquaculture
- Horticulture
- Infrastructure for public and private transport (roads, canals), tram-train-bus, conveyor belt system, pipelines, cables
- Water resources management
- Environment-friendly controlled storage and processing of harbour silt and waste products
- Potential possibilities for wind, solar and water energy
- Economy and employment

Central, Regional, Local Authorities involved:

- Central Government
- Government of the Province of South-Holland
- Municipality of The Hague
- Municipality of Middelburg
- Municipality of ’s-Hertogenbosch
- Municipality of Rotterdam (Dock of Holland)
- Delta Water Board
- Westland Regional Council

Fig. 6. Towards an integrated coastal policy for South Holland

Fig. 7. Situation of Subsidiary Plan 2. The first segment of this plan, complete with thirteen harbour silt basins, is visible west of the Europa Road. This segment already shows a dynamic equilibrium coastline. Furthermore, natural forces have already begun to form a sandbank with the surf in front of it.

Photo 8th March, 1982 - low water
the method "building with nature", thereby creating a dynamic equilibrium coast. An important contribution to the design was made by Nethconsult-Group member W.H.A. van Oostrom (ADC).

Plan 2b, with the longitudinal axis in WSW-ENE-direction, parallel to the coast of Goerres is more difficult and expensive to realise. The reason is that in this case it will be difficult to obtain an overall dynamic equilibrium coast and the costs will increase considerably because greater depths have to be met.

However, Plan 2b is to be preferred, taking into account an existing demarcation line (between a recreation/nature zone on one hand and an industrial/harbour zone on the other) and the wish to save more sea-space and an open salt-marsh between Plan 2b and the Voorne coast. In this way the contact between the Voorne dunes nature reserve and the open sea is maximised (a.o. interaction between wind plus salt-spray and the unique vegetation, which consists of more than 700 species of higher plants).

The Voorne dunes area is unique in Western Europe and therefore the higher costs are fully acceptable. The marsh area and the open sea are very important ecologically as they also have a very valuable flora and fauna population.

From the viewpoint of construction, the harbour entrance as part of Plan 2b would consist of several solid sea-wall elements such as breakwaters and harbour moles. The remaining parts, however, could be created by "building with nature". The maximum size of Plan 2b is approximately 3000 hectares. Plan 2a and 2b can be carried out phase after phase, segment after segment.

Fig. 8. The two variants of Plan 2, the southwestern lobe to the Maasvlakte: Plan 2a and Plan 2b

Plan 2a takes most account of the currents and is most in line with natural forces; very few "hard" elements have to be used here.

Plan 2b also takes into account the environmental and local interests of the island of Voorne, which demands preservation of the "open" character of Voorne's dune coast. This implies a slightly rotated peninsula, with more "sea-space" between the new land and the old. But it also necessitates more "hard" elements; reinforced dykes, to keep the currents from washing away the coast.

salt marsh, a long fairly narrow zone as nature reserve;
- an extended Hartel canal with loading and unloading quays;
- an area for controlled storage and processing of various types of harbour silt, polluted soils, industrial waste products;

The storage would take place in excavated basins, the bottom and walls of which are impermeable. An internal drainage system can collect all effluent, consolidation and percolation water. Contaminated water can be pumped directly to a treatment plant without coming into contact with groundwater. Special basins with semi-permeable walls are also a possibility, complete with a monitoring system. The remaining soil and classified sand and clay types, after being leached and dried, can be used for...
various purposes. If it is clean clay, it may be used for soil improvement in e.g. agriculture, in claylining of dykes, in noise-abating embankments along highways in populated areas, and visual separation walls.

If it is not sufficiently purified clay, it could still be used for the manufacture of pavings, bricks, clay pebbles or artificial gravel.

The firing process immobilises the heavy metals and burns off pesticide impurities.

Necessary energy for e.g. blending and firing processes can be supplied by various types of energy. In an analogous way, such waste products as fly-ash, slags, gypsum, etc. could be stored and treated, insofar as it is not feasible to treat these products at their site of origin.

Industrial processes should be advanced which manufacture at a higher yield environment-friendly products, using less energy and less raw materials, coupled with less pollution emissions to air, water and soil and with less solid wastes.

Various types of contaminated silt dredged from harbour areas along the polluted Rhine basin, other contaminated soils and toxic wastes that cannot be stored elsewhere can be brought to this new area for storage and treatment;

- infrastructure: a road system, an extended railway, a conveyor belt system, subterranean pipelines and cables;
- on the western side of the peninsula, a harbour (Delta-port) could be planned for landing, storage and transport of liquid natural gas, petroleum gas or other hazardous substances far from the population centres, if in view of safety the wish and necessity should exist;
- an area (Rhine Plain) for modern industrial development and harbour related activities;
- recreational activities near the seashore.

4.2. Experience gained

Work on both the northern and southern parts of the new plan has already been started and much valuable experience has already been obtained.

As far as Plan 1 is concerned, a wedge of new land has been reclaimed immediately to the north of the harbour mole near Hook of Holland. In 1971-72, upon the instigation of J. van Dixhoorn, the former Director General of the Ministry of Transport and Public Works, some 10 million m³ of sand were deposited along a stretch from 's-Gravenzande to the Hook of Holland, a length of 3.5 kilometres, with a surface of 100 hectares. The sand was obtained from dredging the Beer Canal and
harbour basins within the Meuse Plain. The principle of "building with nature" was tried out successfully in this relatively small plan which included a range of primary dunes, parallel to historic dune ridges. A new dynamically balanced coastline was achieved with the correct orientation. The groynes on this part of the old coastline disappeared under the sand and it has become apparent that they are no longer necessary to the new coastline. This is of importance for recreational sailing and swimming because the groynes, with their undertow currents, traditionally constituted a serious source of danger.

Another small-scale experiment took place in Scheveningen after completion of the extension of both harbour moles between 1970 and 1980. The capacity of the beach was improved by beach replenishment. The Municipality of The Hague voted (1989) for an environmental impact assessment concerning a coastal extension for a new Scheveninger-4 harbour coupled with an improvement and a step by step change of functions with regard to the existing harbour and the adjacent area.

As far as PLAN 2 is concerned, it should be realised that southwest of the Meuse Plain, new land has already been reclaimed and that this has led to the formation of a new dynamically balanced coastline. This is a strip of land west of the Europe highway, varying in width from 250 metres to 1.6 kilometres over a length of 4.5 kilometres. Its surface area is 350 hectares. Here, thirteen basins were constructed for the storage of slightly polluted harbour silt from the Caland and Beer Canal silt trap. These basins were not impermeable and the drained water still communicated with the groundwater. The clay soil, after drainage and drying is already being used for several applications. The experiment has proved to be a successful combination of "building with nature" and a well thought-out resources policy. The realisation of this coastal extension plan was followed by another even larger plan.

In 1987 the so-called Slufterdam-project was completed, based mainly on a design by Rotterdam Municipal Works and the Ministry of Transport and Public Works. The main purpose of this design was the absolute environment-friendly storage and processing of contaminated harbour silt and various types of waste products, including a storage capacity for 150 million m³ contaminated dredged harbour silt (sufficient for the period 1987-2002). In addition to that: a new industrial site, infrastructure including road system, railway extension, extended Hartel Canal, conveyor belt, pipelines and cables. Furthermore, recreation along the new beaches and a nature reserve area on the southern side. Both executed plans fitted in to the larger concept of Plan 2b. Concerning Plan 3a, we can make the following statement. Nature itself built the larger part of the new land south of the southern harbour mole at Ijmuiden. The new land has a slightly hollow coastline and it is triangle-shaped, with a surface area approaching 100 hectares. The north-oriented net coastal drift of sand caused it to grow to its present size. It will be an excellent base to create within a few years the complete Plan 3a "Ijmuiden on Sea".

With regard to Plan 4, nature itself has a tendency to close the gap between the small island Noorderhanks and the large island of Texel. In the case of Plan 5, nature started building a sand deposit (the so-called Middelplaat) attached to the Brouwersdam which can be used as a base for linking the peninsula for pumped storage of energy (Lievense basin) to the aforementioned Brouwersdam. In the period between 1980-1989 basic comprehensive studies and reports were completed concerning many different aspects of the various plans including environmental impact assessments in several cases.

5. CONCLUSION

The experience obtained in small-scale and larger scale projects to change the existing coastline along the North Sea has clearly demonstrated the technical feasibility of the more ambitious plan for a partly new coastline for The Netherlands. The execution of the plan and the creation of new land will undoubtedly reduce the lack of space which presently hampers the development of the area. It provides for long term safety from flooding and other factors. It pays attention to water resources management. The possibility in due time of net-environmental gain concerning the combined terrestrial and marine environment is also a valuable aspect.

In addition to general economic expansion, employment opportunities will also be improved, both during construction and also permanently in the future. Challenging opportunities will also arise in the field of research, engineering design, construction and follow-up work. Successful completion of the plan will stimulate the serious consideration of the realisation of other similar possibilities in The Netherlands.

Finally, it should be noted that similar coastal conditions exist elsewhere in the world. The example set in The Netherlands may stimulate planning based on an integrated coastal policy and using the method of building with nature, to be undertaken in other countries.

Dutch know-how to assist in planning and its execution coupled with local knowledge and capabilities can help to solve the existing and forthcoming problems in deltas and coastal areas via building with nature.
The first flood banks along the coast of the North Sea were built around the year 1000 A.C., but only since the 12th and 13th century has a consistent line of flood banks been devised. During the early Middle Ages planned embanking along the lower-lying parts of land around Hamburg started (Fig. 1). This planned building activity of water defence works became necessary, because, a continuous rise in flooding has been apparent even since the Middle Ages. In 1825, the waters of one particular storm flood ran as high as 5.2 m.a.s.l. on the St. Pauli water mark. The ensuing high number of casualties and property lost convinced the Senate of Hamburg to raise the existing flood protections to 5.7 m.a.s.l. Those flood banks were sufficient until 140 years later. In 1962, a storm flood reached 6.5 m.a.s.l. (Fig. 2). Flood banks along the river broke in 80 places, 315 people lost their lives, 20,000 were made homeless. Flood damage amounted to some DM 100 million. After the catastrophe a group of researchers suggested raising the water defence works to a nominal level of 7.2 m.a.s.l. or 9 m.a.s.l., in places with extraordinary wave run up. With the building of these new flood banks the total length of the public dykes was shortened from about 130 km to approx. 100 km. The last, and so far highest, storm flood reached

**Fig. 1. Geographic position of Hamburg and Venice in Europe**

**KEY WORDS**

Hamburg case - Elbe Estuary
Flood damage - Defences - (from Sea - River)
6.45m.a.s.l. (Fig. 2) in 1976 and prompted industrial owners in the harbour area to build approximately 75 polders with 120km of protective walls. With 7.5m.a.s.l., their nominal level is about 0.3m higher than the public protection measures, because any private safety areas for flood relief were considered comparatively small in the event of a water overflow. In total, the length of sea defence works in Hamburg measures approx. 220km and has cost approx. DM 1.7 billion since 1962.

Due to the apparent and continuous rise in high storm floods over the last 20 years, the city commissioned an extensive risk analysis of flood dangers for Hamburg. Within the context of the analysis, reasons and risks of future floods were to be examined, existing sea defence works evaluated, the danger for people and goods verified, and the possibilities and limits of various concepts evaluated. The analysis established that more than 200 square km of land could be flooded (Fig. 3). 180,000 inhabitants and 140,000 employees in the city area endangered by the rising storm-tide water levels, if the rise in tidal water levels occurred as predicted and feared today. The potential damage caused by flooding amounts to approx. DM 16 billion, and 80,000 homes and 8,000 industrial plants would be in danger. The risk analysis made very clear that Hamburg will need better protection against future storm floods, if a tragedy like 1962 is to be avoided.

2. DESCRIBING THE PROBLEMS

Although the City of Hamburg is situated on the river Elbe, 120km from the North Sea (Fig. 4), the rise and fall of the tides have a notable impact on the city and its harbour. From the sea coast to the harbour, the river Elbe forms a funnel that channels the rising tide towards the city. The mean tidal high waters in Hamburg run up approximately 0.7m higher than the waters on the coast near Cuxhaven, and in case of extraordinary high floods the water in the Elbe funnel can run up
We are however, of the opinion that our available data does not yet allow a scientifically correct prognosis of any further developments. While rising tidal high waters threaten our coastal regions, at the same time the tidal low waters constantly decrease (Fig. 5). Accordingly, an even greater amount of water flows faster into and out of the tidal flats causing increasing erosion particularly in the tidal rills, although no decrease in the tidal flats has yet been verified.

Opinions about a possible sea level rise on the coast of the North Sea are divided, since rising mean high water (MHW) is not necessarily proof for generally rising sea levels. In a comparison of North Sea half-tide levels, with the rise of the sea level in the Baltic Sea, numbers correlate: the North Sea half-tide levels have increased between 12-15cm over the last 100 years and so has the water level in the Baltic Sea. Thus a general rise in sea water levels seems reasonable to assume. For a prognosis of further sea level rises, it is important to realise that the rise in sea water levels is 20cm higher for the last 50 years, than the five decades before 1940.

If a worldwide sea level rise does, in fact exist, it could be due to cyclic changes in the world's climate. This has been noticed to fluctuate over the centuries. According to Prof. Grassl, as yet there exists no scientific proof for an extraordinary change in climate due to human interference. This of course does not mean that we can wait for more scientific results, because recent developments clearly indicate an unnaturally rapid change in the world's climate. Recently suggested results of this supposedly man-

![Alternative flood barriers near Brokdorf and Finkenwerder](image)

![Change in MHW and MLW since 1850 in Hamburg and Cuxhaven](image)
made greenhouse effect are most alarming. After all, since 1860 the mean global temperature 2m off ground and the temperature of the oceanic top water layer, has risen about 0.7°C. Due to a warming climate the glaciers of a number of mountain ranges have shrunk; precipitation in the northern hemisphere has notably shifted during the last 40 years: the land between 5 and 35 degrees latitude has dried, whereas between 35 and 70 degrees latitude precipitation has increased. The temperature in the stratosphere, 30km above the earth, has decreased over the last 150 years. According to our knowledge today, a heightened greenhouse effect is not only followed by higher mean temperatures, but also diminishes the difference between the temperatures of equatorial and polar zones; summer and winter, day and night, cloudless and overcast weather. The rising temperatures will also reduce the permanent frozen zones, melt down mountain glaciers and inland ice zones, and increase water discharge from formerly frozen areas.

In a generally warmer climate the shifts in precipitation would continue faster than expected and the actual danger of droughts, storm floods and hurricanes would multiply.

Insufficient data on possible reactions of the water cycle to the greenhouse effect does not allow accurate forecasts. The delay in the reactions of the slow reacting components of the climate system, should not excuse stalling by politicians or planners.

As the general direction of possible developments is known today, immediate action will have to be taken to minimise an unnatural greenhouse effect and its subsequent sea level rise.

Tied in with a possible general sea level rise is, of course, a possible notable rise in tidal high waters on the German coast (Fig. 5).

Mean tidal high waters have been noted to have risen over centuries. In Cuxhaven the mean tidal high water has been measured over a long period of time and we have references to a rise of:
- 24 cm in the hundred years between 1876 and 1976, that is rates per century of:
  - 19cm between 1920 and 1976,
  - 30cm between 1955 and 1976,

Due to a high fluctuation in tidal high waters, it is of foremost importance to choose the right time factor for any research on sea level rises. Therefore the north German coastal federal states, have decided on an approximated average of a 30cm increase in mean tidal high waters until the year 2085.

For Hamburg, it is not only the general rise in sea water levels that causes floods to run up faster and faster in the city area. Hamburg is the biggest and most important sea harbour in the Federal Republic and one of the most important in Europe. Therefore, to furnish navigable water deep enough mainly for container ships, it proved necessary to deepen the navigable waters of the river to 13.5m below s.l. Thus the soil ground friction was diminished and the cross-sectional area of flow increased. Thus storm floods can run up faster and higher than before. In addition, they run up longer and the duration of flood periods has increased.

According to the Danish Hydraulic Institute (DHI), the widening and deepening of navigable waters in the lower parts of the river Elbe have led to a rise of 10cm in mean tidal high waters in Hamburg. Not only more water flows up the river, but there are less discharge areas along the river as well. After the severe storm floods during the last decades, not only in the city but also along the lower Elbe, new flood banks were built, thus shortening the overall length of dykes (Fig. 6).

As a consequence, the flood absorption capacity of low-lying foreland almost disappeared and today only one polder helps to relieve Hamburg's sea defence works.

The impoldering along the lower Elbe destroyed 20,000ha of discharge areas and raised the mean tidal high water in Hamburg by 40-50cm.

A last, but completely non-human reason for rising sea levels on the German coast is the slow subsidence of subaquatic land that might correspond to the rise of salt deposit further inland. So far, the subsidence of subaquatic land has been proven only for the east Frisian Islands and the east Frisian coast, which have sunk approximately 6cm in 100 years.

How long this constant moving is going to last, cannot be said. So, as the main reasons for higher storm floods in Hamburg, you have a rise in tidal high waters and the sea water level; the deepening of navigable waters in the river, impoldering of low-lying land along the lower river and the subsidence of the mainland.

3. SOLVING THE PROBLEM

In order to receive information on dangerously high floods and find solutions that would prevent damage or at least minimise dangers, the Senate of the Free and Hanseatic City of Hamburg appointed in 1985 the "Independent Storm Flood Commission" to investigate the problem.

Members of this commission were representatives from the Chamber of Commerce, harbour industry and commerce, the shipping industry, the unions, political parties, private owners of sea defence works, researchers and specialists involved in coastal protection. In June 1989 the commission finished work and presented its suggestions that included short-term and long-term measures.

As a short-term improvement of Hamburg's flood protection, the commission suggested a programme of DM 180 million.

With this money approximately 60km of low clay flood banks should be improved and raised by 50 to
80 cm. Since this short-term programme does not produce flood banks as safe as the elaborates sea defence works on the lower river, the commission advised raising the old flood banks at least another 15 cm in 25 years, if the long-term programmes were delayed.

Flood protection walls are not included in the short-term programme, because damage from overflow would be only minimal. The short-term programme has been under way since 1986, and is costing approx. DM 20 million a year.

The members of the commission remained divided in their opinions on long-term protective measures for Hamburg. Seven out of thirteen recommend a flood barrier across the river either in Hamburg Finkenwerder or on the lower river near Breidhaf (Fig. 7). The other six recommend raising existing sea defence works by 1.5 to 2 m.

In addition, the commission suggested moving back flood banks on the lower river to recreate low-lying discharge areas, or building additional flood run-offs along the river, for instance to constrict the mouth of the river or building flood barriers in the harbour areas with any lower-lying flood control measures being raised further.

All suggested solutions include advantages and disadvantages which would take too much time to examine in detail. Therefore I will give you only the main points of criticism on the proposals. Constricting the mouth of the river, by means of a discharge polder, would narrow the cross-sectional flow area of the river and cause severe changes in the waterways followed by undesirable changes in the ecological system of the tidal flats which would endanger this fragile and unique system or even destroy it. Moving back the flood banks along the lower river would cost more money than their use could justify. In addition, the people using the polder land would undoubtedly object to the cultivated land being flooded. Discharge polders along the lower river, once again, would produce very high costs and provide, even with most efficient use, only minimal discharge capacities and would lower the overall height of flood levels by only approx. 40 cm. The relatively high, every-day risk of technical failure would have to be taken into consideration as well. Improving Hamburg’s protection against high floods by raising existing constructions means far-reaching interventions into the functions of the harbour and the historical city structure. More than 200 houses would have to be demolished, the face of the city centre would be completely changed and main city functions would be disrupted or destroyed. Moreover, constructions already raised could still not be adjusted to continuously rising flood levels.

Flood barriers in the harbour area would only help if a high number of already existing sea defence works were to be raised, and would include all the above mentioned disadvantages of high costs and drastic changes in people’s living space.

A flood barrier across the Elbe, particularly if built across the lower part of the river, would mean breaking new ground in technical planning and construction, and once again the intervention into ecological systems would be enormous. Furthermore, a solution that includes the lower parts of the river would make Hamburg too dependent on the goodwill of its neighbouring federal states.

4. DECIDING ABOUT LONG-TERM SOLUTIONS

Deciding about any long-term measures, the exact period of time has to be established for which the planning will have to be valid. Even though the above-mentioned climatic developments cannot be estimated for any longer periods of time, a period of 100 years should at least be considered for the dimensioning of future flood protection measures.

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**Fig. 6. Discharge polders (Entlastungspolder)**

**Fig. 7. Flood barriers in the harbour (variation 1)**

**Fig. 8. Intervention in the city structure. (Niederhafen)**
The federal states bordering on the river Elbe have agreed on a synthetic storm flood called 2085 A. It is based on an estimated mean tidal storm curve - including an approximated medial tide curve plus an extreme water run-up level due to wind, the rise of mean tidal high waters by 30cm in 100 years until 2085 and the influence of the influx of river water flowing downstream. How long today's estimates will hold true, depends on future findings of climate research (Fig. 9, point 1 + 2).

So far the wave run-up on the flood banks and the reflections from the flood walls have only been deduced from the watermarks on the flood banks. More recently, the wave run-up has been estimated according to a formula that was developed in the Netherlands. The parameters for the swell in high storm floods have not been measured satisfactorily and have to continue to be estimated according to educated guesses (Fig. 9, point 3).

The local water run-up due to wind can be neglected as far as Hamburg is concerned, because it does not play any significant role in the height of storm floods in Hamburg (Fig. 9, point 3).

The methods used today for dimensioning sea defence works do not always include additional safety margins, because they already take into consideration all possible influences on rising storm floods, for instance, all the influence due to wind, temperature, atmospheric pressure and astronomic influences. Nevertheless, an additional safety margin should be considered, particularly for all areas where great numbers of people or structures are in danger.

Examples are Hamburg and the atomic plants in its vicinity. The extent of those safety margins does not depend entirely on the construction of sea defence works, but also on future changes in climate. Decisions on the planning and building of long-term measures to protect Hamburg from storm floods can only be made after further investigations into the possibility of a flood barrier across the river.

To aid decisions in this field, additional and differentiated climatological investigations are necessary. In addition, technical investigation of possible constructions and their ecological impact on the affected areas will have to be made as well as investigations into estuarine tidal dynamics and morphology, or the influence on navigation and sea traffic. Financing any planned sea defence works at the estimated cost of DM 3 to 4 billion will only be possible if the German federal government takes financial stakes in the projects. The three Elbe states, Hamburg, Niedersachsen and Schleswig-Holstein, will not be able to raise enough money themselves. At the given time difficult negotiations will have to take place.

5. OUTLOOK

At present, Hamburg plans to fulfill the short-term programme by 1996/97, and hopes to reach agreement about long-term projects in the bargaining with neighbouring states and the federal government, within 3 years from now. The complete process of legislative initiatives, planning procedures and the actual construction of sea defence works, will take at least 25 years. Taking everything into consideration, Hamburg is well aware of the fact that any precautions against rising floods can only decrease the risk of flooding, but will never totally eliminate the potential danger to life and limb for any city as closely dependent on tidal influenced waters as Hamburg is (Fig. 10).

![Fig. 10. View onto Hamburg (Blick auf Hamburg)](image)

Fig. 9. Calculation of the nominal level of sea defence works in Hamburg

![Fig. 9. Calculation of the nominal level of sea defence works in Hamburg](image)
IMPACTS OF FUTURE SEA LEVEL RISE ON THE TEES ESTUARY
An Approach Using a Geographical Information System (GIS)

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1. BACKGROUND

Recent concern about the implications of an intensification of the greenhouse effect and a probable warming of the Earth's climate by between 1.5 and 4.5 degrees centigrade has alerted central and local governments, institutions and individuals to the potential for a significant acceleration in the rate of sea level rise. Estimates of the magnitude of future sea level rise have varied considerably. Early estimates from Hoffman (1984) covered a range of scenarios from 0.55m to 3.45m by 2100. More recent estimates, in approximate agreement with the conservative scenarios of Hoffman, from Wigley (1989) and Oerlemans (1989) are more moderate and cover a shorter period. A consensus appears to have emerged recently with a range of estimates of sea level rise of between 0.20m and 0.35m by 2050. Even with an averaged rise of 0.32m by the middle of the next century, representing an increase from the historical trend of sea-level rise of 1.1-1.2mm per year (Gornitz and Lebedeff 1987) to 5.36mm per year, the consequences for coastlines and coastal lowlands will be significant. It should also be noted, based on empirical evidence, that there remains the possibility of a very rapid rise in sea level, decimetres in a few weeks or even metres in a few years (Tooley 1989a). However, the explanations of the causative processes, the accumulation and catastrophic release of subglacial meltwater, have yet to be tested adequately (Tooley 1989b).

The low-lying parts of the east coast of England, with their combination of extensive agriculture, intensive urban and industrial development and attendant infrastructure represent one of the areas most likely to suffer widespread adverse affects of future sea level rise. The extent and nature of these impacts will vary spatially but could result from one or more of the following factors:

1) An increase in the frequency of damaging storm surge events and tidally induced flooding.
2) Slow inundation by the sea or as a result of the backing up of freshwater drainage.
3) Changes in the local groundwater table due to elevation of the local base water level or local accretion of sediments.
4) Changes in rates of coastal erosion and accretion and sedimentary conditions within water courses.
5) Increased salt penetration into coastal and estuarine aquifers and agricultural land.
6) Increased wave heights.
7) Increased volume of tidal prisms.

The political and planning response to the problems posed by these potential impacts, through the formulation of mitigation strategies may, however,
be hindered by the uncertainties over the magnitude of future changes in sea level. This need not be a problem if a flexible approach is integrated into current planning procedures. Such an approach should be based upon a widely available and accurate assessment of the nature and extent of the potential impacts of sea level rise following the identification of areas at risk on a national scale (Shennan and Sproston in press).

In the meantime, modelling of climate change should be refined in order to produce better predictions as a basis for sea level rise scenarios. Improved environmental monitoring is also required in order to be able to record changes and more accurately identify consistent trends. It is only with this information that a probability can be assigned to individual sea level rise scenarios.

Doubt over the magnitude of future sea level changes is however only important in the context of specific questions and should not hinder the identification of potential problems or search for possible solutions. In either case actions and policy decisions must be formulated within the framework of the prevailing political, social and economic climates and must recognise the temporal and spatial scales of the investigation.

Earlier impact studies (e.g. Barth and Titus 1984, Carter 1987, Shennan 1987a, Shennan and Tooley 1987, Shennan and Sproston in press) have noted a range of general options which include retreat, do nothing, advance or formulate structural or organisational responses to higher sea levels. Contrasting policy decisions taken in the USA and the Netherlands provide examples of the divergence of the range of possible responses.

In the Netherlands a political and practical judgement has been made that there are no areas to retreat to and the only option is to maintain the present coastline whatever the cost (J. de Ronde pers. comm.). In the USA, however, where alternative sites are more readily available, loss of coastal land and planned retreat is now part of adopted policy in some states, e.g. Maine and North Carolina (Titus 1987).

In contrast to either extreme, no policy decision has yet been made in the United Kingdom as a first step towards preparing a response to a problem which will affect the whole country to some extent (see also Parker 1987).

In addition, no nationally accepted guidelines or criteria currently exist in this country for the formulation or qualitative assessment of such policy decisions. This may be due in part to the number of agencies with an input into flood defence management and coast protection.

The parties currently involved include the Ministry of Agriculture, Fisheries and Food, the National Rivers Authority and district councils. There is however some potential benefit from the current state of affairs in that all options remain open and specific remedies can be assessed on their relative merits.

Existing solutions such as the Thames and Humber barriers represent a similar view to that of the Dutch, namely that the cost of large-scale engineering projects can be offset against the benefits, in this case, prevention of economically damaging flooding. On the other hand the rapid erosion of unprotected cliffs in Holderness can be viewed in the light of the ‘do nothing’ option.

Significantly, the continued erosion of this section of the UK coast cannot as yet be regarded as a policy response, despite the contribution of sediments to accreting coasts further south.

The factors affecting the choice between such divergent responses within and outside the UK must be evaluated for each locality, recognising national and global factors, within a nationally agreed policy framework. Without the adoption of such a framework and the supporting research the precise questions about the impact of sea level rise, and the methods by which they are addressed, cannot be defined.

It is only with this level of definition that the uncertainty of the sea level rise scenarios becomes problematical. It should also be noted that equally important meteorological and tidal factors may well have a significant bearing on sea levels that cannot be quantified with any more confidence.

Any decisions made at a local or national level regarding the impacts of future sea level change and the mitigation of the perceived hazard will involve some form of cost-benefit analysis. This may be conducted on purely economic grounds or, within a non-monetary framework.

In the case of future sea level rise it becomes very difficult to answer these in the traditional economic framework since the environmental factors which are involved require the consideration of a series of wider issues. Evidence from the case study of the Tees estuary which follows, demonstrates some of the issues involved. In this respect the case study can contribute important lessons to a national scale investigation.

2. THE TEES ESTUARY

The Tees estuary lies at the heart of the administrative county of Cleveland (Fig. 1), with a population of 552,400 is one of the most heavily urbanised and industrialised counties in the United Kingdom.

The concentration of industrial and urban development and range of land-uses in areas below 10m makes the county an obvious choice not only for establishing and examining the potential impacts of sea level rise but also for refining a methodology for assessing these impacts.

In addition to the range of human environments which dominate the estuary there is a variety of
physical environments along the Cleveland coast, each of which may respond differently to a rise of sea level. In this context it is important to note that the physical processes that influence the response of the various coastal units transcend administrative boundaries.

It is therefore vital that the policy framework used to formulate mitigation strategies be as broadly based as possible.

Out of a total area for the county of 6000km², just over 100km² around the middle and lower estuary lies below 10m OD, with 35km² below 5m OD. Although the main centres of population of Cleveland (Hartlepool, Billingham, Stockton-on-Tees, Middlesbrough and Redcar) are mostly away from the major flood prone zones, a wide range of industrial, commercial and recreational activities together with port and transport facilities and wildlife habitats lie within these areas.

Partly as a result of long-term deindustrialisation, the industrial base of the county has undergone a period of considerable change. Decline in traditional heavy industries such as ship building has been accompanied by extensive restructuring in other sectors.

Despite this, the main activities continue to be manufacturing, chemicals, petro-chemicals and iron and steel production together with fabrication yards servicing offshore industries.

Of necessity many of these facilities are close to the river, located on areas reclaimed from the estuary over the past 150 years.

More recently Local Authorities and the Teesside Development Corporation have carried out a number of major redevelopment schemes on derelict industrial land adjacent to the estuary as a means of expanding and diversifying the industrial base of the county.

A number of factors have influenced the choice of the Tees estuary as a case study for the examination of the impacts of future sea level rise. Firstly it is a compact and well defined area containing a wide range of environments and land-use types. As a result, a variety of methods for identifying and assessing the possible impacts can be evaluated economically and without excessive data collection. More importantly, Cleveland and the Tees estuary represent, within a relatively small area, a microcosm of most of the potential impacts likely to affect the rest of the United Kingdom.

In addition the development and evaluation of an approach to the problems posed in Cleveland by future sea level rise is aided by the availability of a range of digital data for the county.

One essential aspect of this case study has been the development of approaches that can be applied to other parts of the United Kingdom, or at a national scale. An early study of the Tees estuary (Shennan and Tooley 1987), using a geographic information system (GIS) to link published sea level rise scenarios, land altitudes and socio-economic variables demonstrated the wider applicability of the approach adopted.

The initial approach has now been expanded to cover the east coast of England and any of the analyses reported for individual estuaries (Shennan 1987a, Shennan and Tooley 1987) can be performed at this national scale.

The advantages of this approach include accessibility of data, application at a range of scales, ease of data manipulation and management and a link between environmental factors and administrative units. However a major disadvantage was that the use of the administrative unit inevitably lead to the over-representation of the area potentially at risk.

The use of digitised contour data provided a partial answer to this problem although the resolution of this data is currently limited to the contours shown on Ordnance Survey 1:25000 and 1:10000 scale maps. A complete solution to the problem of defining areas on the basis of ground altitudes can only be achieved with a significant increase in the resources given to data collection.

Whether this increase is justified must depend on the aim of the aim of the study in question. However all of the data collected and analyses performed should be compatible so that waste of resources is avoided.

This further emphasises the need for national guidelines which can then be integrated with local case studies.

The Tees case study presented in the following sections is a progression from the earlier study which has been integrated into the current work.
3. RISK - THE TEES ESTUARY

3.1. Perception of risk

Perceptions of the risk of tidal and tidally induced flooding of the low-lying land adjoining the Tees estuary obviously vary.

On one hand the National Rivers Authority, which is responsible for the 19km of embankments which protect a number of potentially sensitive areas has recommended a minimum flood defence level of 4.65m.

On the other hand the fact that much of the industrial development in low-lying areas has taken place on land reclaimed from the estuary indicates that a potential for marine flooding risk has not been perceived as limiting factor in location decisions.

A number of current redevelopment schemes make no mention of sea-flood protection (see section 4.8.). This may well be because there is no record of serious marine flooding in the area.

The storm surges of 1953 and 1978 had a very limited affect on the Tees estuary. However it is important to note that the 1993 event occurred before much of the more recent development around Seal Sands commenced.

In order to improve the dissemination of flood warnings from the Storm Tide Warning Service flood hazard maps of the Cleveland coast and the Tees estuary were produced by the Northumbrian Water Authority in 1972.

These maps form part of a series covering the north east coast from Berwick-upon-Tweed to the southern boundary of the county showing areas at risk from tidal and tidally induced flooding.

The areas identified are classified on the basis of ground altitudes, derived from detailed levelling exercises, related to existing water levels.

Four categories of risk cover the range of ground altitudes between 3.10 and 4.20m OD (D. Archer, National Rivers Authority, pers. comm.).

Within the areas identified as being at risk the maps draw attention to susceptible point locations such as factories and low-lying stretches of main roads.

However the utility of the maps is reduced by a number of limitations: failure to take account of intervening defences or increased ground elevations; the need for regular updating to take into account land use changes; preparation of the maps necessitated detailed levelling which was time consuming and therefore expensive; being related to existing water levels no account is taken of potential future levels; the areas shown on the maps indicate only where problems may occur, they need to be linked to information on what will be affected by sea level rise, changes in the ground-water table or associated flooding.

Any examination of the potential impacts of sea level rise on the county of Cleveland must consider the perception of risk in relation to the prevailing economic climate of the area and the wider region.

Against a background of the massive job losses from the manufacturing sector, industrial developments over the past 30 years in what now appear to be risk areas can be justified.

Furthermore, from a total population of 554,500 in 1987 the labour force of Cleveland was c. 210,000 while the current (January 1990) unemployment rate stands at 12.8% (data from OPCS and NOMIS).

In the light of the obvious shortfall in employment the imposition of restrictions on the location of new developments based on increased flood risk needs very careful consideration.

3.2. Definition of the environmental hazard

There are four major environmental factors which contribute to, or result from a rise of sea level. Careful evaluation of each factor is necessary.

3.2.1. Crustal environment

From an analysis of 429 sea level index points Shennan (1989a) has estimated that late Holocene crustal deformation in Great Britain is most probably within the range of +2.0 to -2.0mm/yr.

Against a national pattern of maximum uplift in central-western Scotland and maximum subsidence in East Anglia and the Thames estuary, the Tees estuary, from a limited data base, shows a rate close to zero.

This would suggest that no correction of the global figure for any particular sea level rise scenario is required due to local crustal factors.

3.2.2. Wave environment

The Cleveland coast is exposed to wind generated storm waves, particularly from the north.

The effects of future sea level rise will be felt along the coast and within the estuary through a combination of a deterioration of the wave climate and an increase in the height of the wave base.

These changes imply an increase in the damage to coast protection works during storms.

3.2.3. Tidal environment

The Tees estuary, with a current mean spring tide range of 4.60m and extreme predicted range of 7.24m, is macro-tidal.

In addition there is an increase of 0.20m of mean high water of spring tides upstream within the tidal part of the estuary.

The Cleveland coast is also prone to the effects of storm surges. The orientation of the mouth of the Tees estuary is such that the elevation of surges may be amplified (Rossiter 1954).

Even without a predicted change in the climate as a consequence of the greenhouse effect the return
periods for any storm induced peak water levels will
decrease as a result of sea level rise (see Rossiter
1962 and section 3.3. below).
High water levels will also be affected by freshwater
discharge from the Tees catchment.
The discharge, and hence the level of the Tees is also
subject to very rapid variations due to periods of
intense rainfall in the upland catchment (House and
Pullerton 1960) although some regulation is now
provided by reservoir storage.
The combination of tidal and discharge variations
means that prediction of a rise in mean sea level of
perhaps less than 1m in 100 years could be perceived
mistakenly by some as insignificant. However it is
the potential increase in absolute water levels that is
important (see section 3.3. below).

3.2.4. Sedimentary environment
Although variations in sea level represent a
significant control on the development of a coastline,
other factors including changes in the pattern of
sedimentation and erosion are important.
Changes in sedimentation can vary widely temporally
and spatially.
Their identification and quantification demands
extensive long-term investigations before any
attempts at predicting future patterns can be made.
In the case of the Cleveland coast the pattern of
sediment movement is only known in general terms.
Hydraulics Research (1986) has shown that there is
a major longshore drift component from the north.
Clastic material for the beaches and dunes at North
Sands, Hartlepool Bay and the North and South
Gares (the two artificial breakwaters at the mouth of
the Tees) is derived in part from the magnesian
limestone cliffs of County Durham.
At the present time the dumping of colliery waste
along this section of the coast provides a significant
additional contribution. Some local variation in
sediment movement is also apparent.
There is a smaller, localised, northwest drift from
Coatham Sands to Teesmouth in the lee of the South
Gare.
Even within the major zone of sand deposition of
Tees Bay there are localised areas of erosion of
current sea defences, e.g. north of the Headland at
Hartlepool and at Seaton Carew.
Under these conditions where there is a significant
longshore component, two-dimensional models of
coastline response to sea level rise, such as the
Braun Rule, may provide poor results (see Orford
1987 and Braun 1988).
The relative importance of the longshore component
will also vary according to the rate of sea level
change.
The present sedimentary environment must
obviously be viewed with respect to the present
coastal configuration and known sediment sources.
However a temporal framework for coastline change
can be obtained from a study of coastal geomorphology
and sedimentary sequences.
A relationship can then be established between
palaeogeography, the rate of sea level change and
the magnitude of past coastal changes (Shennan
The response of coastal sedimentary systems to
varying rates of sea level change are likely to be non-
linear (Orford 1987) and characterised by time lags
(e.g. Allen 1990).
Within the Tees estuary, marine sediments,
teracalated with terrestrial deposits have
accumulated since c. 9700 BP (Shennan 1983, Tooley
unpublished data).
The sedimentary record for this area reveals a number
of periods of coastline advance and retreat (Sproston
1986).
In contrast, Hartlepool Bay has changed from an
area of low energy clastic and organic sediment
accumulation around 6000 BP (Tooley 1978 and
unpublished data) to the present high energy eroding
sandy coast.
This has resulted from the combined effect of changes
in sea level and coastal geomorphology.
It is therefore important to identify the conditions
under which both gradual and catastrophic changes
can take place even if the precise method of modelling
them is not available.
The results of such detailed investigations can then
be integrated into impact assessments.
The wave, tidal and sedimentary environments of
the Cleveland coast will inevitably be affected to
some degree by future sea level rise.
Rainfall patterns, and consequently river discharge
rates and drainage requirements may also be modified
as a result of climatic change.
Direct human intervention through reclamation,
dredging and hydrological management, will also be
important.
The uncertainties of the proportional effects of each
of these may well be as large as those for sea level
change.

3.3 Risk definition
Having identified the nature of an environmental
hazard some assessment should be made of the
extent and degree of risk involved. There are a
number of ways of doing this.
A frequently adopted response in this context is the
calculation of return periods of extreme water levels
as a means of setting flood defence standards for the
design of coastal engineering structures.
An additional allowance for wave height and
freboard may be added. The return periods for peak
still-water levels within the Tees estuary have been
calculated using data supplied by the National Rivers
Authority (Table 1).
The recommended minimum defence standard for
Thus the upper lines represent the change in altitude of the extreme combination of a coincidence of a large storm surge at maximum predicted water level. The probability of this occurring is very small but the realistic definition of areas at risk should be based upon a range of possibilities rather than a particular figure. For the initial phase of the analysis of areas at risk and the potential impacts, the 5m OD level has been used, for a number of reasons. Firstly it is a good estimate for various levels of risk by 2050, within a reasonable margin of error. Secondly it is a very practical option, since Ordnance Survey maps show contours at 5m intervals.

The definition of areas potentially at risk is obviously desirable at a higher resolution, unfortunately however, this level of information is not currently available for the UK except for a few small areas. The only alternatives at present are detailed levelling or interpolation of ground altitudes (within urban areas only) from Ordnance Survey digital data (this is part of a CEC sponsored research project at Durham University).

Table 1. Return periods for the Tees and Middlesbrough docks within the Tees estuary. The frequencies were calculated using incomplete records from Tees Dock for the period 1931-1963, and estimates for Middlesbrough Dock were then made. Data and calculations by National Rivers Authority for 1:10 and 1:100yr at Tees Dock. A linear extrapolation used for the other figures must be treated with caution.

<table>
<thead>
<tr>
<th>Return period</th>
<th>Tees Dock metres OD</th>
<th>Middlesbrough Dock metres OD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:10yr</td>
<td>c. 3.65</td>
<td>c. 3.82</td>
</tr>
<tr>
<td>1:100yr</td>
<td>c. 4.00</td>
<td>c. 4.25</td>
</tr>
<tr>
<td>1:1000yr</td>
<td>c. 4.35</td>
<td>c. 4.88</td>
</tr>
<tr>
<td>1:10000yr</td>
<td>c. 4.70</td>
<td>c. 5.11</td>
</tr>
</tbody>
</table>

embankments and frontages within the estuary (4.65m OD) is within the envelope of the 1:1000 to 1:10000 year return period at Tees Dock. It is also in accord with the standards employed elsewhere, including the Netherlands (Knoester 1984). A rise of sea level of 0.32m by 2050, a value within the range of recent moderate estimates (Wigley 1989, Oerlemans 1989 for example), would reduce the return period at any level by a factor of approximately 10.

It is also important to define the areas at risk. This involves a consideration of both a much larger area than the immediate coastal frontage and the range of impacts of sea level rise noted earlier. Within the Tees estuary and along the adjacent open coast the more important factors will be:
1) the increased frequency of storm surge events and tidally induced flooding;
2) slow inundation and elevation of the groundwater table;
3) changes in the rates of coastal erosion and coastal processes.

The definition of the area of the low-lying land adjacent to the estuary at risk relies upon the estimation of the potential maximum elevation of water levels above existing ground levels. In this study the low and mid-range low scenarios of Hoffman (1984), which provide an envelope for a range of recent predictions, are used to calculate the maximum values.

Each graph (Fig. 2a and 2b), shows four parallel lines, each an altitudinal threshold for establishing the areas at risk. The lines represent projections of the altitudes of:
1) Current Highest Astronomical Tides (HAT)(3.25m OD);
2) the Highest Recorded Water Level (4.11m OD);
3) Mean High Water Spring Tides (2.65m OD) plus 1.50m, where 1.50m is the computed surge with a 50 year return period (Flather 1987);
4) HAT plus 2.15m, the surge component during the 1953 event (calculated from Rossiter 1954).

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Fig. 2. a) the low scenario of Hoffman (1984) adapted to local tidal conditions in the Tees estuary to show the rise of various levels of risk (see text), related to ground altitudes (m OD), to 2100
b) the mid-range low scenario of Hoffman (1984) adapted as in 4a
There are both perceptual and practical difficulties involved in the choice of a critical level for determining the areas potentially at risk from the effects of sea level rise. The 5m level used for the Cleveland area is not a universal figure for the United Kingdom because of the variation in the altitude at which Highest Astronomical Tides intersect the coastline. Nationally the altitude of the HAT varies from +1.3m OD at Lowestoft to +8.1m OD at Avonmouth (Admiralty Tide Tables 1989). Along the east coast of England the maximum level, +4.7m OD, is recorded at London Bridge. It is also important to consider the variation in absolute and relative observed sea level maxima. During the 1953 storm surge the maximum disturbance of the sea surface was 2.74m at Immingham (Rossiter 1954), whilst the maximum elevation of the sea surface reached 5.6m OD at Kings Lynn. In some areas along the southern part of the east coast the coincidence of storm surges in 1978 and 1976 with high tides resulted in the levels attained during the 1953 event being exceeded. The peak tidal levels for the Wash and the Thames during the January 1978 event were 6.3m OD and 5.6m OD respectively (data from National Rivers Authority).

The identification of areas at risk is further complicated by the potential for misinterpretation if selectively reported, as revealed by the recent use of the ARK map and report (ARK 1989) by national newspapers. It is the responsibility of scientists to be cautious in their use of such information and to avoid being alarmist, or avoid being interpreted as alarmist. The inaccurate use of publications and an uncritical selection and extrapolation of single extreme figures, when a range had been stated, within scientific literature (e.g. Boorman et al 1989) is misleading and could devalue the work of other scientists contributing to sea level research.

4. IMPACT AND POSSIBLE RESPONSES

4.1. Coastal erosion and deposition

In the absence of long term-quantitative records of sediment movements onto and along the Cleveland coast, the prediction of future patterns may have to be based on an extrapolation of recent trends, despite the fact that these are influenced by human activities. For example, the existing sediment balance may already be out of equilibrium due to the reduction in the dumping of colliery spoil on the Durham coast. This has had a visible effect on local bays and headlands there but it is not known whether any effect has been transmitted south to Tees Bay. The natural transfer of sediment along the coast will also have been disrupted by the dredging required to maintain a navigable channel at Teesmouth. Contemporary changes in local sediment budget are demonstrated by the undercutting of sea walls, at Hartlepool Headland, Seaton Carew and Redcar, and erosion of sand dunes north of Hartlepool. One further area where any increase in erosion will have major effects is at the mouth of the Tees, where sand dunes have developed as a response to the building of the breakwaters. The stability of these areas of dunes is currently partly dependent upon the blast furnace slag blocks which form the breakwaters. These blocks combine with the sand dunes to create an effective sea defence. If these blocks became exposed as the dunes are eroded they would be vulnerable to wave impact. In this state it is unlikely that they would provide adequate protection for the areas around Teesmouth. Any decrease in the ability of the sand dunes to prevent inundation would have serious consequences for man-made structures in their lee. One obvious cause for concern in this respect is Hartlepool nuclear power station.

Prediction of the actual response of the coast to a future rise of sea level must however take account of the potential for an increase in the volume of sediment released by erosion of the cliffs to the north. The southerly movement of this material may in part compensate for sediment transferred offshore from the beaches around the Tees. Various methods of prediction are required, such as those reviewed by Orford (1987) and Leatherman (1984), before any further statements can be made.

4.2. Loss of wetlands and other habitats

At Teesmouth there are four designated Sites of Special Scientific Interest (Fig. 3) which meet the criteria both for designation under the terms of E.C. Directive 79/409/EEC on the conservation of wild birds and for inclusion on the list of Wetlands of International Importance under the Ramsar Convention. The sites, which total 1100 hectares, include sand dune, intertidal flat and salt marsh habitats which support a diverse flora and fauna in addition to large colonies of breeding and migrating birds (Ratcliffe 1977). These areas, which are of international significance, are small remnants of the once extensive intertidal estuarine mud and sand flats. The embankments and installations which now delimit these areas mean that they are particularly vulnerable to disturbance in the event of sea level rise because of lack of any potential for migration landwards and upwards as water levels rise (Sproston 1989).

If the habitats are to be preserved the cost of tidal management schemes, as part of a broader sea defence programme, must be assessed against the non-monetary benefits.
4.3. Urban residential areas at risk

The main residential areas in Cleveland are situated on land above 5m OD (Fig. 4). However, in two major areas (total 1.2km²), approximately 600 houses, the majority of which are in local authority ownership, are below the 5m contour and within the high risk category areas defined by the water authority in 1973. If the 5m contour were to be formally adopted as the basis for a policy decision defining areas at risk and imposing land use restrictions, there could be far reaching consequences for property insurance rates and local authority housing policy. The potential impact on resale values for those houses in private ownership could lead to a blight on the areas involved and contribute to social factors such as stress. These consequences, and the possible legal implications need to be carefully considered before any precise designations are made. The benefits of the GIS approach to an assessment of the impact of sea level rise are particularly applicable to urban areas. Ordnance Survey digital map data, integrated with census data, can be used as a base to attribute information to individual residential properties, such as type, average number of occupants, flood damage information (e.g. Penning-Rossell and Chatterton 1977, Suleman et al 1988). These data can then form the basis of subsequent socio-economic and cost-benefit analysis. An additional benefit of using GIS techniques is that land-use changes can be easily incorporated at the planning stage whereas areas delineated on large-scale paper maps all too quickly become out of date.

4.4. Industrial areas at risk

The area around the Tees estuary identified as being at risk (Fig. 5) includes at least 10 major industrial complexes. The impact of future sea level rise on these complexes needs to be considered in terms of the potential for damage to plant and equipment, raw materials and finished products as well as possible disruption of production. The economic implications for the county and the region can be illustrated with reference to one plant.
in part on land at 3m OD, which is already dependent on sea defence embankments.
The annual production of the plant, which has a workforce of 600, is £75 million and the capital value of the installations is estimated at £100 million.
Given the scale of investment and value of production represented by just one site the economic impacts of sea level rise could be considerable and will be an important input into any cost-benefit analysis.
The nature of the activities carried out around the estuary suggests that the additional potential risk of release of toxic substances during a flood event is one that should not be treated lightly.
Any future assessment of the relative merits of investment in sea defences or alternative policy responses will necessitate the collation of all the relevant economic variables for the industrial activities in the flood risk areas.
Work on this aspect of the impacts of sea level rise is at a preliminary stage.

4.5. Transport networks

The method of reclaiming the intertidal areas in the Tees estuary during the last 40 years has had the effect of elevating the ground surface of these areas above 5m. However the road network serving the industrial complexes located within these areas includes significant sections which cross the peripheral low-lying ground (Fig. 6).
These sections may be subject to inundation or the effects of a rise in the groundwater table on the structure or drainage of the carriage-way.
Any flooding of these parts of road network, which includes two 'A Class' roads, would curtail access to

and egress from the industrial complexes, and hinder emergency services in the event of a major incident triggered by high water levels.

4.6. Landfills and waste disposal sites

For this category the 10m, rather than the 5m, contour is used to define the area at risk (Fig. 7) since the altitude of the base of each landfill is not known.
In an area with an established concentration of iron and steel production and chemical industries it is inevitable that large quantities of waste should be generated and disposed of.
As a consequence there are at least 30 landfill and waste disposal sites within the area at risk.
Changes in groundwater pressure and movement within or around the landfill sites due to sea level rise will be important because of the potential for the reactivation and mobilisation of toxins and their transmission to the environment.
The nature of the risk and the sites themselves indicates that a detailed investigation should be made of each active and disused site to determine the potential effects of groundwater changes and direct inundation.

4.7. Agriculture

Despite extensive urban and industrial development adjacent to the Tees estuary agricultural activity persists north of the river.
At Saltomole, just over 1000 hectares are given over to arable cultivation and grazing, with c. 600ha below 5m OD. The land is valued at c. £5000 per
hectare and annual production is currently c. £500 per hectare.
In addition to the threat of a short-term flood, resulting in the loss of stock or crops, this area could suffer permanent reduction of the agricultural capacity following the transfer of pollutants from the Tees or landfill sites during flooding.
An economic and ecological assessment of the area must include consideration of the consequences of changes in the level of local groundwater on the choice of agriculture practised and the costs and benefits of artificial drainage and sea defence investments.

4.8. New developments

Within Cleveland there are currently three major new projects, at different stages of development, on land which is in part below 5m OD.
At Hartlepool, a marina complex, with a capital value estimate at £150 million, which will include 150 housing units, is in the early stages of development as part of an urban regeneration scheme based on the now derelict dock area.
Work has recently started on an £80 million retail and recreation complex at the site of Stockton racecourse, where ground altitudes of less than 3m OD are recorded.
The river embankments which form part of the boundary of this site are being improved, but details of defence altitudes and land drainage specifications are not known at present.
Further up-river at Thornaby advance works for the development of a riverside park consisting of industrial, retail, office and housing units (total investment around £220 million), are now well under way. A major feature of this project, a proposal to build a weir across the Tees, is delayed at present due to the failure of the associated Private Member's Bill in the last Parliamentary session of 1989.
The proposed structure will include moveable gates with the aim of impounding water upstream so that the proposed structure will include moveable gates with the aim of impounding water upstream so that intertidal sediments would not be exposed in the river channel, thereby improving the quality of the riverside environment.
The impounding level is the current mean high water level (2.65m OD) and the maximum level of the proposed weir is 4.5m OD. The only flood control role anticipated for the structure would be to lower the level of the weir during periods of high river discharge.
As presently envisaged, the role of the proposed barrage does not include a marine flooding protection function other than to prevent the transfer of polluted saline waters into the impounded water body. If this aspect was to be added to the specification some redesign would apparently be required, if only to reach the current minimum defence level (4.65m OD) recommended by the National Rivers Authority. A higher defence level will obviously be required if future sea level rise is to be taken into account.

5. CONCLUSIONS

Within a confined area the Cleveland coast and Tees Estuary provide examples of a wide range of possible impacts of future sea level rise that could be used as the basis for national scale planning.
At present the areas that may be affected and the types of risk can only be generally defined.
The information required for a more precise definition is not in the correct form for systematic assimilation and analysis. In addition there are significant gaps in the environmental and economic data base, such as detailed topographic information, current rates of sediment transfer, property and capital values, and recurrent commercial and industrial costs.
These are all required if the environmental and economic impacts of sea level rise are to be evaluated with cost-benefit analysis as a means of providing a context for national and local policy decisions.
The aim of this case study is to expound a method by which these investigations can be carried out repetitively, either for the same area at different times as economic and environmental baseline conditions change, or for different areas, and on different scales.
The present study is not intended to be a one-off exercise nor is it yet complete. Unavoidable delays accessing and transferring disparate data to digital form have been compounded by significant gaps in the data base. The lack of an accessible systematically collected database is an important limitation to any impact assessment.
However the GIS techniques used to generate a set of land-use risk maps have the flexibility to incorporate material as and when it becomes available.
The capacity to create a framework for the integration of spatially referenced attribute data has obvious benefits in the context of sea level rise and its impacts.
Furthermore, economic modelling is facilitated using the database functions and spreadsheet packages integrated within the system.
The next stage, currently in progress, is to develop the research using the digital data held by Cleveland County Council, thus providing a method of impact evaluation that can contribute directly to established decision-making structures.
The GIS approach advocated here has obvious potential in aiding an assessment of the nature and scale of the impacts of sea level rise through the combination of disparate geographically referenced data. The approach is also applicable at a range of integrated scales.
However, the problems of data quality, availability, existence or incompatibility, especially for physical processes, can be a significant limitation. As data requirements are defined and collection policies are formulated, the potential for the prediction of impacts will improve. The flexibility of the approach adopted here will ensure an efficient re-evaluation of environmental and economic scenarios as the parameters are changed in light of new information.

In order to capitalise on this flexibility there is an urgent need for a nationally agreed framework and objectives for the investigation of the impacts of sea level rise on areas such as the Cleveland coast and Tees estuary. This would facilitate the decision-making process at a national and local level despite uncertainty over the magnitude and timing of any rise. At the same time a coordinated response within a nationally accepted framework would ensure adequate information was readily available, thus maximising the potential benefits from the application of geographic information systems to the range of problems resulting from the rise of sea level in coming decades.

6. ACKNOWLEDGEMENTS

Numerous people at the Northumbria Division of the National Rivers Authority (as successor to the Northumbrian Water Authority) and Cleveland County Council have provided valuable information, but the views expressed here are those of the authors and reflect no endorsement by the NRA or CCC. Michael Tooley made many valuable comments on a draft of the paper. The research was supported by the Commission of the European Community (contract EVAC 0049 to I. Shennan and M. J. Tooley) and the University of Durham (Research Leave granted to Shennan).

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GLOBAL WARMING:
IMPLICATIONS FOR THE THAMES BARRIER
AND ASSOCIATED DEFENCES

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Many important economic and social decisions are being made
today on long-term projects - major water resource management
activities such as irrigation and hydro-power, drought relief,
agricultural land use, structural designs and coastal engineering
projects, and energy planning - all based on the assumption that
past climate data, without modification, are a reliable guide to the
future. This is no longer a good assumption since the increasing
concentrations of greenhouse gases are expected to cause a
significant warming of the global climate in the next century.
It is a matter of urgency to refine estimates of future climatic
conditions to improve these decisions.
(Statement by the UNEP/WMO/ICSU International Conference,
The Assessment of the Role of Carbon Dioxide and of other
Greenhouse Gases in Climate Variations and Associated Impacts,
Villach, Austria, October 1985).

Abstract

This paper considers the implications of global warming for the
Thames Barrier and associated flood defences along the Thames
Estuary. While allowing for the continuation of past trends in
high water level, the design level of the Barrier incorporates no
provision for any acceleration in this trend due to global warming.
On the basis of projections of the future rise in global-mean sea
level induced by global warming, the date by which the allowance
made for sea level rise in designing the Barrier may be exceeded
in determined and the consequent increase in the probability
of overtopping is assessed.
The timescale of global warming is such that, even in the worst
case, sufficient time should be available to permit modification
of the Barrier, although improving other defences along the Estuary
may prove a difficult task.

1. INTRODUCTION

The Thames Barrier and related flood protection
measures afford protection to the one million
inhabitants of London previously at risk from flooding
due to the combination of high tide and storm surge.
While catering for a continuation of the "ominous
rise of the highest flood levels over the last 150-170
years"", the design level of the Barrier does not take
into account the possibility of any acceleration in the
rate of sea level rise due to global warming.
This is, of course, understandable given the
information available at the time the Barrier was
designed.
On the basis of three projections of the likely rate of
sea level rise, the date at which the allowance made
for past trends in high water level may be surpassed
is assessed.
Once this point is reached, there will be no immediate
danger of flooding, but the probability that a surge
tide will occur that the Barrier and associated
defences cannot contain, will increase.
The further rise in high water level required to
increase this probability to an unacceptable level is
determined. Finally, the existence of an additional
margin of safety which may delay the date at which
modification of the Barrier is considered necessary is
discussed.
Inevitably, there are many uncertainties in an
analysis of this nature and a number of critical
assumptions have to be made. These are carefully
documented.

KEY WORDS

London Protection Measures - Flood Defences
Global Warming and Sea Level Rise - Past and Future
Trends
Design Criteria of the Thames Barrier
Future Trends in High Water Level
Flooding in London - Margin of Safety?
UNEP - WMO - ICSU Statement
2. GLOBAL WARMING AND SEA LEVEL RISE

Predicting the rate at which global-mean sea level may rise as global warming progresses is not an easy matter. The societal trends which will determine greenhouse gas emissions are uncertain and there are many scientific aspects of the problem still to be resolved. Any assessment of future impacts has to be based on a range of possibilities, or scenarios, spanning all plausible outcomes.

Current understanding of the likely course of global temperature over the period to 2050 is summarised in Fig. 1.

The upper limit - which represents warming of 2.5°C above the level of the 1980s by the year 2030 - is based on the twin assumptions of rapid growth in greenhouse gas emissions and high climate sensitivity. (The climate sensitivity is a measure of the degree to which a particular change in the greenhouse gas content of the atmosphere will affect global temperature).

The lower limit - further warming of 0.5°C - corresponds to low emissions and low climate sensitivity. The “best estimate” suggests further warming of around 1.5°C by the year 2030, some six times the rate of warming experienced over the past 100 years. This projection assumes moderate climate sensitivity and that current emission trends continue with no concerted effort to reduce them, except in the case of the chlorofluorocarbons.

Estimates of the corresponding rise in global-mean sea level are shown in Fig. 2. The upper limit represents a rise in global-mean sea level of about 0.4m by the year 2030, many times the rate experienced during the 20th century.

Global-mean sea level has risen between 0.1 and 0.2m since 1900. The lower limit represents a rise of 0.05m over the same period, similar to the trend experienced since 1900. In this case, the effect of global warming is partly mitigated by increased snowfall over Antarctica. The best estimate suggests a rise in global-mean sea level of around 0.2m by the year 2030, four times the recent rate. Locally, the change in sea level will depend on factors such as the rate of erosion and deposition and geological processes such as settlement or uplift. In the case of the Thames Estuary, the region is thought to be sinking at a rate of around 0.2m a century.

Any rise in global-mean sea level induced by climatic change will be superimposed on existing trends. When considering the effect on tidal characteristics such as high water level, the dynamics of tides and surges in shallow water and the effects of topography have also to be considered.

3. DESIGN CRITERIA OF THE THAMES BARRIER

Before assessing how the rise in sea level induced by global warming might affect the risk of London flooding, it is necessary to examine the original design criteria for the Thames Barrier.

It is clear from the series of reports issued during the planning phase that the design level was based on a blend of empirical estimation, theoretical justification and pragmatism.

As far as the theoretical justification is concerned, the design level of the Barrier and all other flood protection measures in the vicinity was based on three main considerations:

1) containment of the estimated 1,000-year return period flood at Southend;
2) two, an allowance of 1.0m as a margin of safety.
The most plausible explanation is that it is the result of the particular characteristics of the estuary and the effects of human disturbance. In the following analysis, a range of assumptions is made about the future relationship between high water level and mean sea level rise. It is not inevitable that it will be the same as in the past.

It was awareness of the trend in high water level, coupled with the surge of 1953, that led to the raising of the Statutory Defence Level in 1972 (cf. Fig. 3) and the concern that resulted in the building of the Thames Barrier. During the period to 2030, the continuation of the past trend could raise the high water level by up to 0.4m. This was allowed for in the design level of the Barrier by adding 0.4m to the height of the 1,000-year return period flood estimated from historic data so that it reflected the situation that could pertain in the year 2030.

### 4. THE IMPLICATIONS OF GLOBAL WARMING

#### 4.1. Key assumptions

Given the uncertainties involved in assessing the implications of global warming for the Thames Barrier, it is impossible to provide a definite forecast. Instead, a range of plausible scenarios is presented. Each scenario is based on different assumptions.

For comparison with the projections made by the planners of the Thames Barrier, the period over which potential trends are assessed begins in 1980. A continuation of the past rate of change in global-mean sea level is assumed over the period 1980-1984 (0.01m over the five years) and the projections for the period 1985-2030 follow those given in Fig. 2.

For the sake of simplicity, it is assumed that the change in global-mean sea level will be linear in time. The three scenarios that are considered are:

- **Worst case**: this is based on the assumption that the rise in global mean sea level will follow the course defined by the upper limit in Fig. 2 (a 0.42m rise between 1980 and 2030) and that the trend in high water level will be double the trend in local mean sea level, as appears to have occurred in the past.
- **Most likely case**: this is based on the best estimate from Fig. 2 (a net rise of 0.23m by the year 2030).
- **Best case**: this is based on the assumption that the rise in global mean sea level will follow the lower limit projection in Fig. 2 (a net rise of 0.06m by the year 2030) and that the trend in high water level will be half the trend in local mean sea level.

It is assumed that about half the past rise in mean
sea level on the Thames Estuary, approaching 0.4m a century, was caused by the coincident rise in global-mean sea level of around 0.2m a century, that the remainder was due to geologic and other factors, and that this latter component of the trend will continue at the same rate.

This represents a rise in local mean sea level of 0.1m over the period 1980 to 2030.

While corresponding to the assumptions made by the designers of the Thames Barrier, this estimate of future subsidence in the area of the Thames Estuary may be on the high side and the rate of change is likely to be variable.

4.2. Future trends in high water level

Fig. 4 presents alternate estimates of the course of future high water level on the Thames Estuary. The assumption implicit in the design level of the Thames Barrier is indicated by the trend-line labelled “Past trends” - a rise in high water level of 0.4m by the year 2030.

The trend labelled “Best case” corresponds to the lower estimate of global-mean sea level rise given in Figure 2. The net rise in high water level in this case is 0.13m by the year 2030, composed of 0.1m due to geological and other factors and a further 0.03m rise in high water level due to global warming (half the rise in global-mean sea level; see Table 1).

In this case, the total trend is less than that allowed for in the design of the Thames Barrier and the sea level rise associated with global warming poses no problem during the period of the projection.

The trend-line labelled “Worst case” corresponds to the upper bound of the range of projections given in Fig. 2. This represents a net rise in high water level of 1.04m by the year 2030, composed of 0.2m due to geological and other factors and a 0.84m rise due to global warming (twice the rise in global-mean sea level).

Finally, the two “Most likely” trend-lines result in a net rise in high water level of 0.22 to 0.66m by the year 2030. The global warming contribution in this case is 0.12 (“low”) to 0.46m (“high”), depending on the assumption made concerning the relationship between the trends in mean sea level and high water level.

It is clear that there is a significant chance that the allowance incorporated into the design level of the Thames Barrier to take account of past trends in high water level (indicated by the horizontal line marked “Design criterion” in Fig. 4) could be surpassed during the early decades of the 21st century. Assuming that the area enclosed by the “Most likely” trend-lines defines the most probable course of events, this point could be reached as early as the decade of the 2010s.

In the “Worst case” scenario, this point would be reached shortly after the turn of the century.

Given the many uncertainties, it would be unwise to place too much emphasis on a particular date.

It is, however, fair to conclude that, on the balance of probabilities, the element of the design level of the Thames Barrier intended to cater for sea level rise could be surpassed during the early decades of the 21st century.

Flooding will not then be an immediate prospect but the probability that a surge tide will occur that the Barrier and associated defences cannot contain will

![Graph showing future trends in high water level on the Thames Estuary.](image)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Rise in GMSL</th>
<th>Effect on HWL</th>
<th>Rise due to other factors</th>
<th>Net rise</th>
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</tr>
<tr>
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<td>0.20</td>
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<tr>
<td>Worst case</td>
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<td>0.84</td>
<td>0.20</td>
<td>1.04</td>
</tr>
</tbody>
</table>

Table 1. Estimation of the potential rise in high water level to the year 2030 (metres). See text for explanation. All estimates are rounded to two decimal places.

Key: GMSL = global-mean sea level; HWL = high water level; other factors = geological processes and human disturbance.
become progressively greater and the Barrier may have to be closed more frequently.

4.3. The probability of flooding

Fig. 5 shows how the probability that high water will rise above a particular height would be affected by trends in high water level. It is based on the analysis of return periods for Southend used in determining the design level of the Thames Barrier. The probability that high water greater than a particular level will be experienced in any one year is the inverse of the return period. For example, there is a 0.001 probability (a 1 in 1,000 chance) that high water will exceed the level represented by the 1,000-year return period in a particular year. The line labelled "Design criterion" in Fig. 5 is the flood height/return period relationship for the year 2030 used in determining the design.

![Graph showing flood height/return period relationship](image)

Fig. 5. The effect of trends in high water level on the return period associated with high water greater than a particular height. To estimate the new return period given a particular rise in high water level above the design allowance, select the appropriate point on the line labelled "Design criterion", move horizontally across to the line corresponding to the additional rise in high water level and then down vertically to determine the new return period. The horizontal and vertical lines on the diagram correspond to the examples discussed in the text.

The level of the Thames Barrier. The Barrier was expected to contain the 1,000-year event, a surge reaching a height of just over 5.5m at Southend. If the trend in high water level induced by global warming results in a rise of 0.2m above that catered for in the design level, as occurs in the "Most likely (high)" projection by 2030 or so and in the "Worst case" projection as early as 2010 (see Fig. 4), what was considered the 1,000 year event will then have a return period of around 500 years (Fig. 5). The probability of occurrence will double. If the trend in high water level exceeds the design assumption by 0.6m, as occurs in the "Worst case" projection by 2030, what was considered the 1,000-year event will then have a return period of around 100 years, a tenfold increase in the probability of occurrence in a particular year.

This is close to the original probability of occurrence of the 1953 flood, deemed an unacceptable level of risk and justifying the construction of the Thames Barrier. This point would be reached by 2060 in the "Most likely (high)" scenario.

4.4. An additional margin of safety?

As noted above, the design level of the Thames Barrier incorporates an element of 1.5m intended to allow for amplification of the surge as it passes up the estuary from Southend (due to the funnelling effect of the estuary, local winds and river discharge) and wind and wave freeboard (taken as 0.3m). Horner has observed that this safety margin may have been over-estimated by as much as 0.7m and that the Barrier could tolerate a rise in high water level greater than that considered above.

If so, this would delay the dates given above by some decades. Whether or not this is the case is a moot point. For example, a differential of 1.2m between Southend and London Bridge was observed on December 31st 1978.

Adding 0.3m to allow for wind and wave freeboard suggests that the original safety margin of 1.5m was a reasonable estimate.

It should be stressed, though, that the effectiveness of the Barrier is not totally compromised even if the gates are overtopped. Overtopping of up to 0.5m for a limited duration would not result in large-scale flooding. There is a large reservoir capacity behind the Barrier. This does not, of course, apply downstream of the Barrier where the level of protection is similar to that afforded by the Barrier but overtopping of the defences along the banks could present a serious problem, compounded by the damming effect of the Barrier.

5. CONCLUSIONS

This analysis has demonstrated that the acceleration of sea level rise due to global warming might surpass the allowance made for trends in high water level in the design of the Thames Barrier and other flood defences along the Thames Barrier during the early decades of the 21st century. This does not mean that catastrophic flooding will then be an immediate prospect. While the probability that the defences will be overtopped will increase from that point on and the Barrier may have to be closed more frequently, it will be a further twenty or thirty years before the risk of flooding reaches an unacceptable level (as defined by the 1953 flood...
which resulted in the Barrier being built). Even then, the Barrier will continue to afford some degree of protection to areas upstream. There should be sufficient time to modify the Barrier and associated defences. Nevertheless, the results of this preliminary study do have a number of implications of immediate concern.

First, there is a need for further research. Inevitably, there are many uncertainties in an analysis of this type. Some could be appreciably reduced with relatively little effort, providing a firmer basis for decision-making and assessment of the risk. In particular, there is a need to improve understanding of the critical relationship between global-mean sea level change and the response of high water levels in the Thames Estuary.

Other aspects of global warming that may affect the effectiveness of the Thames Barrier warrant examination. For example, will the frequency of the particular storms which generate surges decrease or increase? Will the flow of the Thames alter?

Second, the engineering design of the Thames Barrier and the prospects for improving other defences along the Thames Estuary should be reassessed in the light of the increased risk due to global warming. Thames Water recognised the problem and its successor, the National Rivers Authority, is considering its implications. Modification of the Barrier is feasible; indeed, it is considered that an additional one metre of protection could be gained without substantial re-design. The main problem is likely to lie downstream of the Barrier where substantial measures would be needed to improve protection along the banks of the Thames. The foundations of existing defences may not permit substantial heightening.

It is important that detailed analysis of the possibilities for modification is undertaken and that the likely timescale of implementation be determined. It is not inconceivable that critical decisions may have to be made with some urgency as soon as the early 21st century.

Third, the threat to London highlights the need to control emissions of the greenhouse gases - to adopt a preventative approach in emergency planning. With effective control, the rate of global warming and sea level rise could be reduced, leaving valuable time for the redesign and improvement of all flood protection systems.

Finally, the long-term risk posed by global warming highlights an issue of very definite concern in the present-day. There is currently no body with statutory responsibility for emergency planning in the event that London floods.

Given that there is even now a finite possibility that an event will occur that the Barrier cannot contain, this is a matter that should be resolved with some urgency.

6. ACKNOWLEDGEMENTS

Thanks are due to Mike Taylor and Ian Whittle of the National Rivers Authority and to Tom Wigley of the Climatic Research Unit for their invaluable comments on this research. The study was supported by the London Emergency Planning Information Centre.

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Problems and solutions

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Lengidroenergospetzstroj
Leningrad - USSR

Founded by Peter the Great nearly three hundred years ago, this wonderful city owes much to the industriousness and tenacity, as well as the ability and courage of a few men, as Leningrad grew up on the low-lying marshy banks of the River Neva.

Today, this important Russian industrial, scientific and cultural centre is one of the most beautiful cities in the world, and the great monuments of Leningrad belong to all mankind.

Since its early years, the city's low level and proximity to the sea have made for a dangerous city-sea interaction. Leningrad is subject to flooding from the sea practically every year, and irreparable damage is often caused to the historic centre as well as to the cities of Petrodvorec, Lomonosov and Kronstadt.

Complex interconnected meteorological and hydrodynamic processes upset the balance of the water masses of the Baltic Sea and the Gulf of Finland, giving rise to the formation of the so-called "long wave". This increases in size as it passes through the bottleneck the banks comprise, and in this way goes all the way down to the bay and delta of the Neva.

In concurrence with the action of the wind and variations in the currents, the long wave provokes sudden brief rises in the water level in the eastern part of the Gulf of Finland and the Neva delta.

Since 1703 around three hundred floods have been reported in which the water level rose above 1.6m. Calculations show that, even without making allowances for global sea level rise, flooding at Leningrad is possible with a rise in sea level as high as 5.4m, and that would submerge 30% of the city.

Flooding in Leningrad is usually unexpected and of brief duration, and there is a great difference between high and low water levels.

Flood prediction is possible with a reasonable degree of certainty, but only 4-6 hours before the event. Flooding usually lasts somewhere between a few and 24 hours, and is usually accompanied by squalls of up to 30-40m/sec. The rise in water level has exceeded 3 metres on more than one occasion, and one flood in 1824 saw a rise of 4.21m.

A series of engineering works to stop flooding at the mouth of the Neva and in Leningrad has been created. They furrow into the surface of the water at the mouth of the Neva where it meets up with the eastern part of the Gulf of Finland. The works extend from the village of Gorskaja on the northern bank, across the island of Kolnin to the village of Bronka on the southern bank of the Gulf. The project consists of six flood gates, plus two navigable ones, as well as eleven earth dykes (Fig. 1).

During a flood, all the passages open to the passage of water and shipping are closed by means of special devices.

On the Gulf side, rise in water level is due to cyclone effects, whereas on the river side it is due to the inflow of the Neva and, at times, even rain water.
When the defence works are in operation the level can rise as fast as 1m/hr or even more, while it does not exceed 2-3cm/hr at the mouth of the Neva, thanks to the cumulative capacity that is dispersed over a water surface area of 44km² during periods of flooding. In short, the volume of water that builds up with a rise in water level less than 1.6m, is sufficient for several days, and no damage is caused to the city. A lowering of the wave coming from the sea means that the passages can be opened up, and the flow soon returns to normal.

Moreover, 60% of the flow must pass north of the island of Kotlin, that is across the northern reach, whereas 40% crosses the southern reach (further south of the island).

These subdivision criteria are essential also in the process of raising the defence works for maintaining the proportions in use since the work began.

The total length of the works is 25.4km. 2.5 million m³ of reinforced concrete was used, and the volume of the embankments is 40 million m³.

When there is a risk of flooding, the navigable parts are closed by structures with floating gates.

When the device is activated, shipping cannot continue. These works, both to the south and north, in themselves represent access points that allow shipping to pass without having to cross a basin.

The six-lane motorway that runs along the top of the flood gates of the defence works, crosses the navigable access points in the north by way of a bridge over the top, and in the south by way of a tunnel excavated under the navigable channel.

The flood gates form a multi-span bridge that is...
Fig. 5. Cross-section of the dam of the flood defense works (planning solution)

Fig. 6. Flood gate

ВОДОПРОПУСКНОЕ СООРУЖЕНИЕ

ВЕС ЗАТВОРА
С БАЛЛАСТОМ - 30

УСИЛИЕ ГИДРОЦИЛИНДРА
РАБОЧЕЕ - 15
МАКСИМАЛЬНОЕ - 25

1 - ТЕХНОЛОГИЧЕСКИЕ ГАЛЕРЕИ
2 - РЕМОНТНЫЕ ЗАТВОРЫ
Fig. 7. Construction of vertical drainage channels on dam D2 (1988)

Fig. 8. Complex B2 (1988)

Fig. 9. Plan of the shipping channel with the floating flood gates

Fig. 10. Masses of ice on the dam
closed when flooding is imminent by way of modular locks.
Each closable span section has a 24m coverage. There are sixty four spans in all. The earth dykes that connect the flood gates and the navigable works consist of a dyke with a levelled out profile, on the top of which runs the six-lane motorway.
The central body of the dyke consists of clayey soils of morainic origin and sand.
The upper part of the banks is reinforced with stone and there are pedestrian zones in sandy gravel. Above the water level up to 8m on the Gulf of Finland side, reinforced concrete wave buffering is under construction.
There is a monolithic slab of reinforced concrete along the banks up to the pedestrian zone, while above it there is a 1.5m high protective parapet in reinforced concrete like a breakwater.
To date, six of the project's planned flood gates have been constructed and are in operation.
Work on the most important part of the whole project - flood gate n.1 - is well under way, and work is proceeding fast and furiously on navigable flood gate n.2 to the north.
At present only 900m of the defence works are still to be finished, and shipping is continuing there until the shipping lane is transferred to cross the navigable mouths which are under construction.
Many engineering and organisational innovations have been involved in the construction of the defence works.
These include the innovation of pouring clayey soils of morainic origin into the water to a depth of 5m all year round, for the first time in open water surface conditions.
Underwater technical work has been successfully carried out using a floating mechanised complex with a large floating excavator from the Austrian firm "Osvag".
Deep drainage under the earth dykes of the southern stretch of the complex involved great responsibility. This is being successfully executed thanks to a high-yield drainage plant that was specially prepared by the Italian firm "Trevi-Solipex".
In order to speed up construction and improve the level of industrialisation, two flood gates n.4 and n.2 (numbering starts from the south) were constructed with the use of two large floating blocks 130m in length, 53m in breadth and 14m in height, and weighing as much as 30,000 tons. They also supported the locks that were, for the most part, dismantled.
The scientific research, project design and construction experience and expertise from the Leningrad flood defence works constitutes a valuable contribution to the development of world hydraulic techniques.
US CITIES SUBJECT TO SEA LEVEL RISE

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The University of Maryland
Maryland - US

1. INTRODUCTION

Many of America's most important cities are located within a few metres of present ocean water levels. Greenhouse-induced global warming will cause an acceleration in sea level rise, which could have dire consequences for some urbanised areas.

Sea level rise amounted to approximately 30cm along the US Atlantic and Gulf coasts during the last 100 years. The rate of rise is expected to double or triple in the coming decades, and many countries are planning for a 1-metre rise over the next century.

Coastal development has historically been dominated by major urban centres, such as New York City and Boston. Elsewhere, coastal settlements were relatively small seaside resort areas that are gradually evolving into high density, year-round communities.

Atlantic City, NY and Galveston, Texas are good examples of cities on the beach. The general response of cities on the water to accommodate rising water levels will vary on a site-specific basis, but primary reliance will be placed on bulkheads and sea-walls. Where recreational beaches are desired, sand pumping will be necessary to counteract erosional trends (NRC, 1987).

Five cities on the water along the US Atlantic and Gulf Coasts are profiled with regards to the impacts and possible responses to sea level rise.

2. BOSTON

Boston is the oldest major city in the US; the European settlers found a great natural harbour here. The glaciers from the last Ice Age had left behind large drumlins known as the Boston Harbor Islands, which served to provide some sheltering of this seaport.

The city was built on these same glacial deposits, but there was a limit to this high ground. Therefore, marsh filling was undertaken even in early times to reclaim land from the sea. The Backbay area where Boston University was built was formerly marshlands.

Flooding during storms was an immediate problem along the coastal and riverine fringe. Bulkheads were built to develop the port of Boston and prevent flooding of low-lying areas.

Finally, a complete dyke was built across the Charles River, converting this waterway into an enclosed lake. While water quality has since been a problem, flooding via the river channel has been precluded. Future sea level rise can probably be accommodated by simply raising the heights of the bulkheads for the city proper.

However, more elaborate plans are now being formulated to form an outer harbour dyke by connecting some of the glacial islands with moveable gates to be closed during storm conditions.

KEY WORDS

US City Cases: Boston - New York City - Atlantic City - Washington, DC - Galveston
It is interesting to note that Boston is a sister city to Venice, which is also being forced to cope with rising water levels in this manner.

3. NEW YORK CITY

New York City consists of five boroughs or governing bodies; Brooklyn and Manhattan are the most susceptible to sea level rise.

While Manhattan in New York Harbor is largely sheltered, Brooklyn on the south shore of Long Island is exposed to open-ocean waves. Therefore, the defence strategies will be quite different.

The small town of Broad Channel in Brooklyn is essentially America’s equivalent of Venice.

This community was built by filling marshlands in the centre of Jamaica Bay protected by an outer barrier island (the Rockaways).

The people of Broadwater were not fleeing from armies of northern invaders as in the case of Venice, but instead were attempting to escape from the high taxes and property costs of New York City.

Defence of this area will be problematic, but a ring dyke around this residential area would probably be the most cost-effective measure to combat future flood problems.

The Rockaway barrier is terminated and anchored by a large jetty, which has served to cause major progradation of the adjacent shore.

Elsewhere, beach nourishment has been necessary to maintain the recreational beach and provide a suitable storm buffer between the high-energy surf and beachfront buildings.

This sort of activity, complemented by dune building, will likely be the response to higher water levels in the future.

The mainland portion of Brooklyn, which is a highly urbanised area, will be protected by bulkheads.

As long as the Rockaway barrier landform remains intact, then this area will be sheltered from open-ocean waves, alleviating the necessity of building massive coastal defence structures.

Because this glacial outwash plain is similar to the low-lying coastal plains to the south, flooding during coastal storms has already been a problem.

If sea level were to rise by 1 metre, then a significant area of Brooklyn would be flooded during a 50-year event (Fig. 1).

Lower Manhattan is also vulnerable to rising water levels. Although the city was built on hard granite rock, a fringe of low-lying land exists along the Hudson and East Rivers (Fig. 2).

Storm flooding could also endanger the underground subway system so that anticipatory protective dykes will certainly be built or heightened in the coming decades with higher sea levels.

4. ATLANTIC CITY

Atlantic City was built on a barrier island along the

Fig. 1. Future flooding of Brooklyn during a 50-year event and a 1-metre sea level rise

Fig. 2. Future flooding of downtown Manhattan and the port of Jersey City during a 50-year event and a 1-metre sea level rise

outer New Jersey coast. While the fortunes of this coastal resort area have waxed and waned, renewed prosperity in the past decade is attributable to legalised gambling.

Net proceeds from the Atlantic City casinos now exceed those of the well-known Las Vegas. Atlantic City is representative of many of the "cities on the beach" with regards to its development characteristics and vulnerability to sea level rise.

Barrier elevations average only 2 to 3 metres above existing mean sea level so that a 1-metre rise in water level would be potentially devastating because of the much increased storm floodings.

Also, higher sea levels will accelerate the rate of beach erosion, which is already a serious problem; Atlantic City's beach is presently nourished on a 5-year basis.

Beach nourishment and dune building along the ocean side and bayside bulkheads will continue to be
the means of choice for protection of this coastal city. The beach is considered to be a valuable resource, and it must be maintained. Evacuation of the city during the advent of hurricanes will still be necessary in spite of these protective measures because of the low-lying, exposed nature of this barrier island landform.

5. WASHINGTON DC

The capital city of the United States is well inland and would not normally be considered to be subject to sea level rise impacts. However, rising ocean levels will cause a backwater effect as the base level of the Potomac River will also be raised. Therefore, Washington, DC is hydraulically connected to the sea, and the Capitol mall area was built on low-lying terrain. Washington was established at the confluence of the Potomac and Anacostia Rivers. The early settlers sailed as far inland as possible, reaching the unnavigable falls. This fall line represents the contact between rocky piedmont and unconsolidated sediments of the Atlantic coastal plain. In fact, many of the state’s capitals were built along this fall line, namely Raleigh, NC, Richmond, VA, and Philadelphia, PA.

A 1-metre rise in sea level would allow the Potomac River to flood a large portion of the Capitol mall area during only a 50-year event (Fig. 3). The riverine waters could almost reach the steps of the US Capitol itself, completely flanking several of the Smithsonian Museum buildings.

Fig. 3. Future flooding of Capitol Mall area, Washington, D.C., during a 50-year event, assuming a 1 meter rise in sea level

Of course, this scenario will never be realised as dykes will obviously be installed or heightened along the river banks.

6. GALVESTON

Galveston was the most important city in Texas at the turn of the century. This busy port city, built on a barrier island, boasted of its wealth by having some of the grandest Victorian mansions on the US coasts. Unfortunately, the great hurricane of 1900 devastated the city, destroying most of its buildings and resulting in the loss of 6,000 lives. Rebuilding occurred slowly after replacement of a protective sea-wall in the ensuing years by the US Army Corps of Engineers. Only in recent decades has this city truly assumed part of its prior importance as an economic centre along the Texas coast.

Galveston is located on a microtidal barrier island with average elevations of 2 metres. Therefore, even small changes in water level will result in much increased vulnerability to the existing development. Galveston is a densely developed “city on the beach” which is subject to hurricane flooding. Changes in storm surge levels and inland inundation were projected in response to different sea level rise scenarios (baseline, low, medium, and high) at particular time periods (2025 and 2050).

Because the Gulf coastal plain is quite low and slopes gently seaward, a slight rise in sea level will result in significant horizontal displacement of the storm surge envelope. The amount of damage to inland buildings and hazardous waste sites during storm conditions largely depends upon surge elevation and penetration. Sea level rise would alter storm surge levels in proportion to the amount of rise for any
given scenario. There are three sources of information on inland coastal storm surges: the Corps of Engineers' flood frequency curves, Federal Emergency Management Agency (FEMA), flood maps (FIRM), and the National Weather Service's SLOSH simulation computer model. Predictions of storm surge elevations are generally based on historical records of water levels occurring during previous storms. Frequency curves have been developed from a statistical analysis of tide gauge records and can be used to determine recurrence intervals for storms of particular sizes (Table 1).

<table>
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<tr>
<th>Frequency (years)</th>
<th>Storm tide height above mean sea level (m)</th>
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<tbody>
<tr>
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<tr>
<td>20</td>
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<td>4.1</td>
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<td>150</td>
<td>4.6</td>
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Table 1. Frequency of Storm Tide Heights for Galveston (from U.S. Army Corps of Engineers, 1966)

The SLOSH model was used to forecast storm surge flooding; the methodological approach is discussed elsewhere (Leatherman, 1984). Under existing conditions, Galveston is still unaffected by a 100-year storm flood (Fig. 4). However, a 1.6-metre rise in sea level is shown to cause extensive flooding of the city from the bayside (Fig. 5).

This analysis assumes that the massive Galveston sea-wall is not undermined, but it must be remembered that these large-scale engineering works were designed on the basis of existing water level, tide, and wave energy criteria. While the FEMA maps in conjunction with the storm frequency curve and topographic maps could have been used to yield some indication of storm surge levels, the SLOSH numerical model yields far more reliable results and allows for predictions on a grid-cell basis rather than a single averaged value for the entire basin.

The National Weather Service is planning to model all the significant basins along the US Atlantic and Gulf coasts, but the dates of completion for particular areas range from years to decades. This type of analysis can be utilised for any area so...
The suggestion has been made to emplace such a structure at Galveston, but the cost is prohibitive and the success uncertain. In order for this type of protective device to be effective, there must be no "holes" in the dyke/dam system. While the inlet gate may be made secure, the low-lying barrier islands to either side must remain intact for many miles in either direction, which virtually precludes this alternative from future consideration for the Galveston area.

7. REFERENCES


modelled. It should be noted that there is a fairly wide band in predicted values (accuracy within 20 percent of true value) so that ranges are more appropriate than absolute values for characterising a storm surge.

In general, the principal strategy that should be employed along developed shores in the face of rising seas will involve fortressing small urban enclaves. Fortified levees and dyke systems with moveable locks encircling all critical facilities will prevent storm surge flooding.

These fortifications will have to be well engineered to provide structural continuity.

The other alternative, which has already been suggested by the US Army Corps of Engineers (1979), is to seal off the entire Galveston Bay area during storm attack. This procedure is being utilised to protect London with large moveable gates that can close off the Thames River to ocean waters. After the 1938 hurricane, gates that function in a similar manner were installed along the upper part of Narragansett Bay to protect Providence, Rhode Island, from future stormwater damage.

Where high relief terrain exists, such as along the glaciated New England coast, or in narrow sections that necessitate blockage, this approach will be acceptable.
A TALE OF LAND LOSS IN LOUISIANA

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Environment Protection Agency
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There never has been and probably never will be another Venice. But if there was, my candidate would be the city of New Orleans. Approximately one hundred years ago, New Orleans used many canals, perhaps more than Amsterdam uses today. When the city sank one hundred years later, a dyke was built to encircle it; the canals were filled and replaced with drainage pipes. Across the globe, most of the low-lying land vulnerable to a rise in sea level is located in river deltas. River deltas are created by the sediment washing down the river. In principle, they have the natural ability to keep pace with rising sea level. However, many activities that make these deltas inhabitable, such as dykes and water management facilities, have disabled the natural ability of the deltas to grow and keep pace with rising sea level. Therefore, almost paradoxically, many of the well-developed areas are vulnerable, while undeveloped areas are keeping pace with sea level. The Mississippi Delta of Louisiana in the United States, which can be seen in Fig. 1, is perhaps the best geological test case for future sea level rise due to the “greenhouse effect”.

In addition to the rate of sea level rise, this area has been gradually subsiding as sediments deposited in the last few thousand years compact and sink. Without receiving new sediment, the marshes would not be able to keep pace with sea level. As a result, vegetation would die, causing the marsh to deteriorate and be replaced by open water. Louisiana may also be a political test case to challenge the ability of one urban area to enact long-term environmental planning that is co-existent with short-term economic goals and focuses on protecting, not threatening, the city.

The more recent activities to manage the river have disrupted the natural delta-building processes of the river and helped to reverse the expansion of the Mississippi Delta. Fig. 2 depicts some of the conditions on deteriorating shorelines in Louisiana. The problem is that Louisiana is losing about a hundred square kilometres of land every year. Over a twenty-year period, the marsh at the mouth of the Mississippi River declined by more than 50% and the trend continues. Fig. 3 illustrates the wetland changes in the Mississippi River active delta during the periods of 1956 and 1978. Approximately every thousand years the river switched to a shorter course and built a new delta along the main channel. Fig. 4 shows the various delta lobes over the last seven thousand years: the currently active delta; a previous delta one thousand years ago; and another delta location of several thousand years ago. Eventually the river shifted to the “Bird Foot Delta”, south of New Orleans, which appears to have an

KEY WORDS

Mississippi Case
Historical Deltaic Evolution
Subsidence - Water - Oil Exploitation
Erosion - Barrier Islands
Defences - Effects
unusual shape because of an extra 150 kilometres that extend into the sea.

If the river followed its natural course it would flow into the Atchafalaya River which flows west of New Orleans and the Mississippi River.

Refer to Fig. 5 for an illustration of more recent land change rates in the coastal zone of Louisiana from 1955 to 1978.

The cultural history of the area begins approximately 300 years ago when a group of French people settled in New Orleans. The other part of Louisiana was settled by French-speaking Canadians we now call the Cajuns, who chose to reside in the uninhabited marsh and swamps.

When New Orleans was originally built, property owners were required to build dykes along the river. These are known as river levees.

During the cultivation of the midwestern region of the United States about 200 years ago, a tremendous amount of soil erosion was created.
The Mississippi River, which drains about two-thirds of the United States, carried increased amounts of sediment. Although river water follows the shortest course, instead of travelling straight to Atchafalaya Bay, the flow of the Mississippi was re-directed by a logjam of trees. In the mid-1850's, the U.S. Army Corps of Engineers cleared the logjam. Rapidly, within a ten-year period, the amount of water flowing down the river dramatically increased, so much so that ever since then measures have been taken to reverse the impact and direct water to the Atchafalaya. Two river control structures that have cost well over a billion dollars are blocking the river from following its natural course. The city of New Orleans is faced with a dilemma. They need the water flowing toward the port of New Orleans for the ships, and the population needs a supply of drinking water. With the increase in the size of ships during the middle part of the 19th century, the depth requirements for the channels increased. The Corps of Engineers began dredging, which is very expensive. A retired officer, who was also an engineer, presented a proposal to the Corps and later to the US Congress...
to save dredging costs by building large jetties at the mouth of the river.

Since the worst situation usually occurs at the mouth of rivers, the jetties would keep the channel open. He convinced the US Congress to permit him to build the jetties free of charge under the condition that if they worked successfully he would receive one million dollars, which was far less than the costs of dredging. The idea worked so well that the Army Corps of Engineers gradually implemented it upward along the river all the way to New Orleans.

Under natural conditions, the water would be distributed in every direction over a large area of the delta. Necessary fresh water would be provided to the wetlands, and flooding would bring more sediment to the delta.

Even though the delta is sinking, new sediment from the floods would let it keep pace. However, river levees were preventing the downstream area from being flooded, and the sediment washed off the edge of the continental shelf.

Gradually, the land was sinking which was not a big problem until the area protected by levees was increased.

In 1900, the Corps of Engineers closed off the third largest distributary, Bayou La Forche. Before that time, the river had overtopped its banks during floods in several areas.

During a devastating flood in the 1930's, the river overtopped its banks, killing a number of people and destroying a lot of property. Then the Corps of Engineers decided to build very large river levees along the part of the river above New Orleans.

Since then, the flow of the Mississippi River has been confined. No fresh water reaches the marshes. Almost no sediment reaches the marshes, except for a small natural delta along the Atchafalaya River, where levees have not yet been built.

In the 1940s and 1950s, there was increased activity on the Mississippi River by the oil industry. Many canals were dredged in Louisiana's coastal marshes to create easy passages to oil wells for barges, as shown, for example, in Fig. 6 and 7.

Today, in Alaska, hovercrafts are used instead. As a consequence, the marsh was removed. Dirt from the canal was placed next to the canal which blocked the flow of water across the marsh.

The canals also provide an avenue for salt water to go upstream into the freshwater wetlands. The cyprus swamps, for example, are freshwater swamps that lose their trees to the salt water.

The area is transforming into a collection of lakes. Refer to Fig. 8 for a view of a former cyprus swamp after salt-water intrusion. All of these factors describe
why Louisiana is gradually losing a significant amount of land. Louisiana's marshes support 40% of all of the seafood caught in the United States. With the gradual disappearance of marshes, there is a temporary increase in the amount of shrimp. Once the marsh has completely gone, less shrimp becomes available. In the case of developed barrier islands, it is commonplace to see eroding due to destruction from canals where once there was solid marsh. Fig. 9 depicts the levels of severity of barrier island erosion in Louisiana. There are several proposed solutions to the threat of wetlands loss in Louisiana, given the current trends in sea level rise. The shoreline, considering all possible permutations, by the year 2030 will look like the black line on Fig. 10. There may be some wetlands gained around the Atchafalaya Bay. The sediment washing down into this great delta, which by itself could sustain the delta even in the face of an accelerated rise in sea level, is going off the edge of the continental shelf into the deep waters of the Gulf of Mexico.
Moreover, if holes in the dykes were cut, it would be bad for shipping. This first option would be to divert the river to where it really wants to go, that is, down the Atchafalaya River. Environmentalists and privately, some members of the Corps of Engineers, have evaluated the river control structure that prevents this flow from happening as the worst idea they had. But it is hard to publicly admit it. Once one has spent a billion dollars on a structure, even if it was a bad idea, institutions have to circle their wagons.

If the water were redirected, sedimentation in the Mississippi would occur upstream of Béton Rouge, so that it would not hurt the shipping. There would be siltation in the Mississippi, but it would occur above the port of New Orleans which is mostly barge traffic. There are two other problems with this option. First, if we let the water come down the Atchafalaya, Morgan City would be flooded, unless a very large dyke was built around the area. In addition to this potential problem, the New Orleans population currently drinks the water flowing down the Mississippi. If the water were diverted down the Atchafalaya, salt water would go up the Mississippi to New Orleans. In fact, during a recent drought, a year and a half ago, the Corps had to build a barrier across the bottom of the Mississippi River to prevent salt water from intruding into the New Orleans water supply. If the river was directed, then New Orleans would lose its water supply. The Mississippi River is so polluted, though, that in New Orleans this might be a blessing in disguise. Apparently, one third of the population drinks bottled water. In any case, the city would have to find an alternate drinking water supply. There is an aquifer under Lake Pontchartrain that could be used. However, the time it would take to develop a new source of fresh water, which is at least a couple of decades, makes it difficult to consider development from this aquifer as an option today. Another option is the Dutch solution. Dykes are built in those areas designated to be preserved. This technique may be appropriate in the Netherlands, given the scarcity of land. But this option is probably inappropriate in the United States, particularly in Louisiana, because the entire culture of this area, and even the city itself, is predicated on having plenty of seafood. One could pump the water level artificially to
maintain the marsh, but the problem of getting the shrimp from one side of the dyke to the other without being damaged has to be solved. The important fish resources have to be protected.

Another solution is to start cutting holes in the river levees. Restoring the natural processes would be the best for the delta.

However, many proposed structures would divert about 8% of the water into the marsh, which is important in the short run. In particular, there is a significant number of oyster farmers.

As the marsh disappears it is replaced by shallow water, where they can grow oysters. If we implement solutions to rebuild the marsh under natural processes, the oysters would be buried.

The oyster people do not own the marsh, they own the lease to the oysters. So, they would lose their leases. Even though it would be good for the

![Projected future coastline of Louisiana (after Ramsey and Moslow 1967) for the year 2033 A.D. Given a rise in sea level of 54.9 cm as predicted in the high scenario (from Hoffmann et al. 1985)](image)

insufficient to solve the problem. It would slow the loss of wetlands where the salt-water intrusion is a problem, but it still would not provide sediment. The solution that would truly save this area is tearing down all of these levees.

It has not been done because the city of New Orleans depends on shipping. And basically if we cut holes in the levees we will undo what the engineers discovered 150 years ago.

We will have a natural delta and the ships will not be able to pass through, and that is untenable to the city of New Orleans. Another alternative is to build a number of parallel canals to separate navigation from river flow. If canals were built east of New Orleans through the marsh, and the rest of the delta was left to become natural, then the delta would be restored. The problem is that shippers do not like to go through locks. The port of New Orleans fears that it would lose business to Houston (Texas), Mobile (Alabama), and other cities just because the ships would not want to queue up to wait for locks.

Even though the wetlands are ultimately important for sustaining the fisheries, these are not always environment and create more fish productivity, the oyster lease holders are able to block it.

Even some of the shrimpers would be affected. Shrimp depend on wetlands. Some shrimpers are against creating more marsh because in the short run when marsh degrades, productivity increases; fishery productivity responds to the total amount of shorelines and while wetlands degrade, their shorelines increase.

It is a paradox: but many of the shrimpers are against doing what is necessary to sustain the shrimp industry in the long run, because it would hurt profits for a while.

Many people feel that Louisiana is a problem without a solution. There is an abundance of options that would work, but somebody has something to lose from each option. People cannot agree, and it is hard to say what will happen.

How this relates to the “greenhouse effect”? First, global warming would accelerate the rise in sea level. Wetland loss would occur rapidly.

This represents all of the wetlands, the marshes and the swamps. In one hundred years under current trends, almost all of the shoreline area south of New Orleans, Houma, Morgan City and Cameron could be gone, as depicted in Fig. 11.

If the sea level rise accelerates as projected, most of

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the delta could be lost within sixty years from now. Because the loss of land is steady, the period of concern may even be shorter than this for at least one half of the delta.

To save these wetlands any engineering solution will take 20 years to build, at least. It will probably take us 10 to 20 years to agree on solutions once a project is authorized, because of the wide variety of interests that would be affected and the large number of options available. The majority of the delta could survive in the long run if we can restore the natural cycle of the Mississippi River that used to deposit all of its sediment in the wetlands.

Nobody is demanding urgent action: “We’ll still have wetlands when I die.” In short, if there is an acceleration in the rise in sea level and a solution were implemented today, only half of the delta, approximately, would be saved at the completion of the project. If the project were initiated ten years from now, we might lose as much as 60% to 70%. There is enough deterioration already that even if sea level rise does not accelerate and we initiate a solution today or ten years from now we could still lose as much as 25% or 35% of coastal wetlands.

Accelerated sea level rise simply means that we do not have as much time to act as we thought. This may seem like a unique case, but it is not completely unique. Egypt blocked the sediment and its delta is now opening up because of the Aswan Dam. Accelerated sea level rise will just accelerate the process by which that delta decays.

Bangladesh is an interesting case, because it has not yet built the river levees. Bangladesh still floods. The sediment keeps up with sea level rise, but building levees is being proposed to control the flooding. If they build a levee along the river, they could have the same problem. In the short run, they will stop the flooding, but at the long-run expense of losing much land.

And in a nation like Bangladesh that does not have enough land, anyway, one wonders whether that would be a very wise choice.

Finally, for the Mayors of the Cities on Water and their representatives, I think that there may be a political lesson. Perhaps throughout the conference you have been saying, “Well this is very interesting, sea level rise, but it’s so far in the future, why should I worry about something that’s going to take a hundred years or longer to unfold?”

I think Louisiana is the answer: Louisiana did not worry about what was going to happen. People kept doing things that made sense at the time. It made sense to build those jetties and levees because the ships could go up the river.

It made sense to build levees to stop the river flooding. Each individual action made complete sense. Nobody thought about what would happen in the long run. In the long run, basically the whole area is threatened, including the city of New Orleans.

Perhaps you can forgive the people of Louisiana because a hundred years ago they did not understand all of this science about delta building and delta decay and sea level rise.

But today’s generation of policy makers does not have that excuse. You are getting the warning that sea level is likely to rise and you have the human resources to develop options to contend with this issue. Sea level rise does not mean that you have to go out and embark on a lot of expensive projects that will not be necessary for a hundred years.

It does mean that you should at least make some effort to ensure that whatever development does take place is consistent with the long run rise in sea level.

It is no longer a question of whether it will take 50 years or 200 years. It is going to happen eventually. Of course, you have more pressing concerns. You are not going to get re-elected solely by planning for sea level rise; no doubt about it. But, on the other hand, the public does care about the “greenhouse effect” and about the type of world their grandchildren inherit.

You have a responsibility to history, and I hope you can rise to the challenge.

Note: This is an edited transcript of conference remarks. The views expressed are the author’s. They do not express official views of the US Government or the Environmental Protection Agency.
EFFECTIVE ADAPTATION STRATEGY
TO SEA LEVEL RISE RISK
Forecasted Impacts and Strategies Learned from Experiences of Flood and Land Subsidence in Japan

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1. IDENTIFYING IMPACT CATEGORIES
OF SEA LEVEL RISE

The impacts of sea level rise on cities and regions show wide variations of hydrological disadvantages in stormwater drainage, salt-water intrusion into ground/river water, difficulties of protecting lives and property from storm surge. More frequent inundation due to typhoon and other flood tide conditions is forecasted in the early period of 21st century on our earth suffering greenhouse effects. The impacts of sea level rise on regional society are formulated into sequential multiple processes:
1) the original greenhouse effects
2) associated meteorological effects such as hydrological regime, rise in temperature, etc.
3) marine current and tidal effects
4) morphological coastal change
5) ecological effects in coastal and estuary environment
6) deterioration in level of protection from water related natural disasters, decreased fish catch, and other users’ benefits.

The Japan Environment Agency (JEIA) organised the advisory committee on global climate change in 1988. In June 1989, the subgroups on impact study and counter measures study presented their interim reports. Agricultural production, forest ecosystem, urban climate system, water resources and hydrologic system, and other major impact categories were mentioned in the course of increasing awareness to global climate change. In the first stage, the following were examined:
1) how to forecast energy consumption and degree of human activities;
2) how to identify the influenced natural and socio-economic systems;
3) how to design the countermeasures.

However, in all three, there is no clear priority on either the regulatory limitation policy or the adaptation policy. The interim report called attention to the sea level rise problem, because large numbers of people inhabit areas along the shoreline of Japan. Concerning the symptoms of abnormal weather on both nation-wide and global scales, the Japan Meteorological Agency released a summary of the results of the world-wide research, international joint committee activities, and IPCC documents in April 1989.

In the publication (1989), the Japan Meteorological Agency acknowledges that CO₂ concentration in the troposphere in 2030 will become around 450ppm, and the atmospheric temperature will increase by 1.5-3.5 deg., and then the sea level may rise by 0.2-1.1 m in the mid-northern hemisphere of our planet. In August 1989, the Ministry of Construction and the Ministry of Transport presented preliminary reports on the impact study and policy analysis.

KEY WORDS

Sea Level Rise - Impact Categories - Japan - History
Floods - Extension - Damage cost - Risks
Engineering Practices
Strategies - Adaptation - Choice
Erosion (Coastal)
Drainage (Basin)
Scenic Beauty
Storms - Typhoon Impacts

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related to the sea level rise problem. The Ministry of Construction's intensified perspectives concern marine shoreline hazards, increased difficulty of flood control, associated excessive sand yield and landslide, a deterioration in balance and water quality in regional water resources system, and inferior amenity services in rivers and waterfront due to warmer climate and sea level rise.

The Ministry of Transport concentrates its assessment in the field of coastal disaster prevention and protection of high tide impacts in the harbour area. Table 1 shows that three agencies in Japan concerned with the sea level rise have identified impact categories with different approaches. These specific impact categories in reports are influenced by the scope of policies, and administrative responsibility of each authority.

A more systematic flow diagram of impact categories and linkage is proposed by a Dutch research group (1988a, 1988b). A case study for the Netherlands about the Impact of Sea Level Rise on Society showed "driving forces," "physical system" and "socio-economic system" in the so-called ISOS system diagram (ISOS, Impact of Sea Level Rise on Society). Taking these categories into consideration, the author adopts a matrix-type framework for spatial zoning and user service varieties.

In Table 2, four types of spatial zones and five resource and infrastructure categories are specified. Here, in an urbanised area, land resources should be protected by means of structural defence services. The role of sea-walls and embankments becomes more significant. On the contrary, in natural beaches or shores, geophysical, biochemical and ecological characteristics should be of concern.

### Table 1. Impact Categories in Sea Level Rise Identified by Japan Environment Agency and Other Agencies

<table>
<thead>
<tr>
<th>Japan Environment Agency</th>
<th>M. of Construction</th>
<th>M. of Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land-water interaction in coastal area</td>
<td>Coastal defence system &amp; disaster prevention</td>
<td>Coastal defence system</td>
</tr>
<tr>
<td>Vulnerable estuaries</td>
<td>Flood control</td>
<td>Port &amp; harbour defence system</td>
</tr>
<tr>
<td>Degraded port &amp; harbour services</td>
<td>Landslide and related natural disaster</td>
<td></td>
</tr>
<tr>
<td>Interior function of urban infrastructure</td>
<td>Water quantity and quality in natural resources system</td>
<td></td>
</tr>
<tr>
<td>Natural ecosystem</td>
<td>Waterfront amenity</td>
<td></td>
</tr>
</tbody>
</table>

### Table 2. Influenced Resource and Infrastructure Service Categories in Various Spatial Zones Related to Sea Level Rise

<table>
<thead>
<tr>
<th>Coast</th>
<th>Estuary</th>
<th>Harbour</th>
<th>Alluvial Lowland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land resources</td>
<td>Submerged land losses</td>
<td>Subsidence &amp; land losses</td>
<td></td>
</tr>
<tr>
<td>Safety &amp; defence services</td>
<td>Failure of coastal defence</td>
<td>Failure of harbour defence</td>
<td>Failure of river dykes and levees</td>
</tr>
<tr>
<td>Water resources system</td>
<td>Saline intrusion in groundwater</td>
<td>Saline intrusion in river water</td>
<td></td>
</tr>
<tr>
<td>Recreation, ecological &amp; scenic value</td>
<td>Coastal sand balance</td>
<td>Aquatic environment &amp; waterfront</td>
<td></td>
</tr>
<tr>
<td>Urban infrastructure</td>
<td>Damage of navigation</td>
<td>Damage of harbour services</td>
<td>Rehabilitation of roads &amp; bridges</td>
</tr>
</tbody>
</table>
viewpoint of desirable civil engineering practice in the metropolitan area. However, a natural disaster prevention system in the high tide situation, during storm surge events, tsunami and rare events has been highly developed in a stage of an integrated mechanical system which has to be operated on the basis of synchronised control. Once a subsystem for disaster prevention breaks down partially, in the case of as pump accidents during in an emergency, a storm drainage system that fails to cope, or at the worst, a slightly stronger storm, then the breakdown results in remarkable large-scale inundation. Therefore the most sensational topics derive from cognition of likely sea level rise in Japan is not the magnitude of land directly lost, but the expanded area lower than the high tide water level coupled with large numbers of people affected. People and property in coastal cities can not be moved onto safe land.

3. COASTAL DISASTER PREVENTION WORKS AGAINST SEA LEVEL RISE

Based on the report of the Japan Meteorological Agency, the Ministry of Transport predicts that an additional 1,700km$^2$ with 3.8 million inhabitants and property worth $370 billion could possibly be submerged unless there is additional improvement of hazard mitigation facilities against storm surge and inundation.

The simple zoning of three alluvial areas by means of tracing contour lines 0.5, 1.0, or 1.5m greater than the high water level gives the relationship of sea level rise and potential damage as shown in Fig. 1, which was reported by the Ministry of Construction (1989). The contour line corresponding to the high water level when sea level rise is 1.5m, is illustrated in Fig. 2. The urban centres including some of the international trade centres, financial market centres, political and government institutions are located in those vulnerable flat plain areas. The sea level rise leads to a different morphological equilibrium along the land-water boundary. The vertical deformation in the steep D-form shore expected to show both cliff erosion and deposition close to the water's edge is illustrated by J. G. Titus (1986). A typical example of disadvantageous vertical deformation may occur, accompanied by more narrow sandy beaches as a result.

The Port and Harbour Research Institute (1977) showed eroded, balanced, and deposited shorelines for all of Japan. An example of a shoreline evaluation map is shown in Fig. 3.

The recession of beaches and dunes is unavoidable in the eroded zone. The eroded zone is found in the following three types of spaces:

1) the front of a sandy delta near a river mouth, where the river had supplied a great deal of suspended and bed materials, but dam construction for water resource development has checked further accumulation;
2) local points of easily eroded shore determined by tidal current, coastal residual flow, the "Kurosio" current and others;
3) sandy beaches which are not capable of maintaining the balance of sand transport because of coastal

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**Fig. 1. Inundation Risk Bearing Land Lower than High Water Level (by Ministry of Construction)**

**Fig. 2. Potential Inundation Risk on Most Densely Inhabited Area.**
geographical changes after land reclamation, the construction of hydraulic facilities, etc. The three famous scenes in Japan - Matsushima, Amanohashidate, Miyajima - have different types of water and land relationships. The anticipated effects on the three sites are formulated in terms of the coastal cross-sections as in Fig. 4.

First, Matsushima which is located in Sendai Bay and faces the Pacific Ocean directly, is famous for the beautiful small islands with rough cliffs and pine trees on them. When the sea level rises, the angry waves deprive the islands of vegetation and destroy relatively stable cliffs.

The normal type of erosion protection practice will not be preferred, even if the sea water level will have risen, because solid concrete breakwaters or embankments will seriously damage the scenic beauty of Matsushima.

Amanohashidate is a natural heritage brought about by tidal current in Miyazu Bay which faces the Japan Sea; waves are rather violent in winter. Recession of the beach had been observed and an intensified shoreline protection project has been practised by throwing sand there, and stimulating sand deposition by natural tidal currents.

When the sea level rises, additional investment may be necessary, as well as the practice of shore protection carried out so far. The most simple calculation based on past design parameters by the Ministry of Transport, shows that an additional 2.5m over the present will be required for the same level of coastal safety as at present in inland seas, or 1.8m of embankment in ocean.

Of the total 34,300km of coastline in Japan, half needs to be protected from storm surge by constructing seawalls and riparian works. The Ministry of Transport (1989) estimated the total cost for additional riparian works on the 4,500km of shorelines under that authority, to be more than $10 billion dollars, assuming that the sea level rises 1.0m. The supplementary cost for vulnerable coasts including those under the administration of other agencies is around $40 billion dollars.

Considering the premise that the conventional structural measures for safety along the shorelines, without attention to the sea level rise, requires roughly the same or more than these additional costs, and the adaptation strategies should assist in effective conjunction with the fundamental infrastructural investment for coastal safety.

4. VULNERABLE ALLUVIAL LOWLAND

In estuaries and rivers in alluvial plains, the sea level rise could cause the intrusion of saline water upstream into river water, thus a decrease of slope gradient and flow-down capacity. The total 700km of reaches in the major 109 first class rivers will be affected by a 1.5m rise in sea level.
It will then become necessary to re-assess it in terms of the planned high water level for flood control practice, based on the report by the Ministry of Construction (1989).

The report remarks that, taking the examples of the Nakagawa and Ayase river basin, the potentially damaged area in a 100-year return period floods increase by 20%; simultaneously with the 20% increase in the affected population and property, due to a 1.5 metre sea level rise.

At present, for all river basins in Japan, it is unclear how many citizens and how much property will be exposed to inundation risk with a 100-year flood as a result of the indirect hydrological effects of sea level rise. In densely inhabited areas, it is very difficult to have tall banks, wider streams, or a larger cross-section river area.

The individual embankment system with breakwaters in each local space has been replaced by the zonal protection system with the water gates and pumping system for storm surge in estuaries as shown in Fig. 5. Upstream of these estuaries and alluvial river mouths, a comprehensive flood control system has been developed in order to have retention ponds, infiltration facilities, spillways, pumping equipment etc.

The flood control system has become highly integrated in the course of upgrading safety service levels in urban areas. The initial and maintenance costs should increase with a more sophisticated system control program. The policy analyst should evaluate the indirect cost covering the cost of land use when hydraulic engineering practice is applied to high-priced land at the waterfront or near the urban centre. The indirect cost of flood control due to sea level rise would be far beyond ten times the estimated amount of $40 billion mentioned above.

5. WATER QUALITY AND RECREATIONAL SERVICES

The sea level rise stimulates intrusion of salinity into groundwater and a rise of the water table level. High saline concentration is detrimental to a fresh water ecosystem, agricultural irrigation, and other freshwater use. For example, as shown in Fig 6, the contour line of saline concentration in the subsided areas of Osaka detected earlier signifies that industries could not use groundwater from wells in the coastal zone, several kilometres far from the coastline, for the processing purpose.

Silt or muddy beaches at ebb tide have recently been evaluated as significant ecological space where primary production is most active and various species grow. In the area undergoing urbanisation, the hinterlands of these beaches are occupied by houses, roads and factories. Therefore, the process towards the desirable equilibrium of sedimentation cannot occur due to the recession of beaches.

Ebb tide beaches separated from hinterlands by seawalls would be submerged completely without provisions for the occurrence of a rise in sea water level. The Yatsu tidal beach in Tokyo Bay, as an example of urban natural parks where people can enjoy bird watching, and also the large-scale Ariake tidal beach in Ariake Bay would be seriously damaged. Two well-known topics of debate concerning environmental conservation in big-scale hydraulic
engineering projects are the Lake Shinji development and the Nagara River water resources development. These two planned projects require a water gate or weir to keep saline water out.

The unusual shellfish and fish that are sensitive to local ecological characteristics, face the danger of a deteriorated environment, when the water body has a high concentration of saline water.

While assuming stoppage of water flow by a gate or weir, the construction of hydro-structures can have serious harmful effects on the fish which have double shelters in river and marine environments in their life stage.

The irrigation project in the Lake Shinji basin has lost social and political justification in the growing awareness of overproduction of rice in Japan.

The huge water gate, which was completed despite a citizen’s movement of environmental conservation, has no function in the present situation.

This water gate is destined to be open and left unoperated. Speaking ironically of this Lake Shinji case, the sea level rise makes us discover and appreciate the function of the gate to protect sensitive fish from saline water.

The picture of Miyajima Shrine shows the most elegant style of building in a “breathing” water environment. The flow tide reaches the inner part of the water palace and the ebb tide leaves on the smooth surface of the soil bed.

This dramatic scene may be injured by a 1m rise of sea water level. There is no effective measure to sea level rise in the case of Miyajima Shrine in Seto Inland Sea National Park, and also the fantastic Hama Imperial Palace located near the shoreline of Tokyo Bay.

6. HISTORY SHOWS HOW TO BE SAFE FROM SEA LEVEL RISE

The coastal cities in Japan have suffered from storm surge, tsunami, typhoon, and other hazardous natural events. The Isewan Typhoon (1959) in particular brought about dreadful storm surge causing more than 5,000 deaths. The hydraulic engineering system in Nagoya City was completely destroyed, and accounted for more than $3 billion damage about 30 years ago. The industries in coastal zones had pumped out groundwater for cooling and processing in production.

Ground level subsidence was clearly observed in the 1930s in Osaka and other industrial cities in the alluvial plains. The typical trend of ground subsidence is shown in Fig. 7.

This subsidence has effects on storm surge protection works relatively similar to those of sea level rise.

Near the mouth of Yodo River, the land has sunk about 1m in 5 years at the worst, and the cumulative subsided height comes close to 3 metres.

The central and local governments enacted the regulatory laws concerning intake of groundwater for industries (1957, 1962) and business activities (1962), established industrial water supply system, and they executed flood control and other urban engineering practice related to land subsidence. Around 1,500 square kilometres of land are specified as withdrawal-prohibited zones in Japan.

The overview of flood disasters in Osaka teaches us that the recent history of flooding is punctuated by three phases. Once the Yodo River was controlled by prioritised riparian works, inundation over sea-walls and flooding in the medium sized rivers in urbanised areas was concerned.
After the disaster caused by Typhoon Jane (1950), banks 2.2 metres higher than the planned high water level (O.P. + 4.8 m) during flood tide were installed. The use of this design standard height of the banks on the basis of high water level in standard flood tide has been expanded, following the experience of storm surge events. Original banks subsidized by about 1m have been recovered by another practice of riparian works. The safe height (O.P. + 6.0 to + 8.1 m) protects cities from storm surge as shown in Fig. 8. Considering the difficulty of the construction of thin wall-type structures in fully occupied urban areas, the zonal protection system has been put into operation. A set of gates and pumping stations were constructed; when the gates at the mouths of tributary rivers are closed, storm waters are pumped out.

In the second phase, tributary rivers overflowed into alluvial plains which failed to contain flooding in the rare event exceeding designed specification, as shown in Table 3. In order to mitigate inundation hazards, spillways have been constructed in joint operation with off-site storm water retention.

Recently, in the third phase, storm drainage in urban areas has been a concern as a target phenomena, because of the growing percentages of impervious areas. Therefore, many on-site retention facilities are introduced; roof-top retention, parking lot retention, built-in storage with a drainage pump in buildings, permeable trench and retention ponds originating from irrigation use only.

As a result of a brief historical review on flood control in the subsided lowland of Osaka, the advanced safety services against storm surge and flood in Osaka and other cities have reached a relatively high grade of engineering reliability and probably a sufficient level of satisfaction on the part of the residents. When sea level rises by 1m, explicit hazardous damage is not expected to occur directly in the predicted storm surge and rainfall.

The change of a 1m rise would not be beyond the adaptability of the vital business city Osaka in the continuous succession of sea level rise to 2030.

Of course it takes a considerable amount of financial support, collaboration with engineering specialists and policy analysts, and cooperation of landowners and local government.

<table>
<thead>
<tr>
<th>Phase</th>
<th>1st (1934-70s)</th>
<th>2nd (1972-80s)</th>
<th>3rd (1979-90s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazard</td>
<td>Storm surge</td>
<td>Flood in rivers</td>
<td>Urban flood</td>
</tr>
<tr>
<td>Event</td>
<td>Typhoon</td>
<td>Typhoon &amp; local storm</td>
<td>Local storm</td>
</tr>
<tr>
<td>Year</td>
<td>'54, '55 &amp; '61</td>
<td>'72a, '72b, '75a, '75b</td>
<td>'79, '79 &amp; '82</td>
</tr>
<tr>
<td>Precipitation</td>
<td>22, 65, 43 mm</td>
<td>238, 122, 114, 106 mm</td>
<td>269, 92, 151 mm</td>
</tr>
<tr>
<td>Inundation</td>
<td>49, 58, 31 km²</td>
<td>18, 17, 13, 0.2 km²</td>
<td>8, 10, 20 km²</td>
</tr>
<tr>
<td>Policy</td>
<td>Zonal protection</td>
<td>Spillway, riparian</td>
<td>Retention</td>
</tr>
</tbody>
</table>

Table 3. Three Phases of Experienced Flood Damages and Control Policy Orientation

7. EFFECTIVE STRATEGIC CHOICE OF ADAPTATION

Sea level rise due to greenhouse effects has the uncertainty of a quantitative cause-effect relationship in the scientific sense. The range of risen level, the time when a distinct symptom is observed, the magnitude of growth of both energy consumption and CO₂ emission in the early part of the next century, and other relevant factors are not forecast with reasonable precision.

On the contrary, the societal needs for flood tide prevention practice have been intensified notwithstanding sea level rise, because of increased property value, population, and moreover perceived magnitude of requirements for safety services.

The construction and control of gates, pumping equipment and drainage for the purpose of accomplishing countermeasures to sea level rise are combined with the conventional planned/programmed infrastructural hazard mitigation projects.

Secondly, flood control and high tide control have to involve the concept of a coordinated approach with priorities on fundamental needs such as boat traffic services and urban amenity services in shore and river waterfront.

The tie-in policies, which combine the traditional continuous structural and non-structural countermeasures to inundation with the anticipatory risk management against sea level rise, require
higher cost-performance or higher benefit-cost ratio than that in the posterior totalling of individual cost or benefit in separate practice.

For example, a tide gates system and drainage system with pumping would be planned to complement each other; the coupling of the two systems might result in cost-saving.

The hazard reduction program concerning seismic hazards refers to the reinforcement of embankments and sea-walls, and requests to follow the new seismic design standard of structures in Japan.

The time and place for the incremental extension of height, strength and other characteristics of facilities in the defence system are chosen in the scope of multiple perspectives in comprehensive risk management.

The uncertainties of prospective phenomena and technological visibility of countermeasures would be weakened in the scope of well-structured modelling, however societal uncertainty might grow in international negotiation and cooperation/refraining among nations and payer/taker sectors. As to the former, the surveillance system to monitor sea level in each harbour and morphological parameters on each coast tell us when an emergency programme will have to be practised, when it has linkages with the global scale of climate change monitoring.

As to the latter, in the sense of domestic policy-making, the choice of measures depends upon the judgement concerning the amount of funds possibly thrown into investment on infrastructural rehabilitation in post-industrial society, which accompanies a great deal of financial expenditure of achieving and keeping up a high level of welfare in the public sectors.

The flow of money from private homes, businesses, and industrial sectors to the public sectors is expected by means of taxation, establishing a "conservation" fund, and creating something like the limited market of transferable right of CO₂ emission.

Even if the uncertainties are left aside, the adaptation approach to the sea level rise problem should be on stand-by.

The contingency planning technique may be applied to designing options of adaptation technologies and hazard mitigation technologies.

Writing scenarios to show alternative course of action, is most desirable. When unpredicted events and indications appear, decision-makers can continue to select reasonable options in any temporal section by means of gaining best-available information and to practise posterior assessment in scenarios that follow.

8. REFERENCES


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1. INTRODUCTION

It is forecasted that sea level rise will bring about a variety of changes to coastal areas in Japan. Therefore, several authorities and agencies have recently started studies and research concerned with sea level rise. The Osaka City Government has also been taking them into consideration, because Osaka is quite vulnerable to sea level rise. However, at present, the correct prediction of rising sea level is so difficult that the adaptation policies have not been studied yet. Therefore, in this report, I will show a case study of Osaka concerning measures against land subsidence and storm surges which we implemented in the past.

2. OUTLINE OF OSAKA

Fig. 1 shows a map of Japan, and Osaka City is shown by the black circle. Osaka is the second largest city in Japan, and also the economic centre for Western Japan.

![Map of Japan showing Osaka City](image)

*Fig. 1. Osaka in Japan*

The population is about 2,600,000 and the area is about 213 km², almost all of which is urbanised. The annual production of industries in Osaka City is approximately $490 billion US dollars. Topographically, Osaka faces Osaka Bay, and is surrounded by the Hokusetsu Mountains and the Ikoma Mountains as shown in Fig. 2.
Fig. 3 shows a latitudinal cross section from Osaka Bay to the Ikoma Mountains. The land level is quite low except for the Uemachi Plateau. Therefore, Osaka City is quite vulnerable to storm surges.

Fig. 4 shows the rivers in Osaka City. Yodo River, Yamato River and Kanzaki River are the principal rivers through the city. Other small rivers are used as canals or for irrigation. Many industrial facilities are located along these canals in the coastal area, but the inner city canals are used only for rainfall.

3. THE MAYOR OPINIONS IN JAPAN CONCERNING SEA LEVEL RISE

Future weather modification caused by global warming has been forecasted throughout the world by various institutions and groups. In Japan, the Meteorological Agency recently published the "Unusual Weather Report '89", which predicts such matters as rising temperature, sea level change, precipitation change and unusual weather.

The report concluded that, judging from the correlation between the average global surface temperature and sea level in the past, a 1.5 to 3.5°C increase in average global temperature would cause the sea level to rise by 20 to 110cm.

If the sea level actually rises by 100cm or more, there will be a need to consider various possible measures, such as the reinforcement of coastal disaster prevention facilities. Such facilities have been arranged for a long time without considering a drastic sea level rise.

4. MASTER PLAN AGAINST LAND SUBSIDENCE AND STORM SURGES

The coastal region of Osaka has suffered greatly from storm surges many times in the 20th century. The Osaka City Government started with a storm surge protection project for building tide embankments at the beginning of the century. However, due to rapid industrialisation, pumping well water for a long time has caused land subsidence. Following the land subsidence, these tide embankments were not effective against big storm surges around the middle of the century.

After World War Two, we examined measures in the master plans to be taken against land subsidence and inundation due to storm surges in 1950 and in 1965. The basic story and the conclusions are shown in Fig. 5: regulation of pumping well water, upgrading tide embankments, constructing new tide gates, and using sand to raise the ground level.

However, as the majority of the city was destroyed by bombing during the war, little money was available to be distributed to these projects.
Therefore, based on financial priorities, in 1947 we started with the project of upgrading the tide embankments. Following that, in 1950 we began the projects of raising the ground level, and in 1959 the regulation of pumping well water. And after the review of the master plan in 1965, the construction of tide gates was added to the master plan.

5. MEASURES AGAINST LAND SUBSIDENCE

Fig. 6 shows the level of land subsidence. The black line indicates areas of equal land subsidence from 1935 to 1967.

The maximum subsidence level is 280cm in the coastal area, and the inland area also reached a land subsidence level of approximately 40cm.

The results of the subsidence in the city centre around 1960 is shown in Fig. 7. The building supported by piles did not subside, but the sidewalk of the street did.

Fig. 8 shows an abandoned factory in the coastal area at the same time, resulting from the subsidence of the tide embankments.

Under these conditions, two projects were carried out to prevent the land from subsiding.

The first was regulation of pumping well water in the majority of our city, and the second was the...
construction of a water supply system for industrial use, utilising water from Yodo River.
The regulated areas are shown in Fig. 9.
The first regulation was started in 1959 and the final regulation in 1966. Regulation was carried out step by step during this period.

6. MEASURES AGAINST STORM SURGES

In 1950, Typhoon Jane attacked Osaka, causing storm surges. Consequently there was a large-scale inundation, the area of which is shown in Fig. 10. The total inundated area in Osaka City was 6km² which was 29% of the city area.
Many sea-walls along the shore line and the tide embankment were also destroyed. After Typhoon Jane, we accelerated the project to upgrade the embankments. But unfortunately, in 1961, Typhoon Muroto II attacked Osaka City.
This typhoon was nearly as large and as destructive as Typhoon Jane. From the beginning of the century, hundreds of typhoons have attacked Osaka City, three of which, in 1934, 1950, 1961, caused large scale inundation.
These three typhoons followed the same course as shown in Fig. 11. This figure gave us important insight for planning against storm surges.
Fig. 12 shows the tide curves of these three typhoons. Tidal level usually ranges from OP 0.5 m to 2.5 m.
Here, OP means Osaka Peil. OP 0m is the lowest mean tidal level. But in the case of three big typhoons, the maximum tidal level reached about OP 4m. This level is almost higher than the entire city area.

After Typhoon Muroto II in 1961, we reviewed the planning criteria for storm surges. Consequently the storm surge protection plan was revised in 1965. On reviewing the planning criteria, we assumed the worst case possible in which the maximum experienced typhoon follows the worst possible path in Osaka Bay at full tide. The worst possible path is the route of the three big typhoons.

According to this review, embankments along rivers in the city centre would have had to be raised by 2m. If this plan had been implemented, rivers in the city would have needed to be lined with levees several metres high, which would not only have disfigured the urban landscape, but would also have been an obstacle to cargo handling.

Raising these levees would also have involved improving many bridges and roads. Such construction was impossible, because of heavy traffic in the urban areas. This conclusion resulted in the adoption of the "Tide Gate Method" which is an improvement of the conventional tide embankment method.

This method is based on the meteorological characteristics in the Osaka Region of "windy" typhoons which cause storm surges not accompanied by much rain. In order to confirm the feasibility of this method, experiments were done by using models.

In the end, we decided to carry out these new measures. Fig. 13 shows the master plan of the tide gates decided in 1965, called the tide gate method. The policies of this plan are as follows:

1) Prepare higher walls than the worst possible tidal level along the shoreline, the small rivers in the coastal area and the three big rivers.

2) Construct relatively low walls along the rivers in the inner city.

3) At the junction of the high and the low walls, build tide gates as shown by the circles in Fig. 14.

4) On the ocean side of the tide gates, upgrade the land level by banking as high as possible.

The raised areas are shown in Fig. 15.

This plan was carried out starting from 1965. According to this plan, sea and river walls of 85km in length were improved, 8 tide gates were constructed, 14 drainage facilities were built and 29 bridges were upgraded. After the implementation of this plan, inundation due to storm surge has never occurred.
3) There is a growing need for further technological advancement in order to plan and improve coastal disaster prevention facilities and urban infrastructures.
4) Concerning the above items, there is a need for more opportunities and systems for technical and information exchange, both domestically and internationally.

Fig. 15. Raised Area (the black area)

But several problems arose that must be taken into account. Of these problems, two appear to be the most serious. One is the landscape: some people refer to new walls as “the razor”, and the other is that the water recreation areas were lost. These problems affect the livelihood of people in the urban area. We are suffering from these problems at the present time in Osaka. Returning to the problem of the rising sea level, if it rose by one or two metres, these facilities would become useless.

7. CONCLUSION

Osaka City has accumulated technical know-how concerning storm surge and land subsidence protection, as mentioned above. Therefore we could contribute to the study of protection against sea level rise. We do hope that the relevant agencies and related groups will be able to find workable solutions, through appropriate and active joint efforts, to the following problems:
1) There is a need for an adequate monitoring system to study the current state of global warming and sea level change.
2) At present, the problem of sea level change due to global warming is being discussed on a global scale. There is a need for accurate prediction techniques that can be specifically applied to Japan or even smaller areas.
1. INTRODUCTION

Australia is a highly urbanised nation, with over 80% of the population concentrated on the coastal fringe. All State capital cities are on coastal plains and the majority of the population is vulnerable to any sea level change.

On global and national levels, some issues are being addressed to slow the rate of global warming by reducing greenhouse gas emissions and protecting and replanting forests.

Even so, it is only at the local level that specific adaptive measures can be implemented to accommodate predicted climatic changes. Standards that include higher building floor levels in flood prone areas, building setbacks from beaches or upgraded stormwater control plans, are initiatives that are locality specific and generally the domain of the local Council.

2. THE INFORMATION BASE: "UNCERTAINTY" AND THE PLANNING RESPONSE

A fundamental problem in attempts to plan appropriate responses to potential sea level rise, is the lack of certainty in present predictions as to the rate and extent of climatic change.

It is generally accepted by scientists that climatic change will occur, although there is disagreement as to the detail of the predictions.

A considerable amount has been written on the impacts of various scenarios, but with the range of predictions presently available it is sometimes difficult to persuade decision makers of the urgency to act now.

Over the last 250,000 years (Fig. 1A) sea levels on the east coast of Australia have been as much as 130 metres below the present position (Chapman et al 1982). Since the end of the last glacial period (about 20,000 years B.P.) the rate of sea level rise was consistent and dramatic (about 1.2mm/yr) for a 12,000 year period.

This rise suddenly ceased, resulting in a sea level still-stand over the last 6,000 years (Fig. 1B). These sea level changes have been caused by climatic change because this section of the Australian Plate is tectonically stable and has not been subject to major uplift or subsidence over this period.

Within Sydney Harbour, the Fort Denison tide gauge has provided continuous tide records for over 100 years. Fig. 2 presents the tide record for Sydney Harbour with a number of different interpretations depending on the period of analysis.

The length of this record is certainly one of the best in the southern hemisphere, and highlights the range of sea level rise rates that can be extracted from a set of data. The natural variability of the system is large and can overshadow small incremental changes to sea levels.
3. FEDERAL GOVERNMENT PROGRAMMES

There are three distinct tiers of government in Australia, consisting of Federal, State and Local Government, administering different jurisdictions. Each level of government has responsibilities in relation to different aspects of sea level rise issues, and some of the policy approaches that have been taken in Australia are outlined below. In the Federal Government’s environment statement entitled “Our Common Future” (1989), specific allocations were made for improved data collection in relation to sea level rise. The Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia’s premier research body, has been funded to coordinate collection and analysis of tide gauge data from the southwest Pacific, and Asian regions. The Division of Atmospheric Physics has been extensively involved in climatic analysis and development of global circulation models.

Public awareness of the scientific debate has been encouraged by CSIRO sponsorship of major conferences and publication of literature. The Australian Government is a signatory to the Hague Convention and the Montreal Protocol for reduction of CFCs and limitation of production of other greenhouse gases.

One of the more ambitious programmes of the Federal Government, is the project to replant 1 billion trees before the turn of the century. This is part of a programme to reverse land degradation caused by salinity invasion and soil erosion, and to restore previously forested areas. This scale of planting will absorb large volumes of carbon dioxide and may have some limited impact on the availability of carbon dioxide as a greenhouse gas.

4. STATE GOVERNMENTS

There have been a variety of responses at a State Government level. The New South Wales, Tasmanian and Northern Territory Governments have not yet published policies, although individual government departments have considered aspects of the problem as they relate to their specific areas of responsibility. The Western Australian Government has published a policy statement entitled “Greenhouse: Meeting the Challenge” (December 1988).

In relation to coastal development issues, the State Planning Commission will “identify areas having the greatest potential risk, and management plans for these areas will be prepared with local government and community consultation.” Planning and design guidelines will also be developed by the State Planning Commission.

South Australia developed sea level rise strategies from as early as 1985, particularly due to the efforts of the Coastal Branch of the Environmental Protection Authority. The potential problem is more
acute in this region due to identified tectonic subsidence around major urban areas. The present South Australian policy encourages developments to "be protected from, or be able to be protected from" an identified sea level rise. In this area the predicted rate of relative sea level change is 0.4m over 50 years. Although no specific greenhouse induced sea level change is included in the calculations, the general policy of incorporating flexibility in the design of structures allows modification to protect developments when this becomes necessary. The Queensland Government has developed a more comprehensive approach for many facets of the greenhouse effect. With reference to coastal management, a similar philosophy to the South Australian model was adopted. The Queensland document states: "To avoid circumstances where some local authorities require consideration of sea level rise in design of development on the coast and others ignore it, and to protect local authorities and other approval agencies from legal action by landowners who consider themselves adversely affected, it is proposed all agencies with the responsibility for approving developments likely to be affected by sea level rise to adopt the following policy:"

1) design of developments is to be such that a sea level rise of 0.8m by the year 2030 can be accommodated, either in original construction or by later modification; and

2) the siting of coastal developments to be such that the expected coastal erosion due to sea level rise of 0.8m by the year 2030 may be accommodated."

The essential elements of the Queensland policy are that developments are able to be modified to accommodate sea level rise when this becomes necessary, and that approval authorities are provided a common standard and therefore avoid legal liability for approval of developments that may become at risk due to future climatic change. The Victorian Government published a Draft Strategy (June 1989), which included a number of more specific recommendations. Areas of "high vulnerability and high consequence" are to be identified "to facilitate the preparation of management plans."

Further definition is provided to "Prohibit development in areas at risk, that is, those which will be inundated by an extreme tide or a combination of rainfall and tides, which has a probability of occurrence of 1% in any year (average return period of 100 years). Median values for a sea level rise of 30cm for 2040 will be added to the 1% annual tide to determine the appropriate building design levels. The figure will be reviewed as new information becomes available." This is a more prescriptive approach although it incorporates flexibility as better information becomes available.

5. LOCAL GOVERNMENT

Thirty Local Government areas are adjacent to the open coast in New South Wales. Many more Councils surround estuaries or administer coastal floodplains. Two main Council functions will be critically affected by changing climate. Firstly, as a construction authority, in the provision of roads and drainage. Secondly, as a regulatory authority of land subdivision, and for assessment of applications for building construction and other developments. Conditions applied to a development consent rarely address the possibility of increased stresses over time due to climate change. The balance to be sought is between the short-term added cost of construction and/or land use planning, against improved long term protection.

Although a general sea level rise will have significant ramifications, a greater concern is the possibility of increased intensity and frequency of extreme storm events. Gradual changes to average conditions can be incorporated into design criteria and planning policy when reasonably accurate predictions are available. It is extreme events that are least predictable but cause the greatest community disruption.

Problems of floodplain management, stormwater drainage control, and coastal protection are matters that challenge existing emergency services. Any increased 'storminess' must exacerbate the situation with cost implications to Councillors and individual property owners. Stormwater drainage systems are the second largest asset of most Sydney Councils. Pipe networks are currently designed for a 20 or 100 year recurrence interval depending on location within catchments. Drainage systems are likely to be subject to more frequent failure in light of predictions of increased rainfall for eastern Australia. Where possible, planning should incorporate a design philosophy that anticipates extreme events and can accommodate exceedance of design criteria.

A practical method of addressing this issue is to identify 'surcharge paths' for stormwater when failure of pipe systems occur. By protecting these areas and encouraging appropriate development along the path e.g. playing fields or other open space land uses, a significant reduction of damage to property can be achieved, and increased storm events will have minimal impact. With reference to coastal management, a fundamental question is the present and future predictions of sea level. Although this is only one aspect of water level analysis (which includes storm surge, wave set-up, etc), ambient sea levels are an important starting point for consideration of coast management issues. A set of sea level rise curves, published by the US National Research Council in 1987 (Fig. 3), were
With changing climatic conditions the extent of risk to a development will vary over time. A realistic assessment of the time period until redevelopment of the site is likely, must form part of the risk management approach to development approval. The engineering "design life" of structure is a useful indication although it is very common for residential properties to remain long after the design life has been exceeded. From a Local Council perspective, the present applicant is transitory, while intrinsic problems of a site will be transferred to future owners. Inappropriate developments have provided long term legacies for many Councils.

6. PROFESSIONAL ASSOCIATIONS

The Institution of Engineers Australia adopted a policy in 1989 that requires professional engineers to consider the implications of changing climatic conditions in engineering design. No set standards have been proscribed, although the level of professional responsibility, and therefore liability for negligence, has been significantly raised "to ensure that (engineers) activities reflect the best information at the time". The major impact of the policy is that it is no longer available for engineers to design with assumptions of static climatic conditions. The Australian Marine Sciences Association has also developed a position statement that adopts the predictions established as part of the Villach Statement i.e. 0.8m (+ 0.6m) sea level rise by about the year 2040. The major thrust of the policy is for consideration of greenhouse impacts to be incorporated in all planning decisions. Particular directions for research are also identified with specific reference to marine sciences, and an appeal for the establishment of a national committee to coordinate research on the greenhouse effect.

7. CONCLUSIONS AND PROPOSED POLICY RESPONSE

Sea level rise predictions may vary with location due to subsidence or other regional land movement so care must be taken before adoption of fixed standards. The quality of local sea level data should be critically examined due to generally short periods of record, the extent of natural variability of sea levels, and the effect of local subsidence or uplift on the tide record. Increased risk due to changing storm conditions must be balanced with examination of the consequences of failure.

Parks, playing fields, and other low intensity developments should be favoured in locations where existing risks are high and are likely to increase over time. Where the effect of failure of a structure is dangerous to life, or very expensive to repair, a higher standard of design should be encouraged. A balanced view towards coastal development in
light of a possible sea level rise must consider:

- the extent of present and future risk;
- the potential consequences of structural failure;
- the anticipated design life of a proposal.

By adoption of reasonable greenhouse predictions, standards can be set which ensure the cost of improved individual protection is paid by the person gaining the benefit rather than the broader community.

The real cost of development is included in land sale prices. An important result is that long-term Council liability is minimised.

Many responses that accommodate the greenhouse effect are merely sensible management of existing problems.

Urban drainage and coastal management are two areas already stressed by extreme storm conditions. The existing problems are a substantial drain on community expenditure so, by implementing design philosophies that improve the existing situation and incorporate planning for the consequences of structural failure the negative impact of predicted climatic change can be accommodated.

8. REFERENCES


Abstract

Data collected from tide gauge stations located on coastal land reclamations in Hong Kong are found to be unreliable for indicating the local rate of future sea-level rise or fall unless "long term" ground settlement and crustal movement are taken into account. Because of this, tide gauge stations should be monitored for ground movement annually using state-of-the-art surveying methods including satellite radar altimetry.

For reducing the risk of flooding, the formation level of reclamations must take into account the rate of future sea-level rise, the amount of ground settlement, past storm surge levels and past rainsstorm flood levels. Because allowances for long term ground settlement have been insufficient in the past, reclamations affected by large post-constructional settlement are facing a high risk of inundation during storm surges and rainsstorms.

1. INTRODUCTION

Estimates based on the global rise of sea level over the past century have been used for predicting the rate of future sea level rise by Gornitz et al. (1982), Hoffmann (1984) and others. However, much closer scrutiny and study are needed if fundamental planning errors based on incorrect assumptions are to be prevented (Belperio 1989).

Because there is no global synchronism in eustasy (Morner 1983), it is of utmost importance to determine the rate of sea level rise for any area based on local data. In this account, the evidence for relative future sea level change and how it affects coastal land reclamations in Hong Kong is presented.

The main objective is to provide information to assist planners and other decision-makers to enable them to take the correct action.

Hong Kong, with a population of just under 6 million and the largest port in the world in terms of container traffic, is situated near the Pearl River Estuary (Fig. 1). An estimated 5% of its total land area was created in the past through reclamation of coastal land from the sea. Since the middle of the nineteenth century, there has been a dramatic shift of the coastline into Victoria Harbour (Fig. 2), where approximately 70% of the present day population is found.

The main factors causing an increase in demand for coastal land reclamations are:

1) The rapid population growth particularly since the end of the Second World War.

2) The shortage of naturally flat land for urbanisation and related activities.

3) The shortage of naturally flat land for agricultural activities.

4) The threat of disastrous landslides during building on steep slopes.


Major infrastructural developments are scheduled for completion by 1997 and beyond, in order to

KEY WORDS

Land Reclamations
Temperature Gauge - Measurements
Tide Gauges - Measurements
Crustal Movement
Storm Surge Records
Coastal Development
stimulate economic growth and to boost the confidence of Hong Kong people. Major schemes of coastal land reclamations are currently being planned by the Port and Airport Development Strategy (PADS) of the Hong Kong Government. These include the construction of a replacement international airport and new port facilities. The total capital expenditure for these works is estimated at over $US1.6 billion.

In view of the ambitious coastal development planned, it is essential to determine whether a future rise in sea level constitutes a real threat for the reclamations.

2. COASTAL LAND RECLAMATIONS

An account of the coastal land reclamations in Hong Kong was given in McBeat-Smith et al. (1989). Large ground surface settlements are known to occur in these reclamations as the result of the consolidation of marine clay layers where they have not been removed by dredging (see Foot et al. 1987). It is not uncommon for a 10m thick marine clay layer to take four years to achieve 95% consolidation, including 1.6m initial compression (McBeat-Smith et al. 1989). Although engineering solutions involving dynamic compaction, sand drains and surcharging are often employed during the construction period, long term post-constructional ground settlement has been detected in the past through surveying checks of bench marks located on reclamations (M.T. Wong, personal communication).

It is therefore possible for ground settlement to be misinterpreted as sea level rise, and it is necessary to quantify the rate of ground settlement to assist the estimation of the rate of sea level rise or fall.

3. ANALYSES OF TEMPERATURE GAUGE RECORDS

Global warming attributable to the greenhouse effect is not supported by temperature gauge records either in Hong Kong or its neighbouring city Macau over the past one hundred years. In an analysis of secular trends in the urban temperature of Hong Kong, Koo (in press) found that the increase in running mean temperatures of the Hong Kong urban station of about 0.7°C during the past century is best explained by the urban heat-island effect.

A gauging station located on a remote outlying island away from the urban areas of Hong Kong failed to show any clear-cut temperature rise during the past twenty years. On the other hand, the Macau urban station which is located near the southern limit of the Pearl River Delta approximately 40km to the west of Hong Kong, was found to show a marginal decline in running mean temperatures over the past century. This difference found between the Hong Kong and Macau urban stations may be explained by the enclosed nature of Victoria Harbour which is less favourable for heat dissipation.

4. MEASUREMENTS FROM TIDE GAUGES

There are at present nine tide gauges operating in Hong Kong (Fig. 1). The oldest station North Point has been in operation since 1952 but was relocated to Quarry Bay in 1986.

However, because the two stations are less than 1km apart, tide gauge data collected from Quarry Bay is used as continuous series. The uncorrected mean annual sea level at North Point 1957-1988, is shown in Fig. 3. A rising trend is indicated by the five-year running mean, and, from 1971 onwards, a positive deviation from the mean is discernible. This is in general agreement with the conclusions of Yim (in press) who found a mean rate of sea level rise of about 40 cm/century based on a graphical method of plotting the 1962-1986 mean annual sea level.
gauge stations are found to show a declining trend which is in agreement with North Point after correction for ground settlement (Fig. 4). Therefore uplift of the Hong Kong region as a whole is probable. Because of this, it is desirable to carry out geodetic surveying in the future to permit assessment of ground stability at these tide gauge stations.

5. SEISMOLOGICAL EVIDENCE FOR CRUSTAL MOVEMENT

In addition to tide gauge measurements, evidence for local crustal movement is available through the seismograph network established by the Royal Observatory in 1979.

Minor local earthquakes felt by residents but below a Richter magnitude of 2 are known in Hong Kong. For example, three were reported and discussed in Poon (1985). Such events may account for the uplift indicated by the record of tide gauges in addition to causing ground subsidence in reclamation.

Although a large proportion of microseismic events in Hong Kong are likely to be man-induced, through events such as blasting in quarries, rock slopes and tunnels, it is also conceivable that some are natural. The latter may be accounted for by the southerly migration of the Pearl River Delta causing loading on the crust and triggering earthquakes.

This is supported by two lines of evidence. Firstly, the Pearl River is discharging a considerable amount of suspended sediment load, estimated at 8,936 x 10^9 tons annually (Ren 1986). Secondly, both uplift and subsidence were identified within the delta region by means of radiocarbon dating (Huang et al. 1984).

The net effect of crustal movements on sea levels in the Hong Kong area is however poorly understood.
In an assessment of the geological factors influencing seismicity in Southern China, Lee (1981) suggested that Hong Kong lie within a weak local rift system. Based on this, both tectonically-induced uplift and subsidence may only have a minor affect on the sea levels.

Possible local uplift and subsidence are indicated by the record of the Macau-Sicia tide gauge station of Macau. From 1925-1974, this station was located on granitic bedrock where ground surface settlement may be ruled out, but in 1975 it was moved to a land reclamation site. The mean annual sea level trend for 1925-1974 is shown in Fig. 6.

A sharp fall followed by a rise in mean annual sea level is observed during the period 1960-1963 and 1972-1974 respectively.

Although it is dangerous to link these events to a single cause due to the complexity of factors involved in determining sea level elevations, two factors - earthquakes and rainfall - are particularly attractive as explanations.

Two major earthquakes with a Richter magnitude exceeding 6 located along a major northeast-southwest trending fault passing immediately to the north of Macau have been recorded within a radius of 250 km of Hong Kong (see Lee 1981). They were at Heyuan on March 19th, 1962 (M = 6.1) and at Yangjiang on July 26th, 1969 (M = 6.4). On the other hand, the annual rainfall recorded at the Royal Observatory station during 1963 was the lowest since the start of instrumental records began while both 1972 and 1973 were consecutive years with rainfall well above the mean, ranking eighth and second highest respectively.

Since rainfall is associated with depressions, and rainfall intensity in the Southern China region exerts influence on the estimated total annual mean runoff of 3,400 x 10^8 m³ (Ren 1986) from the Pearl River, sea level elevations would be affected.

Without further investigation, it is not possible to quantify the contribution due to earthquakes and variations in annual rainfall intensity.

6. ANALYSIS OF STORM SURGE RECORD

Hong Kong is influenced by extreme sea levels associated with tropical cyclones known locally as typhoons, during the summer and autumn. In the past some attention was devoted to the formation level of land reclamation with adequate protection from storm surges and rainstorm floods. Consequently, the land reclamation are already protected from a gradual rise in future sea level even though the stability of the ground is in doubt because of ground settlement.

A summary table of meteorological data and maximum sea levels of major tropical cyclones in Hong Kong from 1937 to the present day, is presented in Table 1.

It can be seen that the maximum sea levels recorded at the North Point, Chi Ma Wan and Tai Po Kau tide gauge stations are not consistent with each other. The difference found is attributed mainly to the location of the stations in relation to the coastal configuration and the track of the cyclones (Yim, in press). Tai Po Kau which is located in Tolo Harbour, land-locked except for a narrow opening in to the northeast (Fig. 1), shows the highest maximum sea level due largely to seiching induced by the Coriolis force. In contrast, Victoria Harbour in which North Point is located, has lower maximum sea levels because it is open both at the eastern and western ends.

The highest sea levels in Hong Kong are found to be associated with cyclones entering the South China Sea via the Luzon Strait where they would be able to

<table>
<thead>
<tr>
<th>Cyclone</th>
<th>Year</th>
<th>Knots</th>
<th>Pressure (in mbar)</th>
<th>Direction (in degrees)</th>
<th>Speed (knots)</th>
<th>North Point</th>
<th>Tai Po Kau</th>
<th>Chi Ma Wan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unnamed</td>
<td>1937</td>
<td>130*</td>
<td>949</td>
<td>296</td>
<td>15</td>
<td>4.05</td>
<td>6.25</td>
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<tr>
<td>Mary</td>
<td>1960</td>
<td>103</td>
<td>966*</td>
<td>305</td>
<td>12</td>
<td>2.77</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>Wanda</td>
<td>1962</td>
<td>140</td>
<td>944*</td>
<td>235</td>
<td>12</td>
<td>3.96</td>
<td>5.03</td>
<td>----</td>
</tr>
<tr>
<td>Ruby</td>
<td>1964</td>
<td>122</td>
<td>954*</td>
<td>203</td>
<td>11</td>
<td>3.14</td>
<td>3.54</td>
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<tr>
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<tr>
<td>Ellen</td>
<td>1983</td>
<td>128</td>
<td>960</td>
<td>305*</td>
<td>8</td>
<td>----</td>
<td>3.06</td>
<td>3.06</td>
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* Estimated
7. FUTURE COASTAL DEVELOPMENT

Based on the evaluation of local evidence, future coastal development must take into account:
1) The rate of future sea level rise or fall.
2) The amount of ground surface settlement.
3) Past storm surge levels.
4) Past rainstorm flood levels.

For facilitating the estimation of points 1) and 2), it is necessary that long-term ground settlement monitoring be carried out on all coastal land reclamation.

Two possible methods are suggested here. Firstly, bench marks and tide gauge stations on reclamation should be checked annually using state-of-the-art surveying methods against the nearest bench marks located on bedrock sites.

Secondly, satellite radar altimetry (Fig. 7) should be used annually to measure geoidal changes caused by crustal movement. In order to reduce the threat of storm surge flooding, the existing practice of adopting return periods of maximum sea levels as the formation level of reclamation should be even more conservative. Many old reclamation in Hong Kong are based on adopting a return period of 200 years (Table 2), the value used being a compromise between

<table>
<thead>
<tr>
<th></th>
<th>Station</th>
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<th>Tai Po Kau</th>
<th>Chi Ma Wan</th>
</tr>
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<td>10</td>
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<tr>
<td>1000</td>
<td>4.37</td>
<td>6.62</td>
<td>4.37</td>
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</tbody>
</table>

continue to pick up momentum.

In terms of casualties, storm surges are by far the worse type of natural hazards in Hong Kong. Two cyclones during 1906 and 1937, which were both accompanied by severe storm surges are documented to have estimated death tolls of 10,000 and above.

Since the majority of cyclones are invariably associated with heavy rainfall, their impact is, in reality, a combination of storm surge and rainfall runoff flooding.

In comparison to a gradual rise in sea level, cyclones associated with major storm surges and heavy rainfall are more threatening and are consequently of greater concern.

However, an examination of the annual total number of cyclones entering the South China Sea between 1946 and 1989 failed to show any increase in frequency.

storm surge and rainstorm flood levels. Consequently, the formation level does not offer protection against the higher storm surges. If the reclamation are to be protected from flood damage, the possible options are:

1) The construction of high dykes to protect reclamation from being overtopped.
2) The topping-up of low-lying areas prone to flooding, particularly during urban renewal.
3) The use of urban planning to zone land use according to tolerance to flood damage.
4) The installation of flood pumping stations in important development areas.

Of these options, point 4) is likely to be effective for rainstorm flooding only. As a preventive measure against storm surge flooding, high dykes appear to be the most cost-effective means to protect the important development areas, for the simple reason that they cause the least disturbance to existing land use.
8. CONCLUSIONS

No conclusive evidence has been found to show that the sea level has been rising in Hong Kong during the period in which tide gauge recording has been available. The analysis of data collected from tide gauges was found to indicate a slight decline in sea level when ground surface settlement correction is made. Such a relative decline in sea level may be misinterpreted as an apparent sea level rise because tide gauge stations located on coastal land reclamations may be subsiding at a rate faster than the rate of sea level fall.

Therefore, it is recommended that all tide gauge stations located on reclamations be checked for ground settlement annually by surveying to bedrock bench marks, and by the use of satellite radar altimetry. The latter would be particularly valuable for detecting geotidal changes in elevations related to crustal movement.

High sea levels caused by storm surges are of the greatest concern in the coastal land reclamations of Hong Kong.

Since the formation level of reclamations is a compromise between storm surge and rainstorm flood levels, the two are in conflict with each other. If the amount of ground settlement is large, the risk of storm surge flooding is increased.

On the other hand, if the formation level of reclamations is to be raised, the risk of rainstorm flooding is increased. Therefore, for reducing flood damage, high dykes, topping-up, urban planning and flood pumping stations are the possible options.

9. ACKNOWLEDGEMENTS

We are particularly grateful to the Chief Engineer (Port Works), Civil Engineering Services Department, and the Director, Royal Observatory, as well as the Hong Kong Government for providing information.

All opinions expressed in this paper are purely those of the author. I would also like to thank Dr. R. Wardlaw for Figs. 3 and 4, and the Macau Marine Department for Fig. 6.

This work forms part of a research project funded by the Croucher Foundation.

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THE IMPACT OF CLIMATIC CHANGE AND SEA LEVEL RISE ON SINGAPORE

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Abstract

The Republic of Singapore, located 1° 09′ N of the equator, consists of a main island and over 60 small offshore islets and reefs, occupying a total land area of 625.6km². It has a generally low relief, with more than 60% of land not exceeding 15m above SL. Much of the coastal area is flat and extensively modified by land reclamation. The island is divided into 40 drainage basins. Singapore’s economy and population began expanding in 1960, resulting in intensive development and build-up of infrastructure. The present coastline is likely to withstand a SLR of 20cm by the year 2025. However, a SLR of more than 1m is envisaged to have a significant impact on the Republic. Services, industries and recreational/tourism facilities located in low-lying areas will be most severely affected, resulting in disruption to economic growth. Flood alleviation schemes will have to be further improved and coastal sea-walls and embankments will have to be elevated and replaced to reduce the impact of rising waters. Land use patterns will have to be altered.

1. INTRODUCTION

The Republic of Singapore is situated 136.8km north of the equator between the latitudes 1°09′N and 1°29′N and longitudes 103°38′E and 104°06′E. It consists of a main island and some 60 islets, occupying a total of 625.6km² (Fig. 1).

Although small in total land area and lacking in natural resources, Singapore has emerged as one of the world’s important trade, communication, banking and industrial centres. This has been achieved through the development of an internal infrastructure and specialisation in service and secondary processing activities.

The main island of Singapore has a length of 41.8km and breadth of 22.5km, with no part of the island more than 15km from the sea.

The “coastal zone” considered in this paper is defined as an inland limit of 4km, which encompasses land uses which have a direct impact on coastal resources. Two climatic scenarios will be discussed. These are a 1.5°C increase in temperature, accompanied by a rise of 20cm by the year 2025 and a 4.5°C rise in temperature and accompanying 1.4m rise in sea level (after Devoy 1987).

This paper describes the major impacts that a climatic change and sea level rise would have on the physical, socio-economic and biological profiles of Singapore.

1.1 Climatic and physical features

The climate of Singapore is characterised by almost uniform temperatures year round (between 23°C and 30°C), high humidity (av. 84.5%) and a heavy annual rainfall of approximately 2400mm. The temperature, rainfall, wind and occurrence of storms are largely influenced by the 2 monsoons: NE monsoon (Dec.-Mar.) and the SW Monsoon (Jun.-Sept.) (Ng 1989).
Fig. 1. Singapore and its surrounding areas (Chia et al. 1989)

Fig. 2. Relief of Singapore (Chia et al. 1989)
Singapore has a moderately low relief, with more than 60% of the land surface less than 15m above sea level and only 10% above 30m (Fig. 2, Wong 1968). The mainland is drained by 40 drainage basins. Six of these waterways have been dammed and transformed into reservoirs. These coastal reservoirs store approximately 50% of the nation's open reservoir water (Chia et al. 1989). The total coastline length of the mainland and small islands is 193km (Kent and Valencia 1985) and can be categorised into several different types: artificial coasts, sandy/pebbly beaches, coral, mangrove, steep and cliffs (fringed by sandy/pebbly beaches).

A very large proportion (almost 70%) of Singapore's coastline is artificial (Fig. 3, Bird and Schwartz 1985, Wong 1985). These built-up coastlines consist of those built for the purpose of industry (docks, wharves); those created during land reclamation and those constructed as shore protection barriers. Extensive land reclamation in Singapore was carried out to meet the need for more land for housing, commercial, industrial and recreational developments.

Land reclamation has added a total of nearly 6000ha of land (10%) to Singapore's original 581km² (Fig. 3) at a cost of some $53.15 billion ($US1.63 billion). Two basic "types" of coastlines were formed as a result of land reclamation activities. These are sandy beaches broken by a series of sea-walls (bund-walls) and a complete sea-wall (containment dyke) fringing the entire stretch of reclaimed land.

The East Coast Park reclamation is an example of the former, while the Tuas, Marina Bay and the latest North-East reclamation are examples of the latter. Seawall construction costs may range from $5500 to $510,000 per metre, depending on the location, depth of the sea-floor, degree of coastal erosion, construction material and other technical considerations (personal communication with Dr Yong Kwet Yew, Civil Engineering Dept., National University of Singapore).

Other modifications to the natural coastline include the construction of wharves, docks, shipyards and other industrial-based structures and coast stabilisers such as concrete slabs etc. The waters around Singapore are characterised by low wave and tidal energy conditions with an average wave height of less than 20cm. Higher waves of approximately 1m in height occur during the monsoon season, but refraction and obstruction by shallow waters, islands and reefs reduce their effects at the shore. As a result, coastal erosion is comparatively low.

1.2 Socio-economic profile

The population of Singapore in 1988 was 2.64 million, with 75% of the working inhabitants engaged in the manufacturing, commerce, communications, financial and business services and construction industries. The coastal zone of Singapore, like most countries, is intensively utilised for many activities (Fig. 4).

On the mainland, more activities take place on the southern coast than the northern coast. From west to east, these include the industrial (light, heavy, marine, petrochemical) activities in Jurong; educational and training (tertiary institutions) in the Kent Ridge and Clementi area; commercial business and port activities in the Keppel-Shenton Way district; Government offices, tourism, shopping and recreational activities in the Marina Bay-Orchard area; residential and recreational activities along the East Coast and the International Airport at Changi.

On the northern coast, the coastal strip from the area north of Jurong to the Causeway (the bridge linking Singapore to West Malaysia) has been used for water storage (reservoirs), military activities, future agrotechnology parks and a small nature reserve. To the east of the Causeway, a power generation plant, manufacturing industries, shipping and marine industries are situated in Sembawang; fisheries, aquaculture activities and residential areas stretch from Seletar to Pasir Ris and the petroleum and other industries around Loyang (Chia et al. 1989). Land for traditional agricultural and aquacultural farming has been reduced considerably in recent years due to the demand by other sectors. It is expected that the existing 5000ha of traditional farming land will be diminished even further to 2000ha by 1995.

This has necessitated the change of farming strategy whereby agrotechnology parks will be introduced to improve production methods.
These agrotechnology parks will employ high level technology in farm practice and management and are expected to achieve an output of 80% of the present output ($S203.3 million gross domestic product, 1988) in the next decade.

Aquaculture, which includes floating farms in the sea, and land-based ornamental fish farms, shrimp farms and aquacultural nurseries are also being emphasised. Fig. 4 shows the location of these proposed parks and aquacultural activities.

The 60 islands in Singapore comprise the northern and southern islands. There are 43 southern islands and their utilisation can be broadly categorised into industrial, recreational and other uses.

The industrial uses include port facilities, oil refining and petrochemical industries and power generation. Thirteen islands have been designated as recreation and tourist spots. The other uses include military (live-firing zone and naval base) and navigational (lighthouses) uses (Chia et al., in press).

There are 4 major islands off the northern coast. Pulau (island) Seletar is a recreational park, while P. Serangoon has been joined to the mainland through reclamation. Aquaculture, recreational/educational (Outward Bound School), rock-quarrying activities are being carried out on Pulau Ubin. Pulau Tekong has been designated for military training.

1.3 Biological resources

The coral reefs of Singapore, approximately 66 in number, are almost all situated south of the mainland (Fig. 5). Of these, 40 are patch reefs and 26 are fringing reefs. Highly sedimented waters have caused a reduction of light penetration, thus limiting coral growth to only the upper reef slope (above a depth of 8m from the crest).

In spite of this, the coral reef community is rich with a diversity of some 51 genera of hard corals and 108 species of reef fishes (Chou 1986, Lim et al., in press).

The mangrove forests in Singapore have been reclaimed to create land for the developing nation and have declined drastically, now occupying only 600ha (Fig. 5, Corlett 1987). The remaining forests are situated mainly on the coast north of the mainland along the many northern rivers and the islands of Pulau Ubin, P. Tekong and P. Semakau.
2. POSSIBLE IMPACTS

Past experiences with floods in Singapore may give some indication of the effects of sea level rise. Three major floods, in the years 1954, 1969 and 1978 have occurred, resulting in the inundation of some 10% of the island (Foo 1986). Causes of past floods include physiographic effects; increased runoff caused by urbanisation and a poor drainage system. Although these floods did not result in the loss of life, they did cause damage to property, including public roads and buildings and they disrupted the lives of the people.

Several solutions have been adopted by the Drainage Department of the Singapore Government. These include careful land-use planning; improvement of the drainage system through canalisation, widening and deepening of water courses; installation of tidal gates at the main water-courses; filling and raising of low-lying areas (including roads). Approximately $8100 million has been spent annually on flood alleviation schemes in the past few years.

The impact of sea level rise on the coasts of Singapore depends on the coastal type. Most existing artificial coasts in Singapore (wharves, sea-walls) are likely to withstand the 20cm rise. However, coastal erosion is also expected to increase and coast protection structures will have to be regularly maintained, elevated, repaired or replaced. With regards to salt-water intrusion, a large proportion of existing walls are rip-rap barriers (with a concrete layer), which render them relatively impermeable. As sea level rises, less protected coasts like the reclaimed beaches of the east coast, beaches on the mainland west coast and some of the southern islands, will be inundated landwards, reducing the existing narrow belts even further.

The increase in wave and current action would cause greater erosion, resulting in the transportation of beach/reclamation fill material away from land, not to mention the further landward erosion. Mitigation measures, on a site-specific basis, will be required. To prevent the effects of sea level rise from reaching inland through the waterways and causing flooding, the presently efficient drainage system and flood alleviation schemes might have to be further improved.

It is expected that the climatic change will not affect production of the land-based agrotechnology parks as these make use of controlled conditions to a large extent. The existing aquacultural practices of floating fish farms, shrimp farms and aquacultural nurseries will, however, be exposed to changes in weather conditions. Floating fish farms will not be adversely affected by the rising sea level but the consequent change in water conditions may affect plankton populations, which in turn may affect fish stocks. Coastline-based shrimp farms and aquacultural nurseries may face some problems regarding protection of their seaward facilities.

A predicted rise in temperature is likely to increase personal discomfort of the people and affect refrigeration units which will necessitate the use of

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*Fig. 5. The biological resources of Singapore*
more energy to maintain present levels of temperatures within buildings. The 20cm sea level rise by the year 2025 implies a 5mm/yr rise. Present knowledge of coral reef dynamics (Hopley and Kinsey 1988) indicate that reefs will most likely be able to cope with this rate of increase. The predicted rise will probably shift the reef zones further landward. It is also expected that hermatypic corals would not be able to survive in the lower parts of the reef (presently below a depth 8m from the crest) as low-light conditions would be further reduced. These changes to the coral community would consequently affect the other reef organisms.

A rise in sea level would bring about increased exposure to salinity in the stressing dwindling belts of mangrove swamps in Singapore. The effect on the mangroves would depend on the specific tolerance of the species living in them.

3. DISCUSSION

Singapore is situated in a geologically stable area of the Sundaland, with virtually no problem of tectonic subsidence. The only potential problem to be tackled in the next century could be that of sea level rise. Two main strategies identified for responding to the rise in sea level are coast stabilisation and strategic retreat. In the case of Singapore, where land is a very scarce commodity and reclamation works have been embarked upon to meet these needs, there is no choice but to adopt the former option of coast stabilisation. This is a costly move, but necessary as Singapore has much to lose should its present coastal zone be inundated.

Present considerations of the coast situation in Singapore indicate that a sea level rise of 20cm by the year 2025 would be of some, but not formidable consequence. The main impact will be the financial resources needed to deploy shore protection measures of maintenance, elevation, replacement and the redesign of existing shore protection structures. Several potential problem areas include the limitation of land for the expansion of the present drainage system; salt-water intrusion into coastal reservoirs which would threaten fresh-water supply; increased erosion of open, unprotected beaches; and the deterioration of a proportion of the biological resources, especially mangroves. The scenario pictured so far is only the minimal effect of climatic and sea level rise prediction. The effect on Singapore of a 4.5°C rise in temperature and its consequent 1.4m sea level rise would be quite different. Sea-walls and other artificial coast protection structures will have to be elevated further and low-lying areas, including reclaimed land, may have to be raised. It is expected that relatively unprotected coasts, e.g. East Coast Park and West Coast Park would be faced with the threat of severe erosion and recreational facilities and residential areas affected. Loss of land can also be expected for the islands, as the shores are being inundated. The 4.5°C temperature increase will have more drastic impacts on the global weather system. Climate models developed by GISS (Goddard Institute of Space Science, USA) adapted to the region, suggest an increase in annual rainfall of 5-10% for Singapore (Chong 1989).

This increased rainfall will add to the problem of the rising sea level. Indirectly, water conditions will be affected (salinity) and consequently the biological resources of shorelife, coral reefs and mangroves. Flooding may become more frequent, causing disruption to people.

At present, sea level rise implications are not taken into consideration in master plans for future development (Anon 1989). Large scale plans for the development of coastal areas for recreation and other purposes have been presented with a view to raising the quality of life for the citizens and these may have to be reviewed when the seriousness of a real sea level rise becomes fully realised.

4. ACKNOWLEDGEMENTS

We would like to thank Miss Cynthia Lee from the Department of Zoology and Dr Yong Kwet Yew from the Department of Civil Engineering, National University of Singapore for their valuable contribution.

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CAUSES AND THE PERFORMANCE OF THE CONSTRUCTION WORK FOR FLOOD TIDE PREVENTION IN SHANGHAI

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1. THE GEOGRAPHICAL ENVIRONMENT AND THE TYPHOON SURGE DISASTER OF SHANGHAI

Shanghai is situated at the front edge of the Yangtze River delta. It is downstream of the Taihu Lake basin, along the Huangpu River and near the East Sea. The Huangpu River as well as Suzhou Creek pass through the urban districts and countryside, and act as the stem of busy transportation river network. Shanghai is a seagoing harbour city and occupies a key position for inland navigation as well (Fig. 1). The stratum of Shanghai was deposited gradually through silt accumulation beginning thousands of years ago. Ground elevation is about 2.5-6m (Wusong datum). The elevation of the urban districts is between 3-3.5m, that is lower than the high tide level the spring tide.

Shanghai has the monsoon climate of the north subtropical zone, warm and wet with adequate rainfall. Annual average precipitation is 1100mm. Owing to the Typhoon, there is heavy rainfall and frequent high tides every July to September.

The water level of Huangpu River and Suzhou Creek, which both flow across the urban districts as the tidal waterways, rise and fall twice every day. If the typhoon coincides with an astronomic tide, there will be a surge flood which will threaten the safety of the town.

Since the beginning of the 20th century, there have been eleven storm surges, five of which occurred during the last forty years.

July 25th 1949 saw a typhoon surge tide and heavy rainfall in Shanghai and the highest water stage was recorded as 4.77m at Huangpu Park tidal gauge station. The majority of the urban district was submerged with a water depth of 0.3-1.0m.

On August 2nd 1962, a typhoon was blowing 250km beyond the Yangtze River estuary, and the maximum high water level appeared as 4.76m at Huangpu Park station. Due to poor construction defences to resist the surge flood at that time, the dyke along Huangpo River and Suzhou Creek was breached in 46 places.

Half of the urban district area was submerged by a water depth of 0.5-0.7m. A lot of factories stopped production, urban traffic was halted in most of the town and economic loss was serious.

Then, on August 20th 1974, there was another high water record at Huangpu Park station caused by typhoon No. 13. The water level of 4.98m broke the historic high water record.

As it was dependent on the floodwall which had been constructed previously, only ten places along the river shore that were the joint part between the urban and countryside were breached, so damage was not extensive.

But the floodwall was low and simple.

Not long afterwards, on September 1st 1981 typhoon No. 10 blew hard in the proximity of the city.

KEYWORDS

Shanghai Case, Subsidence Rate, Typhoon Surge Effects, High Tide, Progressive State, Ground Settlements, Monitor, Control, Dykes, Locks, Sea Level Rise, Probability, Flood Defences, Engineering Measures, Prevention, History

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2. THE ANALYSES OF CAUSES IN REGARD TO THE PROGRESSIVE SERIOUS STATE OF HIGH TIDES

Since the record of high tide level has been broken twice within fifteen years, the causes are analysed as follows:

2.1. Ground settlement

It is difficult to know exactly when ground settlement started in Shanghai. According to the historical records, settlement measured by repeated level surveys was only 0.013ft (3.9mm) 1910-1919. This means that, before then, there was no noticeable ground subsidence.

But in 1929-1948, day-by-day ground settlement took place in urban districts. Statistical data showed that the annual average settlement was 24mm, and totalled maximum settlement even reached 1136mm at individual points. Two ground sinking funnels were formed. The 500mm area of sinking enlarged to 19.3km². From 1949-1961, the sinking area continued to grow. In the first eight years, the annual average settlement increased to 40mm, and the 500mm sink area grew by 7.4km².

However in the following five years annual settlement reached on average 110mm, and the 500mm sinking area increased by 66.1km² and developed as far as the peripheral region. It was apparent in this period that both settlement and subsidence rates were high.

The serious situation relaxed in 1962-1976. The ground level had risen at the beginning of the 70s, then stabilised with only some settlements. The main cause of ground settlement is the excessive pumping of groundwater (Fig. 2).

Before the 20s, Shanghai was not industrialised and the utilisation of underground water was not common. Since the 50s, owing to the industrial development, the quantity of ground water pumped was gradually increased, even out of control.

New ground sinking funnels were formed in the industrial region. Not until the middle of the 60s did water exploitation begin to be limited, and measures to raise the ground level taken.

First the administrative authority limited water exploitation, then it was decided to replenish groundwater. As a result, the underground water table rose gradually as did the ground level.

After the use of this technique spread, the ground rose over a large area of 119.7km² and the maximum value was about 53mm. But in the suburban district, owing to the lack of water supply, water exploitation still continued to a large extent, so noticeable settlement did not stop.

But in general, the ground subsidence was effectively controlled (Fig. 3).

Excessive exploitation of groundwater is then the

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The historic high water record was broken once more. Although the floodwall had been raised along the whole line of river shore since 1974 and emergency measures had been taken for receiving the flood water into tributaries, the water level still rose as high as 5.22m and it was only 0.5m beneath the top of the floodwall.

Fortunately the dyke was not breached and there was minimum water spill. They were very dangerous circumstances. Recently this year, the high water level rose once more over 5m, so flood fighting tension occurred again, but no damage was done.

Thirty years ago there was no floodwall along the river shore, only steel chain and posts.

Nowadays the floodwall has not only been constructed but also strengthened several times to deal with the progressive increase in the height of the water level. Why is this so? The reasons are as follows:

1) Excessive pumping of the underground water causes serious ground subsidence;
2) The floodwall and a lot of locks have been built at the mouths of the tributaries of the Huangpu River, so the flood water accumulates in the main river itself, not spreading upwards, causing the tide level to rise;
3) Global warming will influence sea level rise, though it may be the least important reason at present in Shanghai.
external cause of ground subsidence and the existence of the compressive stratum is the interior cause. Total settlement 1921 to 1980 was 1.77m and increased to 1.80m in 1987. From 1976 to 1987, annual average settlement data was as follows:

<table>
<thead>
<tr>
<th>Year</th>
<th>Settlement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1977</td>
<td>+2.4mm</td>
</tr>
<tr>
<td>1978</td>
<td>-7.4mm</td>
</tr>
<tr>
<td>1979</td>
<td>-1.1mm</td>
</tr>
<tr>
<td>1980</td>
<td>-5.2mm</td>
</tr>
<tr>
<td>1981</td>
<td>+4.3mm</td>
</tr>
<tr>
<td>1982</td>
<td>-3.7mm</td>
</tr>
<tr>
<td>1983</td>
<td>-1.5mm</td>
</tr>
<tr>
<td>1984</td>
<td>-8.3mm</td>
</tr>
<tr>
<td>1985</td>
<td>-6.1mm</td>
</tr>
<tr>
<td>1986</td>
<td>-4.2mm</td>
</tr>
<tr>
<td>1987</td>
<td>-13.6mm</td>
</tr>
</tbody>
</table>

Total settlement of 1.8mm would thus be the main cause of the high tide menace. It is also the motive for constructing the floodwall along the river shore to replace the original railing and furthermore for strengthening it as well as building the storm surge barrier.

2.2. The construction of the floodwall along the Huangpu River and the many locks at its tributaries

The flood water accumulates in the main river, and does not spread up, thus raising the tide level. There are a lot of tributaries along the Huangpu River, and as many as sixty zigzag through the urban districts and the countryside. The delta plain of the lower Yangtze River is criss-crossed by a dense network of rivers and canals. Since the 60s a lot of locks have been built one after another at the mouth of most of these tributaries as defence from tidal intrusion. The floodwalls were further constructed on the banks of the Huangpu River to withstand the high tide, so the flood water will accumulate in the main river to let the water level rise. It is a fact that the tidal level at the Huangpu Park station increases today 10-20cm compared with that of the same station before 1962, even with the same tidal level at downstream Wusong station.

2.3. The probability of sea level rise.

The cause of sea level rise all over the world is complicated. Scholars both in China and abroad are studying the probable ranges rising from the present to 100 years in the future.
Estimates of the range are usually conservative such as a sea level rise of 40-50cm to 2085. During the past 100 years (1880-1980), the sea level rose 10-20cm. But in certain places, the change in sea level has differed greatly in recent times.

Changes in sea level owing to the global climate change cannot be the same in different places. The most important thing is not the theoretical global change in sea level, but the actual change of relative sea level as it happened in the different places.

Analysis of the data from twenty tidal gauge stations along China's east coast during the 1950s showed that the relative sea level for the greater part of the sea shore rose; only four stations (Quing Dao, Yan Tai, Ru Shan Kou and Shi Jiu Suo) showed a stable relative sea level.

As for the other two stations (Lian Yun Gang, Wusong) the relative sea level fell in contrast. The sea level at Wusong station was 2.21m in 1950, but 2.05m in 1980, a fall of 0.12m in 30 years.

The cause is very complex.

The west bank of the Bo Sea belongs to a district subject to subsidence caused by modern tectonic movement; it is affected by earthquakes and overpumping of subground water, so the relative sea level along this coast rose overall.

At Tang Gu station in particular, the range was wide-ranging: from 1950-1981 there was an annual average rise of about 0.81m.

From Yan Tai to Shi Jiu in Jiao Dong Peninsula, the earth crust along the coast belongs to the modern stable district, so there was no fundamental change in the relative sea level there over these twenty years.

This was especially true for the Quing Dao tidal gauge station whose mean sea level over seven years (1950-1956) was defined as the unified datum of the country, that is named the "Yellow Sea Mean Level". Quing Dao Station is located in an area of solid rock with stable earth crust, facing the deep sea, with no large rivers flowing nearby, so its relative sea level was fundamentally stable from 1952-1986.

For instance it was 2.44m in 1952 and 2.42m in 1986, a difference of only 0.02m.

Over 35 years, the maximum mean sea level was 2.49m (1964), and the mean sea level was 2.36m (1968) (Fig. 4).

According to another report, the relative sea level rose 8.4cm on average, from 1950 to 1980 along China's eastern sea coast. Emory et al. used the data of eight tidal stations of China (including Hong Kong), then reached a rate of rise of 2.5mm/a, meanwhile Wang Zhi-hao's report stated that the rising rate was 3.5mm/a by using the one element regression method.

It is noticeable that the climatic and eustatic curves of China from 1890 to 1970 coincide very well (Fig. 5). During the so-called "warm epoch of the 20th century",...
the 1935-1940 air temperature was 1°C higher than that in the 1880s, and consequently the sea level 1935-1940 as recorded by the tidal gauge of Wusong near Shanghai, was 20 cm higher than 1910-1920. Tidal gauge stations all over the world were recording the sea level rise during this period. The rising rate of sea level fluctuation calculated by different authors was about 1.0-1.1 mm/a.

In the case of Wusong the sea level fell a little after 1950, but the sea level recorded for Luhua San, not very far from Wusong, was basically stable from 1963-1981.

Therefore, the long-term change in sea level at Wusong is very complicated. Mean sea level may be influenced by the Yangtse River run-off. The change in relative sea level at Wusong over the last seventy years cannot be totally explained by the cause of crustal movement there. Study on the problem of the sea level rise is under way at present. Different scholars have different ideas. Some Chinese research indicates the rising rate from to be between 3.15 mm/a and 5.5 mm/a, and the mean value about 3.15 mm/a.

Following the above mentioned analysis, of sea level rise protection from high tide is considered in the long-term programme to be on the safe side.

3. WAYS OF DEALING WITH FLOOD TIDE DEFENCE AND THE ENGINEERING MEASURES

Ways of dealing with defence against the flood tide are: to continue controlling ground subsidence and to construct engineering works for the prevention of the flood tides.

3.1. Controlling the ground subsidence

To bring the ground subsidence under control means essentially checking groundwater extraction. Based on the subsidence mechanism researched, recovering and raising the level of the ground water are the main measures for controlling ground subsidence. At first, the quantity of groundwater exploited has to be limited in the urban districts in a planned way, then put to rational use. Since 1963, on the condition that normal industrial production had to be guaranteed, some works have been carried out to limit the exploitation of ground-water and the results have been good. Water extraction in urban districts in 1964 was 81% of 1963, and that of 1965 was 41.9% of 1963.

Up until now, the annual water exploitation amounts to about 110 million tons, of which 100 million tons are from the countryside and 10 million tons from urban districts.

Besides the limitation of exploitation of groundwater, the other measure taken was to feed water into the ground in order to promote a rise in the groundwater table. Since extraction work has always been carried out in a concentrated form in summer, many deep wells were left unused in winter, so these double-use wells can be used for the refilling. Low temperature water is fed into the water-bearing stratum which then provides a cold resource used to supply air conditioning and cooling water in summer. Refilling has been practised since 1965, increasing in amount year after year.

For example, total refill water in 1970-1976 was 114 million tons, as the total exploitation in that period was 78.8 million tons, so the artificial supplementary water in the stratum was 35.2 million tons to make the level of underground water rise. The third effective measure is to adjust the layer of stratum for extraction.

Ground settlement control in urban districts by means of different kinds of measures seems effective and produces comprehensive effects.

3.2. Flood prevention based on the analysis of tidal stage

Wusong tidal gauge station was set up as early as 1912 and the Huangpu Park tidal gauge station was established in 1915. Both have carried out continuous hydrological observations since then.

The water levels of the Huangpu River mainly fluctuate with the tide, but they are also affected to a certain degree by the power of the wind, especially typhoons which will raise the river level considerably. Levels affected by the Yangtse River in flood, the run-off of the Huangpu River and the heavy rainfall in urban districts are of less importance.

The Huangpu River behaves abnormally, with a half-day shallow sea tide. The historical maximum levels at Wusong station and Huangpu Park station are 5.74 m and 5.22 m respectively, with historical mean levels of -0.25 m and 0.24 m. To work out the frequency according to the tidal data of Wusong and Huangpu Park stations, accompanied by the study of probable maximum tidal levels from contributing meteorological factors, the high and low tide stages were analysed.

Shanghai is the largest city in China, with an urban population of 7.22 million people. A safeguard for flood tide prevention has to be guaranteed. Furthermore, there are a lot of underground facilities and installations. If there is flood intrusion not only will production be influenced, warehouses submerged, transportation brought to a standstill and simple houses collapse, but human injury and even death could be caused. Damage would exceed any historical disaster. The criterion of flood prevention for many important cities both at home and abroad at present, concerns a period of more than one hundred years. So we have to raise this criterion from the current less than one hundred years to one thousand years to withstand the high tide level.
This standard has been approved by the administrative authority.

3.3. The engineering measures to prevent the flooding tides

According to the newly-approved criterion concerning defence from high water level over 1000 years, recurrence and the actual existence of the current floodwall in urban districts, the engineering measures to prevent flooding are: to build a storm surge barrier at the mouth of Suzhou Creek that is kept open at all times, except for the few hours when it provides protection from high tide; to raise and strengthen the floodwall along the Huangpu River and some of its tributaries. The floodwall has developed gradually by units along the river banks. In different periods, it has had different defensive water levels and a different top elevation. The floodwalls constructed earlier had already been raised and strengthened 2-3 times in general, but still did not have the uniform technical criterion for the structural design of the floodwall. According to the new defensive water level and structural criterion, the existing floodwalls have the following problems:

a) The top elevation of the wall is not totally satisfactory, but will have to be raised;
b) Till now, the constructed floodwalls do not form closed confines for safeguarding from a flood;
c) Part of the wall structure is not safe enough, and in terms of the defensive water level and design criterion, its strength and stability are unsatisfactory;
d) Though the most of the floodwalls have been raised many times, foundation treatment was not carried out;
e) There are 56kms of floodwall along Suzhou Creek, the safety and the stability of which are unsatisfactory. Both the wall and the foundation will have to be strengthened, but it is comparatively difficult.

After comprehensive proof of the necessity, the engineering measures to prevent the flood tides are as follows:

a) To build a storm surge barrier at the mouth of Suzhou Creek;
b) To raise and strengthen the 208km long floodwall along the Huangpu River and its tributaries (including the outbuilding of the floodwall at the bund of Shanghai);
c) To raise and strengthen 47 locks at the tributaries of the Huangpu River;
d) To encircle the isolated district by floodwalls to prevent flooding.

The engineering characteristics of the Suzhou Creek barriers (Fig. 6) are as follows:

a) One opening barrier spanning 60m;
b) The barrier is constructed on the silty clay foundation, the water content of the clay is saturated, so it is high in compressibility. The foundation treatment of the barrier is complicated but it is an important technical work;
c) The Suzhou Creek barrier has long been of importance. The transverse axis has a small bend, with two staggered abutments and the still beam possesses a parallel quadrilateral form;
d) Suzhou Creek is an important navigation channel handling up to 17,000,000 tons of cargo a year, with 1390 vessels passing day and night, so a river block cannot be permitted. A lot of structures have to be precast, floated to the site and sunk at the place;
e) Suzhou Creek barrier is located at the bund of Shanghai, and as architectural art is as important as environmental harmony, the barrier should not influence the landscape of the bund;
f) There are a lot of high buildings around, such as the Shanghai Mansion (Broadway was its old name), so these buildings are guaranteed safe during construction.

According to the characteristics mentioned above, the final design of the barrier results in:

a) The barrier being kept open normally and closed for a few hours in case of high tide. At ordinary times, the gate is set beneath the bridge.
When there is high tide warning, the gate's lock is released and the gate will rotate downward to close the barrier. So, ordinarily it seems like a bridge not a barrier. In this way the problem of the environment is settled (Fig. 7).

b) To divide the 60m of such a big gate into 17 leaves with 3.6m widths, the leaf is hinged on the top with the box girder of the bridge. While the gate is closed, it is stopped by the still beam of the barrier. By means of the physical model test, only a single hinge on the top of the leaf is used (two wheels on each side) to connect with the bridge in order to adapt the deflection of the bridge as well as to avoid the influence of the unfavourable vibration.

c) The pile foundation with caisson, acts as the base of the abutment. The pile is driven into the hard stratum to bear the comparatively large vertical load, whereas the caisson will bear the large horizontal force.

d) The still beam is a precast cellular structure and is the base protection of the barrier as well as the bottom support of the gate. The still beam is supported by the caisson in order to maintain the same settlement as the abutment.

4. PROJECT PROGRESS AT PRESENT

There are more than 200kms of floodwall along the Huangpu River and its tributaries. They are divided into several hundreds segments that are already under construction or are going to be constructed. The time limit is about 7 years.

The construction of the Suzhou Creek barrier has started, with concrete being poured into the big precast still beam. Pile driving work is over and the steel caisson has been floated to the site. The steel cofferdam has to be connected and installed on the top of the caisson. Once installation is complete, the caisson will be sunk until the bottom piles have been cased up for connection, then concrete poured to solidify the caisson and the pile as one unit. This work is being carried out at present. It is estimated that the barrier will be completed in 1991.

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EFFECT OF SEA LEVEL RISE AND LAND SUBSIDENCE ON THE YELLOW RIVER DELTA
A Preliminary Study

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Abstract

The Holocene Yellow River Delta, with an area of 250,000km², is one of the largest deltas in the world. This paper focuses on its coastal plain, including 3 younger deltas, i.e., the delta near Tianjin, the Modern Delta and the Abandoned Delta. In the first two deltas, land subsidence, both natural and man-induced, is serious and recent sea level rise is mainly relative and a result of land subsidence. The major direct impacts of relative sea level rise on the Yellow River Delta are submergence and salinity increase. As a great part of the three younger deltas is less than 2m a.s.l., with a rising sea level, the danger of submergence is great, especially during storm surges. With a rising sea level, the low-lying coastal plain will increasingly suffer from salt-water intrusion and drainage will be more difficult. Decisive action is urgently needed to avert or mitigate adverse effects.

1. GENERAL GEOGRAPHIC BACKGROUND

The Yellow River Delta, well-known as the cradle of Chinese civilization, is a unique delta in the world. Owing to its huge sediment load (average 16x10 tons/yr at Sanmenxia and 10x10 tons/yr at Lijin, about 100km from the sea) and frequent shifts of the lower course over an extensive area spanning more than 6 degrees latitude, the Yellow River has built a huge Holocene delta with an area of 250,000km² (the area of the Holocene Mississippi Delta is 50,000km²). On the coastal zone, three recent deltas can be distinguished. From north to south, they are (Fig. 1): 1) an ancient delta in the vicinity of Tianjin. It is an aggregate of 5 deltas formed successively between 4,000 and 360 B.P., viz.

![Fig. 1. Changes of the lower course of the Yellow River, 1128-1855 A.D.](image-url)

KEY WORDS

Sea Level Rise
Land Subsidence
Yellow River Deltas
a) a delta north of Tianjin formed before 3,000 B.P.
b) a delta south of Tianjin formed around 3,000 B.P.
c) deltas further south, formed successively around 2,200 B.P., 2nd-3rd century A.D. and 400-1,100 A.D. (Fig. 2).

Because the Yellow River was abandoned early on, the coast of these deltas suffered erosion for a long time and no trace of the morphology of the deltaic coast remains. But 4 rows of cheniers on the coastal plain bear clear witness to the former deltaic coast line. 14C dates of these cheniers can be approximately correlated with the formation age of these deltas (Fig. 3, Table 1).

The area of the ancient deltas is extensive because at the apex of 3,000 B.P. and 2,200 B.P. the deltas were located more than 200km from the coast. Their coastal zone, as delimited by the 4m contour, is 50-60km wide and more than 150km long, with an area of about 6,000km² (Fig. 4).

The area is rich in land and offshore oil resources and has large salt farms producing 4 million tons of salt a year. At present it is the most important industrial centre in North China, with large petro-chemical and salt-chemical industries.

Tianjin, the largest city in the area, lies seaward of the 4m contour and has an urban population of 5.5 million (1986).

<table>
<thead>
<tr>
<th>Location</th>
<th>Age (yr BP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4th chenier Tongji-Miaozhuang</td>
<td>4700 - 4000</td>
</tr>
<tr>
<td>3rd Chenier Zhangguizhuang</td>
<td></td>
</tr>
<tr>
<td>Jugezhuang-Changzhuang</td>
<td>3800 - 3000</td>
</tr>
<tr>
<td>2nd Chenier Baishaling-Nigu-Qikou</td>
<td>2500 - 1100</td>
</tr>
<tr>
<td>1st chenier Changtougu-Tanggu-qikou</td>
<td>(probably) 600 - 500</td>
</tr>
</tbody>
</table>

Fig. 3. Cheniers on the west coast of the Bohai Gulf.

It is the third largest city in China and is one of the three Chinese cities with the status of a province. With its outport, New Port, 50km away, Tianjin is the major sea port for Beijing and a considerable part of North China.

2) The Modern Delta. It is formed by the present Yellow River which entered the Bohai Sea again in
1855. With its apex near Ninghai, it has an area of 5,400 km². The modern delta is not so well developed, but with the development of rich oil resources since the 60s, it has become the centre of the second largest oil field in China, and produced 32 million tons of crude oil in 1987. A large oil terminal and sea port, Huanghe Sea port is presently under construction. The potential for future economic development is promising.

3) The Abandoned Yellow River Delta. Located in Jangsu Province in the south, the Abandoned Yellow River Delta was formed during a major shift of the river’s course southward between 1128 and 1854. It has an area of 7,100 km² and is also an important producer of salt (2 million tons/yr.). An extensive coastal plain and wide tidal mud flats in the south were also built by Yellow River silt.

2. SEA LEVEL RISE AND LAND SUBSIDENCE

Relative sea level changes in the last 20-100 years have varied considerably in different parts of the world. A major factor is crustal subsidence. Recently, Fairbridge pointed out that about 60% of the United States coastline is involved in varying degrees of crustal subsidence, so that the problem of land subsidence is not just a local one. (Fairbridge, 1989). In a recent conference of SCOR in Mexico, 1988, there was prevailing scepticism as to whether or not the sea level will rise substantially, and evidence was presented to suggest that relative sea level rise was mainly a result of coastal subsidence (Healy, 1989).

This is also true for the Yellow River Delta area. Table 2 shows relative sea level changes over the last 20-30 years at stations in the Yellow River Delta and its adjacent areas (Table 2, Fig. 5).

From the table, it is evident that relative sea level changes in this area are quite complicated. Two most remarkable facts can be pointed out. The first is the Bohai Sea coast. It is an area of recent severe seismic activity, where the great Tangshan and Haicheng earthquakes of magnitude 7.8 and 7.3 (Richter Scale) and a submarine earthquake in the Bohai Sea of magnitude 7.4 took place in 1976, 1975 and 1969 respectively (Fig. 6).

The effect of the Tangshan earthquake on sea level can be seen in a dramatic way in the tidal gauge record of Tanggu Station, 78km from the epicentre. On July 28, 1976 when the severe earthquake struck, Tanggu Station registered a sudden sea level fluctuation of 72cm (Liu, 1984, Fig. 7).

Moreover, the great earthquake triggered liquefaction of sandy soil, resulting in ground subsidence of 10-50cm over a large area near Tanggu in 1976. Therefore, total subsidence at Tanggu was 2.85m between 1955 and 1985, averaging 9.3 cm/yr, in 1976 alone however, the ground sank 23.0cm (a part of the subsidence is due to over-exploitation of groundwater, see next paragraph).
Fig. 5. Relative sea level changes in China in the last 20 - 30 years
Tectonically, the Tanggu area is crossed by a large active fault, the Haihe fault, along which small earthquakes are frequent. Between 1963 and 1976, 5 earthquakes of magnitude 3-4 were recorded. Precise levelling shows that Tanggu is located in the centre of recent crustal sinking (more than 40mm between 1952 and 1972, National Seismological Bureau, 1977), (Fig. 6). Over-exploitation of groundwater greatly exacerbates ground subsidence. Today, a large ground sinking funnel, with an area of 241.2km², has formed in the coastal plain near Tanggu where total subsidence amounted to 1.31 to 2.13m between 1957 and 1981 (Fig. 8). Therefore, all stations on the Bohai Sea Coast record a rising sea level (Stations 1-6 in Table 2); the largest is Tanggu (0.81cm/yr.), and its adjacent station, Beipotai which has the longest record in the country (0.34cm/yr., 1910-1979) (Pang., 1987). Both are located in the centre of crustal subsidence with large amounts of over-extraction of groundwater.

Fig. 6. Major active faults, epicentres and rate of crustal sinking (mm 1952-1972) in the Bohai Sea area.

Fig. 7. Effect of Tangshan earthquake, July 28, 1976 on tidal gauge record (cm above 0 datum), Tanggu Station.
Fig. 8. Epicentres, ground sinking funnels and major faults in the Tanggu area.

In 1952 to 242cm in 1966, with the highest value of 249cm in 1964 and lowest value of 236cm in 1968 (Fig. 9). The striking contrast of relative sea level records between stations on the Bohai Sea coast and those on the coast of Shandong Peninsula substantiates the conclusion of the scientists of the SCOR conference, that relative sea level rise was mainly a result of crustal subsidence.

Therefore, in studying relative sea level changes, great attention must be paid to the problem of land subsidence, both natural and man-induced. The other 3 stations (Stations 11-13) can only be briefly mentioned. Lianyungang (Station 11), to the north of the Abandoned Yellow River Delta, but located on the rocky coast, has a substantial falling sea level. The reason for this unusual phenomenon is not clear and awaits further investigation.

Wusong, near Shanghai, also has the longest record in the country. It is located at the mouth of the Yangtze River and is greatly affected by the river's huge discharge.

Its record of large falling sea level therefore has little to do with global sea level changes, as can be clearly seen by a comparison with the record of Luhuashan (Station 13), a rocky island 68km offshore, which registers a stable, instead of a falling sea level (Ren, 1988).

3. EFFECT OF SEA LEVEL RISE

Although there is much dispute and uncertainty concerning the magnitude of sea level rise, the best estimate would seem to be about 50-100cm over the next century (Hekstra, 1988).

Also, whatever the cause of relative sea level rise, global sea level rise or local land subsidence, or a combination of the two, the effect on deltas and lowlands is the same.

Therefore, the threat of future sea level rise should be taken into serious consideration.

Assuming a relative sea level rise of 1m over the next century, the major impact on the Yellow River Delta and adjacent coastal lowland may be briefly outlined by regions.

3.1. Ancient Delta

a) Submergence and salinity increase.
The low-lying coastal plain around Tianjin, delimited by the 4m contour on the landward side and including the metropolis of Tianjin, has an average gradient of 0.1%. A greater part of the plain is below 3m a.s.l. and some areas are below 2.5m and 2m a.s.l. Therefore, a large part of the densely populated plain is extremely vulnerable to a 1m sea level rise, especially during storm surge.

In this area, severe storm surges caused by winter storms and typhoons, are frequent. Over the one hundred years before 1949, there were 7 severe storm surges during which the sea inundated an extensive area 15-50km from the coast.

For example, in storm surge conditions on August 31, 1939, the highest water level at Tanggu was 4.6m above 0 datum (mean sea level); in the storm surge, August 16-20, 1985, it was 5.28m a.s.l. and in the storm surge, April 28-29, 1985, an extreme high water level of 6.1-7.0m a.s.l. was recorded.

The present sea dykes are neither strong enough nor high enough (about 4m high) to cope with severe storm surge. Therefore, during the storm surge of August 1985, many parts of sea dykes in the Tanggu area were overtopped and broken and more than 10,000 households suffered from inundation. Moreover, owing to over-exploitation of groundwater, the large area of Tianjin is still subsiding.

Although in the last 3 years (1986-1988), measures have been adopted to cut the pumping of groundwater and the rate of ground sinking in the urban area has been slowed from 86mm in 1985 to 23.7mm in 1988. But compared to the rate of sea level rise, the rate of ground sinking is still quite considerable.

Especially in the Tanggu area, where many large factories are located, a large amount of groundwater is pumped for industrial use. Now, some parts of the Tanggu area have already sunk below sea level. Moreover, due to continuing over-extraction of groundwater, a large ground water funnel has formed on the coastal plain, extending 250km between Tianjin and Dezhou, covering more than 10,000km² where the water table already sinks below the sea level and salt-water intrusion is imminent. In some parts of the coastal plain of the Laizhou Bay and Qinghuangdao, groundwater has already been contaminated by sea water intrusion. With the rising sea level and resulting increase of salt-water head, considerable sea water seepage to the inland will be unavoidable. Economically, this area is a major centre of sea-salt production for the country.

The Tanggu District alone produces 2 million tons of salt a year. Large salt farms are mainly reclaimed from tidal flats and are very vulnerable to a future sea level rise.

The Dagong Oilfield, south of Tanggu, is a major oilfield in North China. The oilfield was for the most part reclaimed from lagoon and swamp land behind the coastal chenier and is less than 2.5-3m a.s.l. In 1989 the adjacent tidal flat was also reclaimed for the exploitation of oil. A large petro-chemical factory and a power plant have been established.

The oilfield now has more than 100,000 employees. A future sea level rise of 1m will obviously be a major threat to the oilfield.

Agriculture is also of considerable importance. The area was used to be a leading rice producer in North China. Rice fields were reclaimed from low-lying swamps on the coast. Xiaozhan rice, south of Tianjin is famous in North China for its excellent quality. In recent years, because of a shortage of freshwater, acreage under rice has been decreasing; instead, dry crops are grown.

At present, the major problem in agriculture of this low-lying coastal plain is soil salinity (and alkalinity) and poor drainage (water-logging). It can be foreseen that with a rise in sea level, the problem will be greatly aggravated.

The construction of dykes and gravity drainage canals cannot eliminate the adverse effects of sea level rise. Because, notwithstanding the dykes, salt water seepage will increase with rising sea and drainage of peat soils will aggravate subsidence and make the problem worse in the long term.

Also, gravity drainage is effective only for a relatively short period of time. With an increasing water level, pumped drainage must be adopted, but this will greatly increase the cost of agriculture (Day and Temple, 1988). This is also true for the Modern and Abandoned Delta.

b) Tianjin Port, Xiangang or the New Port, is the chief seaport for the two largest cities of China, Beijing and Tianjin and for a considerable part of North China. It is a man-made tidal inlet, built in the early 40s by the construction of two long, parallel jetties into the sea. With strenuous improvement and dredging, the navigation channel now has a water depth of 10.5m and is navigable for cargo ships of 50,000 tons.

The luxurious ocean liner, Queen Elizabeth II (67,100 tons), called and anchored at Xingang in March, 1988. With 29 berths for ships of more than 10,000 tons, it is one of the most important container harbours in China, and handled 21 million tons of cargo in 1988. Further harbour expansion and deepening is planned to increase its handling capacity to 52 million tons/yr. by 2000 A.D.

However, as the velocity of the flood current is greater than that of the ebb current, siltation of the harbour will increase with increase of tidal volume. A 1m sea level rise is bound to have adverse effect on the harbour, because it will increase tidal volume entering the harbour and consequently also its siltation, thus increasing the maintenance cost of the harbour. Of course, the present berths, warehouses and other port facilities will need to be reconstructed or strengthened.
Fig. 10. The Modern Yellow River Delta, showing the 1m and 2m contours
3.2. The Modern Delta

A greater part of the Modern Delta and the adjacent lowland in the south (Laizhou Bay) is low and has very small gradient (0.1%). Of the total area of the Modern Delta, 831 km² are 0-1 m a.s.l. and 1038 km² 1-2 m a.s.l. (Fig. 10).

Also, it is in the area of recent crustal sinking (Fig. 6). Therefore, with a 1 m sea level rise, the threat of submergence and salinity increase is great.

The area has also frequent storm surges. In the Bohai Sea, the intensity and frequency of winter storms is much stronger and higher than those of typhoons.

On the average, only one strong typhoon passes the Bohai every year.

But according to records of a station on Cheju Island in the Korea Strait, the average frequency of winter monsoonal surges exceeding 7.5 m s⁻¹ was once every 5.6 days over the 3 month period between October 1 and December 31, 1981 and 5.2 days over the same 3 month period in 1981.

The strongest surge corresponded to a daily mean wind speed of 15 m s⁻¹ (30 km hr⁻¹); and maximum instantaneous wind speeds were 10-20% higher.

(1988) Also, the duration of winter monsoonal storms is much longer, usually lasting from October to April the next year.

Thus the main threat of storm surges is during the winter monsoon. Owing to the special morphology of the Bohai Sea (a semi-enclosed inland sea with a NE-SW orientation), during the strong northeasters, the sea water is driven from its northern part and piled up in the Laizhou Bay.

The necessary condition to trigger a severe storm surge in the Laizhou Bay is usually a strong SE wind which pushes the sea water from the Yellow Sea into the Bohai Sea and raises its water level.

This is followed by a strong northeast gale which piles up the set-up water of the whole Bohai Sea to the Laizhou Bay, resulting in an extraordinary high water level in the latter area.

Thus, during the winter storm surge, while extraordinary high water level occurred in stations on Laizhou Bay, a lowering of sea level was recorded along the north end of the Bohai Sea.

For example, in the storm surge on April 23, 1969, the water level at Yangjiaoguo on the Laizhou Bay was 3.75 m a.s.l., but at Yingkou on the north end of the Bohai Sea, it was 1.5 m below s.l. (Fig. 11).

Therefore, storm surge hazard is especially severe on the coastal lowland along Laizhou Bay, including the coast of the southern part of the Northern Delta.

According to historical record, there were 40 large storm surges between 48 B.C. and 1938 A.D. during which the sea intruded inland 40-50 km and many villages, including several county cities, were completely submerged.

Since the 50s, 3 strong storm surges have occurred in April 1964, 1969 and 1980, all triggered by winter storms. The most serious was the storm surge of April 23, 1969 when the maximum wind speed (NE wind) reached 34.9 m s⁻¹ and the water level at Yangjiaoguo recorded an all-time high of 3.75 m a.s.l.

The 3 m set-up lasted 8 hours.

In this disaster, the sea intruded 30-40 km inland and 140 km long coastal lowland in Shouguang, Weixian and Changyi County, Shandong Province, was inundated, with great loss of life and property.

It must be noted that on the coast of the Modern Delta, high water (high tide) time varies greatly in different localities.

When its southern tip (Yangjiaoguo) is in high water, low water (low tide) occurs at its north tip. Consequently, in the storm surge of April 1969, the maximum water level varied considerably in different localities (Fig. 12).

The existing sea dykes in the Modern Delta and the coast of Laizhou Bay are not continuous, and not of the same height and strength.

They are unable to withstand the impact of present storm surges. It has been calculated that, assuming sea level to be unchanged, the highest water level once in a hundred years will be 4.0 m at Yangjiaoguo. In the face of a rising sea level, strenuous effort.

Fig. 11. Water level at Yangjiaoguo and Yingkou Station during storm surge, April 23, 1969
should obviously be made, and substantial funding be allotted to the improvement of the existing dyke system. After the example of the Netherlands, which has a similar problem of land subsidence, it is suggested that in the design and renovation of dykes, an additional 60cm should be added to the dyke height as a safety measure against sea level rise over the next century. (de Ronde, 1988) (Table 3).

<table>
<thead>
<tr>
<th>area</th>
<th>designed height of dykas (m.a.s.l.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>South part of the Modern Delta and Laizhou Bay lowland</td>
<td>5.6</td>
</tr>
<tr>
<td>Central part of the Modern Delta</td>
<td>4.6</td>
</tr>
<tr>
<td>North part of the Modern Delta</td>
<td>5.1</td>
</tr>
</tbody>
</table>

The Modern Delta is one of the most important oil-producing areas in China. With its huge reserve, its annual output will be increased to 50 million tons in the near future. Over the last decade, a number of large new oil fields have been opened and great reserves discovered in the coast, tidal flat and nearshore waters. With huge oil reserves and extremely favourable geological conditions, the coastal zone of the Modern Delta, known as the “Golden Triangle” by the Chinese petroleum geologists, is expected to become one of the largest oil fields in the world. Thus, the centre of oil production of Shengli Oilfield is moving to the coastal zone. Now, there are five large oil fields along the coast, the largest is Kudong oil field producing 5 million tons of crude oil a year (Fig 13). A considerable part of these new coastal oil fields has been reclaimed from tidal flat and shallow waters. Since 1983, about 100km of sea dykes have been built extending into the sea to the water depth of 1.5-2.5 m at high tide and close bays and deep tidal creeks (max. water depth 4.5m).

The Kudong Oilfield, with an area of 72km² was almost wholly reclaimed from tidal flats and the sea by the construction of massive ring dykes, 40km long. But these dykes have not been connected to form a single sea wall on the coast and the height of dykes is usually 4m.a.s.l. which is insufficient to protect the coastal new oil field against unusually heavy storm surge. Moreover, in the Modern Delta, there are many abandoned Yellow River channels open to the sea. During storm surge, they provide convenient passages for the intrusion of sea water to the inland, flooding a large part of the lowlands.

With future sea level rise, these large coastal oilfields may become isolated by the sea during storm surge. With favourable climate (annual precipitation 500-600mm, evaporation 2,500mm), wide tidal flats and rich resources of brines in the underground, the coastal lowland along the Laizhou Bay is a promising area for salt production. It is planned to increase its annual salt output to 4 million tons by 1955 and ultimately to 10 million tons.

To protect oil fields and salt farms against rising sea, improvement of the existing dyke systems is urgently needed.

The Modern Delta is still currently underdeveloped or undeveloped. Much land remains as wasteland and the population is low (about 1.3 million). But with rapid development in the oil industry, including the petro-chemical industry, agriculture, chiefly stock-raising, fruit-growing and aqua culture will be developed. Drainage is very difficult. It can be
foreseen that with a rising sea level, the problem will become more serious.

Before the mid-80s there was no large sea port on the Modern Delta. To facilitate the transport of oil, a modern oil terminal and sea port, Huanghe Sea port, has been under construction since Nov. 1984. It is located about 55km north of the mouth of the present Yellow River and free from the influence of silt of the latter. A jetty will be built into the sea to a water depth of 10m where deep-water piers will be located. It is expected that a future sea level rise, by increasing the water depth of the piers, may have a beneficial effect on the port.

At present, sea-ice causes considerable difficulty for navigation in winter. A future sea level rise may result in an increase of the flow of the Yellow Sea’s warm current into the Bohai Sea, raising its water temperature. This, together with climatic warming, may greatly reduce the problem of sea-ice at Huanghe Sea port.

3.3. The Abandoned Delta

Being sediment starved, the coast of the Abandoned Delta has been subject to severe erosion since 1855. Although the rate of coastal recession has slowed down in the last two decades, in some areas, it still reached 20-30m/yr.

The region is a major producer of sea salt, producing 2 million tons of salt per year. As salt farms are reclaimed from tidal flats, expensive coastal protection works, including groynes and offshore breakwaters parallel to the coast, have been built to protect large state salt farms (Fig. 14).

Since the shift of the Yellow River northward to the Bohai Sea, miniature cheniers, 0.1-1.6m high and 10-60m wide, have been formed on the coast of the Abandoned Delta. As a buffer to wave erosion, they are useful in coastal protection.

Unfortunately, in recent years, they have been largely destroyed by man’s activity. Consequently, the problem of coastal erosion is aggravated.

It is evident that a sea level rise will make the situation much more serious. The extensive coastal plain south of the Abandoned Delta has largely been formed by the Yellow River sediment and is now a prosperous agricultural region with a dense population.

The elevation of a considerable part of the plain is low. East of Yancheng, about 2500km² are below 2m a.s.l. West of Yancheng and the Grand Canal, there is a similar large area less than 2m above s.l. (Fig. 15).

It is an ill-drained depression, with frequent flooding and inundation. It can be readily seen that a sea level rise, coupled with salt water intrusion, will greatly affect people’s lives and the economy in this rich coastal plain.

A large area of tidal flats (about 150,000ha) in the south was reclaimed after 1950. The elevation of the reclaimed land lies mostly near the mean sea level and is only protected by mud dykes. At present, the lower parts of the mud dykes are often scour and undermined by strong currents and waves during storms, thus reducing their strength and sometimes causing the failure of the dykes as a whole. With a rising sea, the safety of the reclaimed tidal flat will be at stake.

4. CONCLUSIVE REMARKS

Although China is now facing many urgent environmental problems, such as air and water pollution, desertification, etc., and there is such controversy and uncertainty over the global sea rise,
relative sea level rise on the coastal of the Bohai Sea is quite certain and already serious.
As it could take a long time, perhaps 30-50 years, before engineering measures can be effective in mitigating the adverse effects of relative sea level rise, decisive action is urgently needed to cope with this problem. Since relative sea level rise on the coast of the Bohai Sea is largely due to land subsidence and is man-induced, it is evident that man can play an important part in reducing the rate of relative sea level rise even without the construction of expensive coastal protection works.

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CITIES ON OCEANIC ISLANDS:
A CASE STUDY OF MALE, CAPITAL
OF THE REPUBLIC OF THE MALDIVES

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Abstract

A large number of States in the Pacific, Indian and Caribbean Oceans, have extremely small land areas in proportion to the area of their exclusive economic zones. For most of these, land forms less than 0.0001% of the total area falling under their jurisdiction. Of these oceanic states, countries composed of atolls, such as Kiribati in the Pacific and the Republic of the Maldives in the Indian Ocean, face severe consequence as a result of global warming and SLR.

Atoll States have small land areas usually less than 500km² often broken into many hundreds of islands with maximum heights above SL of around 4m. The Maldives, for example, is composed of 1,190 islands, has a land area of 296km², a maximum height above SL of 3.5m and a population of 330,000 people with an annual growth rate of 3.1%. Such countries have high population densities, in the Pacific up to 380 people/km² and social patterns have resulted in aggregation of such populations onto capital city islands. Such cities often provide the only hospitals, secondary schools, services and employment hence causing urban drift.

Majuro, the capital of the Marshall Islands, has a density of 2,188 people/km²; whilst Male, the capital of Maldives, has 56,000 people living on an island 1,700m long and 700m wide.

The environmental problems of oceanic States in general and the capital cities of such countries in particular are currently extreme. Present problems of environmental management such as sewage and solid waste disposal; oil pollution, fresh water supply, and coastal erosion are already critical for such cities. In the face of global climatic change and SLR many of the existing problems will be exacerbated. A failure to solve current problems may leave such cities highly vulnerable to changing environments.

This paper provides a review of the present and future problems of small island States in general and the Maldives in particular. The environmental problems of the capital Male are reviewed, and alternative solutions currently under consideration within the Republic to mitigate and plan for climatic change are examined. Whilst the will to address the problem of SLR and climatic change undoubtedly exists in countries such as the Maldives, the economic and manpower resources to tackle their particular problems are either lacking or extremely limited. In this connection it is important to note that small oceanic islands have not contributed to the causes of global warming yet they may be both the first to suffer and the most dramatically affected. It is incumbent upon the international community in general and the industrialised nations in particular to both recognise the peculiar problem of such states and to mobilise the necessary resources that will enable such states to plan for a sustainable future.

1. INTRODUCTION

Following the UNEP/WMO/ICSU conference held in 1985, to assess the role of carbon dioxide and other so-called greenhouse gases on climatic change, and the subsequent meetings in Villach and Bellagio, held in 1957, world attention has been focused at a number of levels on the issues of climatic change and sea level rise. Although world leaders have stressed the need for developing policy and planning guidelines to address the consequent impact of predicted changes, the node by which such guidelines might be developed has yet to be identified.

Several of the larger developed countries have established national agencies or committees, empowered to examine the nature of predicted impact and assess what alternatives exist for mitigating or preventing the predicted impact. In contrast, most developing countries have yet to
establish such national entities and more importantly, few possess the indigenous financial or manpower resources to adequately address such issues.

International agencies such as the Intergovernmental Panel on Climate Change (IPCC) have, through various working groups, commenced evaluation of the likely implications of predicted changes for various systems and processes, yet the membership of IPCC and its working groups is almost exclusively confined to the developed countries of the northern hemisphere.

Recognising that certain of the least developed states, which include many of the smaller insular micro-states of the Pacific Basin, Indian Ocean and Caribbean do not have the capability to individually address policy and planning implications, the Oceans and Coastal Areas Programme Activity Centre of UNEP, in collaboration with other agencies such as the Intergovernmental Oceanographic Commission of Unesco, established, from 1986 onwards, a series of regional task teams whose brief was to examine the potential impacts of climatic change and sea level rise on terrestrial and marine ecosystems; on coastal environments and on the socio-economic structures of the countries within each region.

Much of the data presented here are drawn from the work of these task teams and in particular from the reports of the South Pacific Task Team.

2. THE GEOGRAPHY OF THE INSULAR STATES OF THE PACIFIC AND INDIAN OCEANS

The Pacific Basin contains a number of independent micro-states, dependencies and territories of major powers such as the United States, France, United Kingdom, Australia and New Zealand.

Table 1 provides some basic geographical data for these “political entities” (hereafter referred to as “countries”) and it can be seen that for most of the 25 countries on the list the land area is insignificant in global terms, being just over half a million square kilometres, of which 85% is contained within the boundaries of Papua New Guinea.

In contrast, the areas of the exclusive economic zones are considerable and, for most Pacific countries, land forms less than 0.001% of the area within the exclusive economic zone.

An isolated atoll as small as one square kilometre and having no neighbouring islands, represents an area of marine resources covering some 125,000 km². It is hardly surprising therefore that most countries of the region depend upon marine resource exploitation both for subsistence and commercial use. Many countries in Micronesia depend heavily on pelagic fish resources such as tuna, as a major source of income for development.

The Pacific and Indian Ocean Islands vary from low-lying atolls at or below 4m above sea level, to high volcanic islands with a steep profile. Island relief is important both in terms of the potential impacts of sea level rise including coastal inundation, and in terms of rainfall levels and run-off patterns. The impacts of climatic change will therefore differ in islands of differing relief.

2.1. Island Types

The archipelagic States are composed of islands which can be divided into four major physical categories having different susceptibilities to potential impacts resulting from changes in sea level. A relative index of the physical vulnerability of Pacific Island countries in relation to their land area, altitude, insularity and various other parameters was developed by Pernetta (1988b), who identified four categories of susceptibility to climatic change and sea level rise (Table 2).

Countries at highest risk were identified as being those composed solely of atoll islands. Since different island types generally have quite different susceptibility to changes in sea level the island types are briefly described below:

Volcanic Islands of volcanic origin, are some of the highest in the Pacific with a generally steep profile and rapid oceanic drop-off into deeper waters. Within the tropics and subtropical zones they are usually surrounded by fringing or barrier coral reef systems of high productivity. In general, orographic rainfall is high, as is surface run-off in the form of streams and rivers.

Soils are frequently fertile and the dominant vegetation is closed canopy, rainforest in areas of high annual rainfall, or more open forest on drier islands.

Mixed: This class of island includes those with a volcanic core and raised sedimentary facies, usually reef limestone, together with larger islands of more complex geology such as New Caledonia and New Guinea. Altitude and profile vary both within and between islands as do soils and surface water bodies. Forest associations of differing composition dominate the natural vegetation of these islands.

Raised Coral: Such islands are composed of raised limestone of coral reef origin, soils are generally much poorer than those of the preceding types and surface fresh water is generally absent.

Fresh water for drinking and agriculture is obtained from the subterranean fresh water lens. The vegetation, although of forest type, is more restricted in diversity and with a less complex layering of the canopy.

Atolls: Atolls are coral reefs growing on submerged volcanic cones (Guyots). When present, atoll islands are piles of bioclastic sand heaped onto the surface of the reef flat. Called cays or motu, such islands are generally no more than 4m above present sea level and are formed in long narrow strips either entirely
enclosing a central lagoon or forming a series of small islets around its periphery. Such islands are dynamic and highly susceptible to total destruction through hurricanes; they are biotically impoverished and fresh water is confined to a small underground lens. Many such islands are currently uninhabited and they presently represent a marginal habitat for human existence.

2.2. Human populations

In terms of density, population levels are high for most of the archipelagic states, up to 386 people/km² in the Pacific, 671/km² in the Maldives. The absolute numbers of people are small in global terms with some of the smallest micro-states in the world both in terms of land area and population being found in the Pacific Basin. Most island states have high population growth rates by world standards and the rate of migration is high from Pacific micro-states. The largest Polynesian city in the world is the city of Auckland, New Zealand, whilst more Tokelauans now live in New Zealand than live in Tokelau. Not only is the rate of out-migration high but internal migration rates are also high with the remaining populations tending to aggregate around centres of services such as Tarawa in Kiribati, Majuro in the Marshall Islands and Male in the Maldives (Connell and Roy, 1989).

Table 1. Land and sea areas, altitude, population and numbers of islands for Pacific Island countries
In the case of atoll states the number of atolls is given rather than the number of coral or atolls.

<table>
<thead>
<tr>
<th></th>
<th>Land Area km²</th>
<th>Eez area km²</th>
<th>Estimated Population</th>
<th>Popn/km²</th>
<th>No. Island</th>
<th>Altitude m</th>
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<td>33200</td>
<td>169</td>
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<tr>
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<td>79500</td>
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<tr>
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<td>120000</td>
<td>156400</td>
<td>53</td>
<td>8</td>
<td>1857</td>
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</table>

Table 2. Prioritisation of Pacific Island countries based on their physical vulnerability to predicted sea level rise impact (after Pereete, 1988)

CATEGORY A COUNTRIES
Tokelau
Marshall Islands
Tuvalu
Line Islands
Kiribati

CATEGORY B COUNTRIES
Federated States of Micronesia
Palau (Belau)
Nauru
French Polynesia
Cook Islands
Niue
Tonga

CATEGORY C COUNTRIES
American Samoa
Fiji
New Caledonia
Northern Mariana Islands
Solomon Islands

CATEGORY D COUNTRIES
Vanuatu
Wallis & Futuna
Papua New Guinea
Guam
Western Samoa

TABLE 2. Prioritisation of Pacific Island countries based on their physical vulnerability to predicted sea level rise impact (after Pereete, 1988)

171
Eauripik Island in the Federated States of Micronesia had a population density of 950/km² in 1980, Majuro in the Marshall Islands has a density of 2,185/km² whilst Male in the Maldives is considerably in excess of that, with 56,000 people inhabiting an island 1,700m long and 700m wide.

Male has an annual population growth rate of 7% due to births and migration, compared with the country's average growth rate of 3.1%/yr (Pernetta and Sestini, 1989).

Out-migration forms an important source of revenue through remittances and indeed many insular communities have become dependent upon the export of labour in order to maintain the local standard of living (Connell and Roy, 1989).

In part, high birth rates in some insular states are a social response to the perceived need for children to both support their parents at home in their old age and to emigrate overseas to remit money for subsistence (Schultz and Tenten, 1979; Chambers, 1986 cited in Connell and Roy, 1989).

2.3. Social and economic considerations

In cultural terms the island states of the world contain a disproportionate section of the world's cultural and linguistic diversity. Over a third of the world's languages are spoken in four countries in Melanesia (Papua New Guinea, The Solomons, Vanuatu and New Caledonia) and each island group is home to distinctive human cultures, having their own social and cultural mores, dance, dress, traditional knowledge and technologies.

To preserve such ethnic diversity following migration to a larger, developed and more culturally uniform society would be difficult if not impossible.

In part the cultures reflect the ecological and environmental characteristics of the island home, and movement away from that environment would automatically weaken those elements of traditional culture dependent upon the native environment for reinforcement in each generation.

Most island societies therefore view emigration as a temporary solution to transient problems and the reaction to forced migration in response to a degrading environment and climatic change is difficult to predict.

Social problems in Pacific societies resulting from forced migration albeit to other islands rather than to neighbouring developed rim countries, have been reviewed by O'Collins (1988; 1989) who concluded that emigration is likely to place severe strains on the migrant community, its host community and the resident sector of the community which resists emigration until the ultimate point of non-sustainable continuance on their traditional island home.

Economically most of the micro-states are viewed by western economists as non-viable at the present time, being heavily dependent upon remittances, aid and development monies for their present survival. As suggested by Connell and Roy (1989) this dependence on outside sources of financial assistance is a consequence of the western-style economic structures which developed pre-independence, and have continued into the post-independence era due to a lack of available alternative modes of development, rather than through active choice and decision on the part of the Governments concerned.

Developments in health care and social services have greatly reduced the mortality rate and at the same time led to the explosive growth in populations which accentuates the current environmental problems. The Maldives for example had a population which fluctuated around 60-70,000 people from the early 1900s and possibly even earlier. Malaria control (next year will see the WHO announcement of the eradication of malaria in the Maldives, provided no new cases are detected) and improved health care, particularly in the treatment of childhood dysentery and diarrhoea, led to an explosive growth in population from the late Sixties to a population of 200,000 just twenty years later.

Regrettably, whilst health care has greatly improved in many island nations over the last two decades, the consequent high survival of children has resulted in pressure on other social services such as education, which have been unable to cope with the exponential increase in school-aged children.

The consequence of this is a dramatic shortage of skilled manpower in all fields and at all levels in most island communities, (for a review of scientific and technical manpower production in the Pacific, see Pernetta, 1984).

2.4. The Republic of the Maldives

The Republic consists of a chain of 19 major atolls running from seven degrees North to half a degree South of the equator in two parallel chains. Although the exclusive economic zone (EEZ) amounts to some 107,500 km² and there are around 1,190 islands, of which 202 are inhabited, the total land area is only 298km².

The atolls vary in shape from oval, elliptical and pear-shaped to circular with lagoonal water depths of between 40 and 60m. From the lagoons arise faroes, patch and knoll reefs. The islands or motu are bioclastic sand piles located on the perimeter reef or the faroes and micro-atolls contained in the lagoon. In some atolls the reefs and island structures have a predominant E-W or E-N-E orientation.

The islands themselves are of varying shapes, are highly dynamic, being moved around the reef surface, or totally destroyed or formed during storms.

No island has an elevation greater than three metres above mean sea level and most are little over one metre high.

The largest island is around 10km² although most
inhabited islands are between 1 and 2km². The soils of the Maldives are poor, being only a few to 20cm thick and largely composed of parental coral rock and sand. The A horizon varies from light grey to a more blackish brown in areas of higher humus and the Ph generally varies between 7.0 and 7.5. The soils are generally deficient in nitrogen, but fairly rich in phosphorus, calcium and magnesium while manganese and aluminium are generally lacking. Excess calcium interferes with the uptake of potassium by plants and turns the iron into an insoluble form not readily available to plants, causing fatal chlorosis in many species. Groundwater resources are poorly surveyed for the archipelago as a whole having been determined for no more than 200 of the 1,190 islands. All are alkaline and the average Ph varies from 7.8 to 8.3. In many atolls the aquifer becomes brackish during the dry season and poor waste disposal has resulted in the contamination of many drinking water aquifers by human faecal pathogens. The Maldives have a tropical climate with a mean annual temperature of 28°C; a daily maximum reaching 32°C and night-time lows of 25.5°C. Relative humidity varies between 75 and 85% and mean monthly sunshine hours are around 230. The weather is dominated by two monsoon periods; the SW monsoon from April to November, and the NE monsoon from December to March. Air circulation over the Maldives is controlled by the equatorial westerlies which migrate north and south annually, and the period of changeover is characterised by periods of unsettled weather. Rainfall averages 1550 mm/annum for North Male Atoll, varying by about 500-800 mm between years. There are few studies of the wave or tidal regimes of the Maldives except for the capital island of Male. Tidal variation averages 1m or less in the Southern Maldives with tidal intervals of 10 hours and 20 minutes. Given the isolated oceanic location of the Maldives long fetch distances have resulted in flooding occurring in association with swells generated by storm centres well to the south in the Indian Ocean. The exceptional flooding event of 1987 appears to have resulted from long distance swell transmission by a storm centre located west of Australia (Goda, 1988). Flooding at Thulhadhoo Island appears to have been caused by high waves (2-2.5 a high, periodicity 12-15 seconds) associated with high spring tides and a SW wind. Damage was enhanced by the absence of beaches and the presence of low vertical sea walls. The local current patterns have been scarcely studied and hydrographic conditions are generally poorly known. Within the lagoons some calculations suggest that 1.4m high waves can be generated with a periodicity of 4.5 seconds. Tide gauges and wave recordings have now been made for 1 year in the vicinity of Male Island, and two tide gauges have recently been installed elsewhere in the country as part of the TOGA programme. No in-country capability for storing and analysing these data exists at the present time. As is the case for most atoll states the terrestrial environment is biologically impoverished with only 583 plant species being recorded in the whole archipelago. Wood for all uses, including boat construction and fuel is now limited and the total cultivable area is given as 46,766 acres, of which most is used for subsistence production. Traditionally staple crops included taro and breadfruit although imported rice now dominates the energy staples in the typical Maldivian diet. This dependence on rice is not recent, as Ibn Battuta records in the 11th century that Maldivians traded fish for rice with neighbouring India and Sri Lanka. Coconut production has suffered a serious decline such that the country now imports dried coconut from Sri Lanka for internal consumption. This decline has been caused by a series of pest problems combined with poor management and husbandry techniques. The reef systems support a complex and diverse community of hermatypic and soft corals and these communities form the fundamental underpinning of the Republic in terms of their natural productivity and indeed the very base upon which the nation is founded. The corals are exploited directly for building and construction materials whilst the bioclastic sands of the lagoons are used for land reclamation. The impact of coral mining has been extensively reviewed by Brown and Dunne (1988), who recommended alternative methods of extracting construction materials which may be less environmentally hazardous. Fish and marine products form the largest component of the countries exports (71 million out of a total of 151 million rufiya in 1986; 1 US $ = 8.25 rufiya) Current environmental problems in the marine environment include coral deaths from bleaching, apparently associated with thermal stress. In 1987 coral deaths were noted in at least 12 reef building species down to depths of around 30 metres. These deaths coincided with periods of elevated lagoon temperatures between 2 and 3°C above normal and during the same period the mean surface temperature of the Indian Ocean was recorded as 1.5°C higher than normal. Such extensive mortalities are cause for considerable concern given the predicted rise in global temperatures which can be expected as a consequence of greenhouse gas generated global warming. Sewage and solid waste disposal procedures are inadequate causing localised problems of environmental pollution, in reef, lagoon and coastal waters. Marine conservation issues have been addressed in
a number of reports most of which remain unimplemented, not because the Maldivian Government is unconcerned about such matters but because the recommendations have been too complex and/or too cumbersome for implementation within the framework of the present manpower resources and public service structures. In discussing such problems it is perhaps worth outlining the present social environment of the country.

The prehistory of the Maldives is not well known although it is clear that the islands have been occupied for at least two thousand years. Early cultures were apparently Buddhist with the conversion to Islam occurring in 1153 AD. Evidence for pre-Buddhist cultures is less well documented but Hyerdahl (1986) suggests that the earliest archaeological remains show affinity with Indus civilisations dated at between 2,500 and 1,500 years BC.

Maldivian modern history commences with the conversion to Islam in 1153 and it is clear that extensive trading links existed between the Arab States on the opposite side of the Indian Ocean, Southern India and Sri Lanka. The country was briefly colonised by the Portuguese in the 16th century but a popular revolt resulted in the Sultanate regaining independence and recognition first from the Dutch and subsequently from the British. The country remained a British protectorate until total independence in 1965. The language (Dhivehi) displays affinity with archaic Sri Lankan and various languages of North India and Southeast Asia. The written script (Taana) was invented in the sixteenth century following the overthrow of the Portuguese whilst earlier writings of the 12th century were incised on copper plates.

The people are Muslim of the Sunni sect, the women do not observe purdah and the most severe punishment for criminal offences consists of banishment to an island or atoll at some distance from family and place of origin. Society is stratified and the largest peer group are the fishermen, with boat-builders being accorded higher social status. Agricultural activities were generally considered less prestigious than those associated with the marine environment and were undertaken by both men and women. Five calendar systems are in use in the Maldives, with the traditional nakai calendar having 27 divisions of 13 or 14 days each with a "predictable" weather pattern, the divisions being based on climatic and lunar cycles which affect fishing activity and success. Literacy is high with only 6,000 people being classed as illiterate in 1986; nevertheless the extent of secondary and post secondary education is limited, only 25 people receiving matriculation level education in 1986.

As a consequence the availability of trained manpower is low and with an annual population growth rate of 3.1% the country faces a crisis situation in terms of educational facilities and trained manpower resources for the organisation and implementation of development projects. The economy of the country is largely based on three "export" activities, fishing, shipping and tourism and whilst the country has registered an impressive growth rate of 8.9% annually since 1978, its economic base is limited and at 17% tourism is the second largest contributor to GDP after fishing, with major power generation and infrastructure projects contributing significantly to the total. Economic development in the Maldives is naturally constrained by the restricted natural resource base available for generating export income and sustaining the present rate of population growth.

Unfortunately many development projects to date have resulted in unacceptable environmental costs either through environmental damage or through increasing the susceptibility of capital structures to episodic events such as flooding and storm damage. Clearly such a mode of development cannot be sustained and the Government of the Republic is fully aware of the problems associated with integrating development policies and sound environmental management.

Recognising this the Government commissioned 4 independent studies of the potential impacts of climatic change and sea level rise with a view to adjusting development strategies to cope with the predicted impacts.

2.4.1. Present and future problems in achieving sustainable development in the Republic of the Maldives

An initial UNEP mission to the Maldives in late 1988 (Pernetta and Sestini, 1989) identified the following problems which would arise as a result of global sea level rise and climatic change over the next few decades:

1) increased rates of coastal erosion and alteration of beach plan form, with increased impacts from "high waves".
2) changes to aquifer volumes with increased saline intrusion exacerbating already critical supplies for human consumption.
3) increased demand for air conditioning and hence increased energy consumption and adverse impacts on the balance of payments through increased fossil fuel importation.
4) adverse impacts on coral growth resulting from coral deaths under increased sea water temperature regimes.
5) social impacts resulting from inter-island migration resulting from changes to island stability and/or habitability.
6) loss of capital infrastructure on some of the smaller more vulnerable "tourist resort islands".
7) changes in reef growth and local current patterns.
8) increased vulnerability of human settlements due to their aggregation and increasing size.

Present human activities identified as being of major importance in affecting the vulnerability of the country included:
1) Coral mining;
2) Land reclamation;
3) Construction of harbours, piers, wharves, groynes, jetties and breakwaters with no prior examination of local current regimes and sand budgets.
4) Overdraw of aquifer resources

All of these current problems are exacerbated by:
- A lack of mechanisms within the government for taking environmental problems into consideration during the planning process;
- A lack of guidelines and procedures for the evaluation of environmental issues;
- A lack of an adequate in-country data base covering many physical and biological parameters; and
- A shortage of trained manpower at all levels.

3. CURRENT ENVIRONMENTAL PROBLEMS IN ARCHIPELAGIC STATES

The problems of the Maldives are by no means exceptional. As a consequence of past development strategies, population growth, inter-island migration and the breakdown of traditional social and cultural values, many insular societies demonstrate extreme environmental degradation. Problems resulting from inadequate sewage disposal are widespread and range from contamination of drinking water supplies, eutrophication of enclosed lagoons, and human health problems. Solid waste disposal is a problem for all small islands, where land for dumping is unavailable. Solid wastes vary in size from items of plastic packaging to cars and ships, with the cars often being disposed of in the coastal marine environment simply because of the absence of alternative means of disposal. Toxic chemicals including pesticides, form an environmental hazard of great importance in small islands (Moray, 1986) particularly when disposal is required. Virtually all sources of land-based pollution in developing island nations are imported. Few states have any internal industrial capability which is generally confined to larger, high island states and includes mining and ore processing, large scale agriculture and processing of products such as sugar and palm oil. For most small, atoll based states some fish processing and drying of copra may be undertaken, but by and large, secondary processing with its attendant environmental problems occurs outside the countries producing the primary product.

Perhaps more significant at the present time, and of greater importance in the context of future climatic changes are the environmental problems resulting from physical manipulation of fragile atoll environments, particularly in terms of stabilisation of the shorelines, and the construction of harbours, wharves, jetties, piers, groynes and other structures which modify the local current and sediment transport regimes, resulting in erosion at other points in the atoll system. In some instances major biological changes have occurred in atoll lagoons as a consequence of joining, by means of solid structures, previously isolated motu to form single long islands. The gaps between the motu in atolls function as channels for the interchange of lagoon and open ocean water and closing such channels has resulted in major environmental problems as for example in Tarawa lagoon in Kiribati.

In many states increased populations have resulted in increased demand for construction materials leading to mining of lagoon sediments for construction sand, or in some instances mining the coral substrate on which the entire nation depends. Not only do such activities cause direct environmental damage but increased turbidity may affect neighbouring coral communities and the area of impact may be quite extensive, beyond the confines of the dredging or mining area.

Many of the current, pressing environmental problems of the small island states will be accentuated both by climatic change and sea level rise; and by the unrestricted growth in human populations. It is apparent that a failure to adequately manage current environmental problems will leave such island nations highly vulnerable to the predicted climatic changes and hence, any policy assistance designed to assist such states in planning for climatic change and sea level rise must take a holistic view which includes the management of current problems.

4. IMPACTS OF CLIMATIC CHANGE

Of major importance to the small island states will be changes in regional circulation patterns which can be expected to change local climates quite dramatically. The absence of adequate regional and sub-regional climatic models which enable prediction of changes in rainfall patterns poses distinct difficulties in predicting impacts. McGregor (1988) predicts changes in rainfall amounts in different areas of the Pacific depending upon the predominance of southeast or northwest season rainfall, and changes in seasonal duration. A northwards shift of the tropical convergence zone may result in changes to the surface wind patterns, oceanic currents and zones of upwelling. Changed wind patterns will impact via waves on depositional beach plan forms, resulting in increased shore-line retreat and erosion in some areas. Changes in the distribution of zones of upwelling may affect both subsistence and commercial fishery
production within the exclusive economic zones of island states.
Frequency of cyclonic storms may increase in some areas currently just outside the hurricane belt such as the Milne Bay Province of Papua New Guinea, in Vanuatu and the Solomons. Changes to both rainfall patterns and temperature may be expected to impact terrestrial biological and human communities through changes in evapo-transpiration rates, humidity, run-off and groundwater supplies. Although impacts will vary, increased temperature will generally increase evapo-transpiration rates thus increasing drought stress in areas of current water limitation.
In areas where wilting of agricultural crops is currently a serious problem an increase in the number of wilting days per annum may be expected. Direct impacts of climatic change on vegetation include vegetational responses to carbon dioxide directly (with potentially enhanced growth of some species); to temperature and to water balance. The latter two sources of impact can be expected to have the greatest effects on natural and anthropogenic vegetation although the impacts will vary greatly on a geographic basis dependent upon local changes in circulation patterns and rainfall. Altitudinally delimited vegetation zones in the Pacific will rise by around 333m but the time lag for the vegetation response following temperature rise is unknown. Alpine grassland habitats will decrease in Papua New Guinea by more than 50% and will be confined to no more than 10 isolated areas.
Such habitats are not found elsewhere in the region but corresponding decreases in the vegetation formations at higher altitudes on smaller islands will occur. Lower and mid-montane rainforest from 1400-2300m altitude will experience increased human impacts due to the improved agricultural productivity which will occur in this zone. The savannah/lowland rainforest boundary in areas of low rainfall will change towards savannah. Marginal ecotones and relict habitats will be decreased or disappear. The extent of this problem in the Pacific region is unknown.
All of the above effects can be expected to have major tertiary implications in terms of species loss, conservation, and changes in species composition with readapted species being at least initially favoured in comparison with k-adapted species. Under warmer and drier conditions which will occur in some areas, increased capillarity in limestone island soils may change the sodium-calcium balance in the soil hence reducing soil fertility. In contrast, under conditions of increased rainfall increased erosion might be expected in areas where land use practices are not designed to reduce soil loss. Vertical shifts of the position of mean annual isotherms will extend the altitudinal limit of important subsistence crops.
This will occur through an increase in the length of the growing season at higher altitudes; reduction in the number of days of frost; increased yield and reduced time to harvest (Hughes and Sullivan, 1988). Since the present limits to agriculture correspond to climatic limits reflecting land pressure in the highlands of Papua New Guinea, subsistence farmers can be expected to extend their agricultural activity to higher altitudes.
Such changes in land use may have profound impacts on human demographic patterns in the highlands of New Guinea but will have lesser impacts in other Pacific Island States where the areas of land outside the current altitudinal limits of agriculture are absent or greatly restricted in extent. Increased subsistence activity will result in reduction of the extent of upper montane forests which cannot be expected to respond with a corresponding upwards altitudinal shift as rapidly as human activity patterns.
Forestry in rainshadow areas may be adversely affected by decreased rainfall, as will many commercial and subsistence crops which may require irrigation. Irrigation may be successfully increased as a response to crop wilting only in those areas where surface run-off and/or underground aquifers provide a large enough water resource. It is likely that in most areas affected by increased drought these two sources will prove inadequate for such purposes. Changed temperature regimes apart from their direct effects on crop plants may be expected to influence agricultural production through changes in other components of the natural/agricultural system. Agricultural crops which are stressed by increased temperature and/or changed rainfall may become more susceptible to diseases, particularly pathogenically caused diseases such as bacterial wilt. The generation time of pests may be changed such that more than one generation may affect a single crop generation hence the impacts may be changed.
Pollination and seed set may be adversely affected in species which are pollinated by animals through changes to the natural pollinator populations. The nature of the resource may itself be changed, winged beans for example set tubers only under certain conditions of temperature and water availability. Stuck fertility (particularly males) may be adversely affected by increased temperature. The balance between plantation and small-holder production of important cash crops may be affected, thus causing changes to national economies.
Coffee in the highlands of Papua New Guinea for example is grown by both small and large scale producers, an upward altitudinal shift will favour increased small-holder production on somewhat steeper slopes than larger plantation production which at present is largely located on the lower
valley floors. Small-holder coffee is of a generally more variable quality than that produced through plantation systems. In general, epidemiological patterns can be expected to change as a consequence of changed climatic patterns. Warmer, drier conditions as predicted to occur in some areas will result in increased wind born dust, hence an increase in respiratory inflammation/infections. The patterns of incidence of tuberculosis, other respiratory diseases and skin infections can be expected to change with increases occurring in areas of higher rainfall and humidity. Perhaps the most dramatic change to health patterns in the Pacific is likely to occur through changes in the distribution patterns of vector borne diseases, in particular malaria. Altitudinal shifts in the distribution of the mosquito vector of malaria can be expected to result in chronic malarial rates occurring in the highly populated highlands of Papua New Guinea. These populations are currently at and beyond the altitudinal limit of the mosquito vector. This impact is unlikely to be important elsewhere in the Pacific since malaria is confined to Melanesia and in the Solomons and Vanuatu no major centres of population are found outside the altitudinal limit of the vector. Other regionally important vector borne diseases include filariasis and dengue fever. Areas which experience increased rainfall and extended wet seasons are likely to experience extended breeding seasons for the mosquito vectors and hence increased frequency of outbreaks and cases of these diseases. Areas where such diseases are currently of low frequency are generally rather dry with distinct seasonal rainfall, and they are unlikely to experience increased incidences of these diseases. As measured by the relative strain index, there will be a generally widespread deterioration of climate from the point of view of human comfort throughout the tropical Pacific and Indian Oceans. This will be particularly so in areas of current high humidity (McGregor, 1988). Changes in temperature and humidity affect work efficiency and whilst this may be uncontrollable in an external environment, buildings are frequently environmentally controlled. More buildings will require air conditioning or electric fans, hence increased power consumption and economic costs will result. Dramatic changes in architectural design and building materials will also be required. We can expect that workers in the primary sector will have reduced productivity, whilst workers in the service, industrial and commercial sectors will require increased environmental control if current productivity is to be maintained. Some areas within the region are currently close to the limit normally taken as that for human habitation, many of these will exceed this limit under the climatic regimes predicted (McGregor, 1988).

5. IMPACTS OF SEA LEVEL RISE

Permanent coastal inundation can be expected to occur to a significant extent in areas of high islands where the coastal profile is flat or gently sloping. The extent and nature of land loss is estimated in a number of case studies presented in Pernetta (1988a) and Pernetta and Hughes (1989) and inundation will be extremely important economically, since in the Pacific most fertile agricultural areas are at, or close to, present sea level. In addition, many roads and most urban centres lie in close proximity to the sea. Loss of coastal agricultural areas will result in increased agricultural activities inland, frequently in areas of increased slope with consequent increases in erosion and soil fertility problems. In the case of high islands there will be an overall decrease in the extent of low-lying wetlands, with a corresponding decrease in freshwater species diversity and abundance for most catchments in Melanesia. By and large the biggest estuarine/deltaic systems in the region are backed by relatively flat coastal plains. Coastal regression may be extensive in such areas resulting in reduced habitats for some species of conservation concern such as crocodiles and turtles. Inundation of outlying islands and loss of land above the high tide mark may result in loss of exclusive economic rights over extensive areas of the marine environment. This potential problem is of concern in the case of several of the smaller atoll states. Episodic flooding of the coastal zone may be expected to increase both in frequency and geographically as a consequence of increased cyclonic activity. Flooding can be expected to have impacts on storm water drainage and sewage disposal systems in urban areas; and to detrimentally affect recruitment of populations of saltwater crocodiles and other species where reproductive success is largely determined by flooding of nests. Extension of the periods of inundation may render coastal areas uninhabitable in the long-term, particularly in areas of beach ridges backed by swamp (Hughes and Bualia, 1988). A critical question for most tropical states is the issue of coral growth rates, and if one assumes that coral growth rates will keep pace with rising sea level one may also assume that existing barrier reefs will continue to provide the same level of protection to the coastline as they do at present. Should this assumption not be correct then increased wave action may result in an increase in wave generated erosion in currently protected shoreline areas. The impact of global changes to carbon dioxide availability on the growth of symbiotic algae and
hence the hermatypic, reef-building corals is not known. A rise in temperature will decrease the solubility of carbon dioxide, but increase the solubility of calcium carbonate. The consequences of these two processes for symbiotic algal growth and reproduction and hence skeleton formation are not known. What is clear at the present time is that many species of hermatypic corals are currently growing at the upper limit of their thermal tolerance, and that any increase in lagoon water temperatures may well cause increased frequency of coral bleaching and death, with resultant changes to the community structure and growth of the coral community as a whole (Sullivan and Peretta, 1989). From the perspective of the atoll states, current models of sand genesis and movement within atoll systems are inadequate to describe and define the processes of motu formation and erosion. Since the bulk of the sand is derived from biological sources, any changes to the growth rates of the organisms concerned will dramatically change the sand budgets of atolls and hence influence the rate of motu formation and destruction. Coral atolls and cays may be expected to decrease in size and/or be eroded entirely as a result of accelerated loss of sand to off-shore sinks. Beach plan forms will be changed by changing wave patterns resulting from modification of regional and sub-regional wind patterns. Such changes will have important consequences for coastal marine communities of sea grasses, coral flats and algal beds and for sand budgets, particularly in the case of areas currently receiving sediment inputs through longshore drift which can be expected to decrease as the volume of coastal sinks increases. In estuarine areas an inland extension of the tidal prism may be expected. In coastal plains saltwater contamination of the groundwater may have profound effects on both the suitability of areas for human occupation and upon the nature of the vegetation. A rise in sea level will cause a rise in water table particularly a vertical rise in fresh water. In the case of sand and limestone aquifers this will result in a significant decrease in the volume of the aquifer both for human consumption and agricultural use (Buddemeier and Oberdorfer, 1989). Loss or reduction in the volume of freshwater resources may render small atoll and limestone islands uninhabitable long before the loss of material results in land loss. Changes in coastal vegetation following sea level rise and inundation may be dramatic in areas currently having a flat coastal plain (Peretta and Osborne, 1988). The distribution and zonation of vegetation, in particular mangroves, will be altered, with the zonation being compressed, this will result not only in an overall reduction in the extent of such transitional habitats but extensive reduction in the seaward seres, and consequent reduction in important economic off-shore resources such as prawns which are dependent upon the mangrove as nursery areas. Recent studies by Ellison (1989) suggest that mangrove communities may be particularly susceptible to increased rates of sea level rise. In general both individual species abundance and species richness will decline. Whilst it is clear that small islands will suffer many of the effects listed above the nature and extent of individual impacts is difficult to evaluate from a regional review of potential impacts. Site specific characteristics will undoubtedly affect the extent and severity of projected impacts not only when comparing between island nations but also when comparing between sites within such nations. As an example of the kinds of problem which may well be faced by one urban centre in a small island country, it is worth examining in detail the current and future problems of the capital of the Republic of the Maldives.

6. MALE: AN OCEANIC, ISLAR CITY

Male is both the name for the capital city of the Republic and for the island on which it stands. The island is 1,700m in length and 700m in width; it houses some 56,000 people and contains a very high proportion of the service sector of the economy of the country. Most tourist resorts are located in North Male Atoll, with some in South Male and others planned for development in neighbouring atolls; the tourist sector of the economy is therefore centralised around the capital. Most government employees are located in Male which also houses the major port for imports and is in close proximity to the sole international airport on the neighbouring island of Hulule. A substantial proportion of the island is artificial having been created by pumping sand from the lagoon onto the seaward facing reef flat (Fig. 1 and 2). The entire perimeter of the island is now formed by sea-walls and the bulk of the reclaimed area is at or just below 1m above sea level. The maximum height above sea level of the original island was just over 2m but more than 85% of the original land area was less than one metre above sea level. The lagoon facing side of the island forms the dhoni (fishing boat) harbour and the port area is at one end of this side of the island. The seaward facing side of the island is now protected by a substantial breakwater of 3 tonne tetrapod units built on-site using imported cement, sand and aggregate. The approximate cost of this construction is estimated at US$8,000/m of reef front. It is instructive to consider the origin of the problems which resulted in the construction of this breakwater as a Japanese aid project. Fig. 1 shows that the
islands original form included a wide strip of fringing reef on the oceanic side of the island. As the population of the capital increased in the early 1970s over-crowding of the original land area combined with the necessity for deepening the island’s harbours led to the development of a scheme for “reclaiming” land by using the sand from the harbour dredging as the basis for an extended island area. Through a series of successive reclamation projects land was created and protected at its seaward edge by piled coral rubble.

In 1987 a storm centre in the far south of the Indian Ocean generated long distance swells which resulted in flooding of various islands within the Maldives Archipelago (Goda, 1987). On Male some 30% of the sand fill from the reclaim area was lost and extensive flooding occurred as illustrated in Fig. 2.

This event raised concern within the country that this might be the first indication of rising sea levels and his Excellency President Abdul Maumoon Gayoom requested the assistance of the United Nations in determining whether or not this unusual event was in any way connected with the greenhouse effect and rising sea levels.

Meanwhile the Japanese Government undertook to construct the southern breakwater as a protection against future events of the kind which was presumed to have caused the 1987 flooding.

Flood damage during the 1987 and 1988 flooding events was largely confined to islands that had undergone extensive land reclamation or sea-wall construction and it might therefore be suggested that land reclamation on the oceanic sides of islands increases susceptibility to damage from long distance storm generated swells.

In Male, groundwater resource availability is now
critical, estimates suggest that the aquifer will become totally depleted within the next three years. The aquifer forms the sole source of fresh-water for the human population and originally the lens was probably in excess of 20m in depth. By 1982 it was found to be only 13m deep and between October 1983 and February 1986 gross freshwater storage had declined from 6.14 million m$^3$ to 4.84 million m$^3$.

The average daily overdraw for Male is currently estimated at 2055m$^3$ per day. In part, this decline in freshwater resource availability for the capital city is due to the increased demands of the growing population; in part due to increased housing density which has reduced the area of land surface for aquifer recharge; and in part due to compaction of the road surfaces, reducing permeability and increasing run-off and loss from the island surface.

Problems of faecal contamination of the aquifer resulted in the construction of a flush sewage system which increased aquifer overdraw by increasing freshwater consumption to 1801/person/day. Furthermore, inadequate design controls resulted in serious contamination of coastal waters on the lagoon side of the island.

An attempt to solve one environmental problem has merely resulted in a proliferation of problems due to the sectoral approach to problem solving used both by the Government itself and by the donor community. Several donor Governments have offered the Republic of the Maldives various types of desalination plant as partial solutions to the water problems of Male. Such offers are of dubious merit - often the manufacturing company obtains the capital finances directly from their own Government which writes the purchase off to aid.

No consideration is given to the consequent economic problems foisted onto the unsuspecting recipient Government as a result of such “altruistic aid assistance”.

In the case of the Maldives for example, it has been calculated that the recurrent costs of supplying the population of Male with desalinated water produced by reverse osmosis plants exceeds the current annual export earnings of the country from all sources (US$48 million in 1989).

Already two desalination plants are in operation in Male and a third is planned for 1990.

Municipal wastes from Male have caused smothering of corals in neighbouring reef areas, whilst an inadequate municipal incineration plant has resulted in extreme problems of air pollution during the southwest monsoon season.

The use of municipal wastes as land fill in the reclaim area of the island has resulted in contamination of groundwater which has in many areas a distinctive hydrogen sulphide smell. Various schemes are currently under consideration to address this problem. However to date no consideration has been given to an holistic approach to development problems in the country largely as a result of the sectoral approach adopted by experts and donor agencies both of whom address problems singly without a consideration of the flow-on consequences resulting from the potential solutions. The history of Male’s water supply exemplifies this; initially the water supply was contaminated and the solution was to install flush toilets. Flush toilets increased water demand and the rate of aquifer overdraw increased. Water volume is now a concern and one solution is to install desalinator, which require an increased importation of fossil fuels and affect the balance of payments.

The chain of problems and solutions ultimately fails when the export sector of the economy fails to generate sufficient income to meet the recurrent costs of the solutions.

Clearly the current environmental management problems of small island States will be exacerbated by climatic change and sea level rise which will place additional economic demands on an already stretched resource base.

Under natural conditions atoll islands are highly dynamic, undergoing seasonal changes in shape and form, depending upon the prevailing winds and currents, episodically such as hurricanes and storm surges and the extent of natural vegetation cover. For islands which have been little modified by human intervention it is possible that the rate of coral reef growth may keep pace with the projected rise in sea level for the foreseeable future. However where the reef systems have been destroyed or their growth rates reduced as a consequence of human induced environmental degradation, recovery and subsequent upward growth of reef systems may be impaired and the islands supported by such reefs may in fact become inundated and lost.

For islands such as Male where the entire island perimeter is artificial, natural sand budgets involving the exchange and movements of sands from the lagoon to the reef flat and the island no longer occur. Any increase in sea level will require drastic engineering solutions if the capital infrastructure and population are to remain in place in the future.

6.1. The National Plan for the Maldives

As a consequence of the findings of the initial visit by the UNEP mission a programme was devised which emphasises training and the establishment of an in-country capability to monitor and evaluate environmental impacts and changes.

It was recognised that assistance should be in the form of national manpower development in subject areas related to the understanding of problems which the Maldives may face, due to expected climatic changes and in the development of national...
capabilities in identifying and implementing strategies suitable for sustainable socio-economic development under the conditions which will be created by expected climatic changes. Assistance is to be provided through an integrated programme centred on an ongoing series of monitoring activities designed to provide hands-on training, whilst at the same time providing an environmental data base which is sadly lacking in the country at the present time. Operation of the programme is further designed to provide experience in post-hoc evaluation of environmental impacts. Over a period of one to two years, various physical and biological monitoring programmes will be established around a coordinated framework designed to produce an environmental picture of a selected atoll. Within the programme subsets will be concerned with examining local current and hydrographic conditions around comparable islands with and without human interference. Whilst such a monitoring programme could be operated by a series of outside experts who establish and collect data, producing a report at the completion of the studies, such a mode of operation would not meet the basic objective of the proposed programme. It was decided therefore that a scientific advisor would be appointed who would be resident in the Maldives for the duration of the programme and would co-ordinate the inputs of other experts who would contribute for periods of 8 to 12 weeks to establish the monitoring and sectoral training within the framework of the programme as a whole. More importantly, the direction of the project will be controlled by the National Environment Commission in the Maldives to whom both the Project Co-ordinator (a Maldivian) and the scientific advisor will report. As the first stage in initiating this programme a national level workshop was held in Male in late October at which a National Action Plan for Environmental Management was developed including a detailed work programme for the next two years. This workshop reviewed all sectoral experts reports relating to environmental matters, produced for the Maldivian Government over the last 10 years; attempted to make a synthesis of the recommendations; defined the areas of responsibility and contributions from existing Government Departments to the proposed programme; and laid the foundations for the future programme. Without such an integrated approach to current and future environmental problems, most small island states will be unable to cope with the potential impacts resulting from global climatic change.

7. CONCLUSION

In conclusion it might be suggested that the changes in assistance and cooperative programmes which will be necessitated by the need for a rapid development of policies and planning mechanisms for coping with global climatic change and sea level rise by developing country Governments, may be as great and as far reaching as the predicted impacts of climatic change itself. Many of the developing countries, particularly the small island states, are currently ill-equipped to handle their existing environmental problems. Many of the current problems will be exacerbated by the predicted impacts of global climatic change. It is therefore incumbent upon the industrial nations, which are largely responsible for the current global crisis, to assist, both financially and technically, those small island states which may well suffer dramatic impacts as a consequence of a problem to which they themselves have not contributed. Furthermore it is imperative that programmes of assistance should be individually tailored to the countries concerned and that they should be designed to enhance or establish general capabilities in the field of environmental planning and management. A failure to satisfactorily solve present environmental problems will mean that global climatic change will place the goal of sustainable development beyond the reach of small island states and may indeed threaten their very survival.

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IMPLICATIONS OF RELATIVE SEA LEVEL RISE ON ALEXANDRIA

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Abstract

In spite of uncertainties surrounding predicted climatic changes and hence the rise of SL, this paper is an attempt to characterise the implications of relative SLR on Alexandria and to provide appropriate adaptive options.

From the time of its foundation by Alexander the Great in 332 BC, the city of Alexandria experienced almost uninterrupted growth and prosperity.

At present, Alexandria is the second largest city in Egypt; it contains nearly 3.5 million inhabitants and 40% of the nation's industry. Alexandria also encompasses the main commercial and yachting harbours as well as the most popular and extended summer resorts along the Mediterranean coast of Egypt.

Alexandria experienced several environmental problems e.g. pollution of the coastal waters, continuous erosion of beaches, intrusion of salt-water to the aquifer, etc. Although the city was constructed on relatively high altitudes, moderate rise of SL would affect the low-lying areas.

The prediction of relative SL change in Alexandria based on archaeological and tide-gauge records indicates the subsidence of the city by a rate of 1 to 2mm/yr.

The current plans of the Egyptian government call for an expansion of Alexandria to the west by the year 2000. However, decision-makers have to consider seriously the implications of the SLR on the northern Nile Delta and Alexandria.

Appropriate adaptive options such as encouraging the preventive actions to protect the city; strengthen the existing coastal protection system in harbours and eroded beaches, etc., would mitigate the negative impact of the relative SLR on Alexandria.

1. INTRODUCTION

Sea level fluctuations are part of a natural cycle, but in recent years the scientific community has noted trends that are at variance with the normal changes we have come to expect.

These trends appear to be at least partly the result of the greenhouse effect, which is attributed largely to the rapidly increasing levels of carbon dioxide in the atmosphere, a direct consequence of the burning of fossil fuels.

Rapid coastal inundation is predicted for many parts of the world, when in fact the present rate of sea level rise is about 1 to 2mm/yr.

Local changes in sea level in many subsided deltaic areas for the next 50 to 60 years may be far greater than the worldwide rise of sea level.

The northern Nile delta is one of the areas of the world that is vulnerable to rising sea level and probably to a continuous subsidence.

Although Alexandria is not considered as part of the northern Nile delta proper from a geomorphological point of view, serious implications of the sea level rise on the city must be expected.

Alexandria is the second largest city in Egypt, it encompasses several economic and social activities. At present, forty percent of the nation's industry, main harbours, major summer resorts and recreational areas as well as an efficient link for communications such as roads, railways, airport, etc., are located in and around the city.

This paper aims to characterise the implications of the sea level rise on Alexandria and to provide

KEY WORDS

The case of Alexandria - Present Scenario
Present Day Usage of Alexandria
Land Reclamation
Fisheries
Communications and Harbours
Beaches
Implications of Sea Level Rise
appropriate adaptive options to mitigate the expected negative impacts.

2. A TALE OF A CITY

After its construction along the Mediterranean coast of Egypt in 332 BC, Alexandria became one of the main centres of Hellenistic civilisation. The history of ancient Alexandria has been witnessed by the archaeological remains. Immensely valuable as these are, they represent only a small fraction of the heritage of a city that occupied such a prominent place in the ancient world (Morcos, 1985). The sea level in Alexandria has changed greatly compared to the Ptolemaic and Roman times. This was witnessed by the submerged ruins in the harbours of Alexandria as well as the inundation of ancient coastal settlements, statues and other artifacts (El-Sayed, 1988). Subsidence of these structures was also regarded as a result of violent shocks and earthquakes during the last two millenia (Butzer, 1960).

3. PHYSICAL ASPECTS

3.1. Geology and geomorphology

The Mediterranean coast of Egypt dates from the Pleistocene to Holocene (Hilmy, 1951). The shoreline of Alexandria is young, forming one geomorphological unit shaped largely by terrestrial depositional agencies and wave action. The city of Alexandria lies on a wide sandy bar, with calcareous sandstone and limestone elevations formed of Quaternary deposits between the Mediterranean and Lake Maryut to the south (Fig. 1). This region is probably dominated by the sedimentary and tectonic influences that governed the development of the Nile delta (El-Halaby, 1975). The major part of the city is located on high formations (more than 5.0m altitudes); the maximum height is about 30m. However, the coastal stretch, particularly in the eastern and western extremities of the city consists generally low-lying lands. The shoreline is rocky in some places with narrow sand beaches in the embayments and wider ones in the remarkably low-lying lands. Submerged hard ground and emerged islets extend more or less parallel and close to the present shoreline; these probably represent the ancient subsided shoreline which was largely affected by the relative rise of sea level (Fig. 2).

3.2. Climatic and dynamic considerations

Alexandria is exposed to a number of storm surges which generally last from October to May, but most frequently between December and February. They blow mainly from northwest and southwest, and occur with depressions approaching from northwest. The wind blows generally in a northwesterly direction and attains its maximum speed (about 8 knots) during winter. The average daily variation of the mean sea level along the Mediterranean off Egypt may approach 80cm (Moharek et al., 1966). During storm surges this variation may reach about
120cm. The values of the maximum and minimum annual m.a.s.l. were about 50cm and 40cm respectively (Rady, 1979). The general current pattern along the Mediterranean off Egypt is from west to east. Along the coast, the tidal current is weak relative to both littoral and coastal currents (Unesco, 1977). The current excursions were generally larger and showed less directional scatter in summer and fall than in winter. The excursion lengths in the winter did not usually exceed 30km, while in summer and fall they may reach higher values. Drogue experiments show that the current is directed parallel to the shoreline of Alexandria (Gorges, 1978). On the other hand, dye experiments revealed that dye patch travelled in the coastal area of Alexandria at an average speed of about 28cm/sec from west to east (Eid, 1979).

3.3. Aquifer

The main delta aquifer is a confined one, increasing in thickness from about 250m in the south near Cairo to about 900m in the north near Alexandria (Fig. 3, Kashef, 1983). This aquifer consists of an unconsolidated mixture of sand and gravel. The aquifer is recharged through infiltration of excess irrigation waters and drainage system; rainfall also helps recharge the aquifer, particularly in areas along the Mediterranean. A wedge of salt-water intrudes into the huge artesian delta aquifer at different depths. Within the delta basin and the western fringes, fresh groundwater with salinity less than 100ppm is dominant, but high salinity levels up to 3000ppm were recorded in the northwestern region near the Qattara depression (Shata, 1986).

4. RELATIVE SEA LEVEL CHANGES

Along the Mediterranean coast of Egypt, it has long been recognised that nature induced subsidence and eustatic sea level changes are very influential in the development of this region. None of the previous studies on eustatic sea level changes has provided a general curve for such a variation in the Mediterranean off Egypt. Recent data from El-Gindy and Eid (1988) show that two thousand years ago, sea level in the Mediterranean was 50cm lower than at present; however in the last 100 years it has risen by 1.3mm/yr. On the other hand, archaeological evidence from Alexandria has revealed that a continuous subsidence of the city has occurred over the past 3000 years at an average rate of 1.2mm/yr (El-Sayed, 1988).

This finding is in accordance with tide-gauge records in Alexandria where the mean monthly average of 50 years records has shown a high subsidence rate of 2.0mm/yr (Fig. 4; Prihy, 1990). However, Emery et al. (1988) reported an uplift of Alexandria over the past 20 years by a rate of 0.7mm/yr from the average annual tide gauge recording Alexandria (Fig. 4). The last finding is highly debatable and in disagreement with the studies of this region. In general, subsidence of the Mediterranean coastal plain of Egypt, particularly in the northern part of the delta, is a result of compaction and crustal loadings (Ross and Uchupi, 1977).

5. PRESENT DAY USAGE OF ALEXANDRIA

Alexandria, the second largest city in Egypt comprises major social and economic activities. The plans of the Egyptian government call for an expansion of the axes of the activities of Alexandria to the west and southwest for the year 2005 (Governorate of Alexandria/ Alexandria University, 1984). Regarding its morphological setting and the actual distribution of population and activities, the low-lying areas along the coastal stretch of Alexandria will presumably be affected by the rise of sea level. Even the rise of 10 to 25cm predicted for the year
5.3. Land reclamation

There are at present, enthusiastic plans for massive expansion of reclaimed lands in Egypt. About 0.85 to 1.25 million hectares of land are expected to be reclaimed by the year 2000. However, the proposed reclaimed areas (only 58,000 hectares) are located to the west and southwest of Alexandria (Fig. 6).

5.4. Industry

Forty percent of the nation’s industry surrounds Alexandria. These are mostly chemical and petrochemical activities, oil refineries, textiles, steel and iron, pharmaceuticals, cement and tanneries. It is worth mentioning that increased urbanisation, rural and industrial activities in and around Alexandria have exerted great environmental pressure. About 6 million cubic metres of drainage waters and one million cubic metres of industrial and domestic waters are discharged daily into the coastal waters off Alexandria.

5.5. Fisheries

The biological productivity of the southeastern Mediterranean off the Egyptian coast was greatly reduced after the completion of the Aswan High Dam, and it resulted in abrupt curtailment of the seasonal outflow of the nutrient rich Nile flood water to the sea (Dowidar, 1988). The total catch of the Mediterranean off Alexandria was 4597 tons in 1986, representing 26.9% of the total catch from the Egypt sector of the Mediterranean. Lake Maryut (6800 hectares at present) is one of the five fishing grounds of the northern coastal lagoons of Egypt. This lake produces about 5900 tons/yr which form 8.5% of the catch from the northern coastal lagoons and 2.7% of the total catch from Egypt.

5.6. Communications and harbours

The main trade harbour along the Mediterranean off Egypt is the western harbour of Alexandria which handles more than 80% of the country’s trade. The eastern harbour of Alexandria is the largest yachting harbour in the country, and it is also one of the major fishing harbours. Efficient road, railway, etc. links connect the city with the whole country, and a dense communications network connects the city with the delta region and the adjacent agricultural lands. Alexandria has an international airport which is the second largest of its kind in Egypt.
5.7. Beaches

Alexandria is an important centre for both domestic and international tourists. Tourism, particularly during summer, along the beaches and summer resorts, plays a valuable role in the economy of the city. The beaches of Alexandria are the major summer and recreational resorts in Egypt. They extend for some 50km from east to west. These beaches consist in most places, of narrow sandy strips delimited landwards by concrete seawalls supporting the sea promenade. More than three million summer holidaymakers spend their vacation along these beaches, and consequently exert great population pressure on the crowded public beaches and in the proliferation of seaside condominiums.

6. IMPLICATIONS OF SEA LEVEL RISE ON ALEXANDRIA

Several scenarios speculate the likely impact of sea level rise on the northern Nile delta. Alexandria, in these scenarios, was considered as part of the delta and it has been included within the areas vulnerable to the impact of sea level rise. The first scenario in which Alexandria was included as part of the northern Nile delta was that of Broadus et al. (1986) in which they pointed out that the low-lying lands around Lake Maryut are likely to be flooded by the rise of sea level. They have also reported that a 1m rise in sea level might inundate 12% to 15% of Egypt's arable land and would affect 15% of the nation's gross domestic product. The second scenario introduced by UNEP (1988) proposed the physical threat of Alexandria as a consequence of sea level rise. In the third scenario suggested by UNEP/WMO (1989), the east end of the Nile delta at Port Said and the west end adjacent to Alexandria were defined as the two major sections of the Egyptian coast that are most vulnerable to sea level rise. Although Alexandria itself is 3 to 5m above sea level, it is surrounded by low land. Thus, if the sea level rises, the city could become an island.

6.1. Present Scenario

The present scenario is based on modern assumptions (UNEP/WMO, 1989) on the impact of global climatic changes and the expected rise of sea level, as well as the actual socio-economic setting in Alexandria. As the background scenarios and the present one are largely based on assumptions, uncertainties concerning the impacts of global climatic changes particularly in the Mediterranean, have to be revised and reconsidered by using adequate and precise techniques in the near future.

The areas along the Alexandria coast that are vulnerable to the rise of sea level, will be the lowlands, including beaches and summer resorts, harbours, lake Maryut and its surroundings (Fig. 7). The beaches of Alexandria are continuously eroded as consequence of sea level rise and subsidence of the coastal area. Inhabitants along the coastal area of Alexandria could hardly fail to notice the gentle erosion of beaches since the construction of the seawall and the seaside promenade in 1932.

El-Wakeel et al. (1980) reported that some beaches in Alexandria will be entirely eroded (average erosion rate 20 cm/yr) by the end of this century. However, it is worth mentioning that the existing engineering counter measures will have an effective protective role along the coastal and low land areas of Alexandria, regarding the modern assumptions on the expected rise of sea level until the year 2030 (Raper et al., 1988 and UNEP/WMO, 1989).

Hard and soft coastal engineering solutions have been introduced to the coastal area of Alexandria. Sea-walls, groynes, breakwaters and beach nourishment are examples of engineering structures commonly used in Alexandria. The coastal lagoon ecosystem in Maryut will be affected by the rise of sea level and climatic changes. The lake ecosystem is already under stress, as this environment receives pollutants widely discharged from land based sources, beside its considerable changes in size (at present 6,500 hectares) as a result of drying up, cutting off areas and silting.

However, Sestini (1988) reported that the ecological impact of global climatic changes and rising sea level on the lagoonal ecosystem could be minimal and possibly self-adjusting. As Lake Maryut and its surrounds are lowlands (-1m), this area is by far the weakest junction point in the natural and engineering defence systems in Alexandria.

The industrial zone in Alexandria is established on high lands, this will be naturally protected, in the short term, from the rise in sea level.
Agricultural and reclaimed lands will not be under the direct effect of the slight rise of sea level.

As a consequence of sea level rise, salt-water would advance further inland in the northern delta aquifer. However, the present usage of ground water in Alexandria is limited.

In general, about 0.7 x 10^9 m^3/yr groundwater is used in the northern Nile delta, while the safe yield is 0.15 x 10^9 m^3/yr (Kashif, 1983). The urgent need for water to meet the demands of land reclamation around Alexandria, would however, motivate the exploration and exploitation of ground water in the near future.

This will ultimately result in salty water besides the acceleration of the subsidence of the area.

7. ADAPTIVE OPTIONS

This endeavour to integrate available information on the present usage of Alexandria and the implications of sea level rise is a scientific exercise for an area which represents an important centre for socio-economic development in northern Egypt.

Although previous attempts at assessing the implications of sea level rise on Alexandria were reliable, they were largely based on assumptions; reality and updated information were considered in this work to provide inventories of the present usage of Alexandria and the negative impacts of sea level rise. Adaptive options which could be implemented to mitigate the expected hazards in Alexandria may be as follows:

1) Update information on site and subject specific regarding the relative rise of sea level in Alexandria, as the sea level manifests itself differently in time and space. It is therefore necessary to construct a precise sea level curve for the region during the Holocene with supporting studies on the future prediction of sea level change as a consequence of the global impacts of climatic changes.

2) Strengthen existing coastal protection system in the Alexandria lowlands with the increased use of a soft engineering.

3) Encourage a hard engineering solution to protect Lake Maryut and its surroundings, as this area is the weakest junction zone in the coastal protection system of the city.

4) Develop land use strategies and encourage functional and inventory research to start in the area.

5) Prevent highly developed capital investment projects in the coastal area of Alexandria going ahead, unless a prediction model of the impacts of sea level rise is developed.

6) Minimise and control the discharge of pollutants as far as possible in the coastal area of Alexandria and in lagoonal water.

7) Rational water management, particularly ground water, should be founded upon a thorough understanding of water availability and movement.

8) Encourage the formulation of a regional sea level monitoring network and a data base centre; the Cities on Water International Centre is perhaps the most appropriate functioning organization in this respect around the Mediterranean.

8. ACKNOWLEDGMENTS

I am grateful to Prof. Roberto Frascetto for inviting me to the First International Meeting "Impact of Sea Level Rise on Cities and Regions", Venice, 11-13 December 1989. I am also indebted to Dr. Rino Bruttomesso and to the meeting secretariat for their efficiency and help.

My participation in the meeting was supported by the Cities on Water International Centre.

9. REFERENCES


ABSTRACTS

IMPACT OF SEA LEVEL RISE
FOR THE MAJOR NORWEGIAN CITIES

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Bergen on the west coast and Oslo on the southeastern coast of Norway are the two major ocean cities in Norway. In the Oslo area the tidal range (30cm) is less than in Bergen (1m). However, both cities are vulnerable to storm surges, during fall and winter time caused by the frequent storms generated in the Atlantic. For example a major storm hit the southern part of Norway the 16-17 October 1987 resulting in a sea level rise of 1.73m in the inner part of the Oslofjord and Drammensfjord. This extremely high sea level, flooding the port area caused damages of $US160 million in the fjord area. One thousand new cars parked in the port area of Drammen were flooded and disposed of. Therefore a future sea level rise of 1m over the next century will lead to several problems associated with the frequent storm surges occurring during fall and winter (a video showing the result of numerical modelling of the circulation for this area will be presented).

Bergen on the other hand is located in a system of fjords, well-protected from the ocean. The use of the fjord system in Bergen (as well as in Oslo) is associated with marine business, water traffic, recreation, and as a recipient for discharge of spill and waste waters. Large activities have been devoted to pollution control over the last 10-15 years.

Four new sewerage systems have been built in addition to several pump stations. Furthermore, 50km of tunnels have been constructed in order to discharge the spill and waste water more efficiently into the open fjord areas. The predicted sea level rise has implications for the mixing and diffusion in the fjord system.

However, the impact of sea level rise due to global warming for Norway may be modified by the tectonic trend of an uplift of several dm over the next century caused by glacial rebound and eastward plate ridge push from the Atlantic.

SEA LEVEL RISE:
ITS IMPLICATIONS FOR BANGLADESH

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Global warming due to the greenhouse effect and depletion of the ozone layer has attracted the attention of scientists, sociologists, politicians, and public administrators round the world. One of the major consequences of this global warming is the sea level rise (SLR). The SLR is likely to have greatest impact on maritime countries with low topography for example Bangladesh. Assuming doubling in concentration of heat trapping greenhouse gases, numerical models predict that SLR could range between 50 to 100cm in a century. Bangladesh is already experiencing substantial loss of life and property as a result of recurring floods, due to both intensely increased run-off and cyclonic surges.

A combination of SLR and local subsidence over the next century could flood an area in the southern half of Bangladesh where between 8 and 24 million people now reside.

An attempt has been made in this paper to review the knowledge on this phenomenon and its possible impact on Bangladesh, and a few recommendations are put forward to study the SLR and take up countermeasure activities. Even a modest rise in sea level would also raise water levels in the
lower courses of rivers draining through Bangladesh in the Bay of Bengal, both in the low flow and flood seasons. Such changes could be monitored by the BWB (Bangladesh Water Development Board) and BIWDA (Bangladesh Inland Water Transport Authority) through netted fog stations and riverine tide gauges. Monitoring through remote sensing by SPARSO (Space Research and Remote Sensing Organization) may be complementary to these observations. The sea level rise would have its greatest impact during the monsoon flood period while during winter the sea normally recedes to a great distance due to shallowness of the coastal land. In this season, of course, salinity intrusion, due to reduced river run-off will be the major problem. The most serious effect probably would not occur in the coastal areas where sedimentation from tidal flooding would continue to build up land levels. Inland flood plain regions which do not receive regular deposits of alluvium would suffer deeper and more prolonged seasonal flooding, the so-called ‘pond’ effect’ with adverse consequences on agricultural production. Monitoring of such changes would be very difficult. The Bangladesh delta is dynamic, not static. Considerable hydrological, geomorphological, infrastructural and land use changes are expected to occur in the next century, irrespective of any change in sea level as happened in the past. Additionally, the considerable regional diversity and local complexity of the physical and agricultural environments imply that SLR might produce differing degree of effects in different areas. Thus several impact monitoring sites might be needed in the face of all the pressing needs and other recurrent natural hazards like floods and cyclones little is being done to prepare for this additional ensuing disaster. The irony is that although Bangladesh is one of the least contributors to the acceleration process of this global problem it will bear the major burden of loss of human habitation and resources. Thus a better understanding and knowledge base be developed soon so that management options can be considered. Other climatic changes due to greenhouse are not discussed.

SEA LEVEL CHANGES ALONG THE EAST COAST OF CHINA OVER THE LAST 20,000 YEARS
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There are still considerably different interpretations of the Holocene sea level curves of different coastal regions of China. After separating the influences of tectonic and hydroostatic movements we were able to construct a eustatic sea level curve showing sea level changes on the east coast of China over the last 20,000 years, because radiocarbon dates are available to establish a time scale over that period. The present paper discusses the following major problems: 1) Identification of sea level fluctuations during the last 20,000 years. Based on the studies of more than 450 prehistoric sites, the distribution of radiocarbon dating of the shell middens and the sedimentological and micropaleontological studies of more than 400 cores, this paper identified 10 intervals of sea level oscillations over the past 20,000 years. The timing of sea level fluctuations correlated exactly with the climatic variations of China. The radiocarbon dating of a sample taken at -155m on the shelf of the East China Sea indicates that it was deposited 15,000 years B.P. After deducting the down-sinking of the shelf owing to hydroostasy of the melting water returning to the sea we inferred that lowering of sea level was 106m in 15,000 years B.P. 2) Abrupt climatic variations accompanied by rapid sea level fluctuations during the Late Glacial. Evidence from spore-pollen analysis of the Late Pleistocene and Holocene deposits of the northern and eastern coastal plains of China, indicate that three cold periods interrupted by two warm intervals obviously occurred during the Late Glacial. The temperature range between the cold period and the adjacent warm interval was around 6°C. Studies based on the paleoclimatic indicators and rate of deposition strongly suggest that the time interval when the warm Allerod dropped into the cold Young Dryas was less than 200 years. From 13,200 B.P. to 12,400 B.P. the temperature rose sharply by 7°C while the sea level jumped from -88 to -35m with the highest rate of 60mm/a. It was the most rapid phase of sea level rise experienced during the last 15,000 years. On the contrary, in 11,100 B.P. -19,900 B.P. the most rapid phase of sea level lowering occurred, displaying a remarkable interruption of the tendency of sea level movement during the Late Glacial. As revealed by drill cores in eastern China, the sea level dropped abruptly from -38 to -33m within 200 years at the beginning of the Waning Dryas. 3) Climatic and eustatic changes during the Post Glacial period. Evidence from palynological studies in northern and eastern China indicate that since the beginning of the Holocene the climate has experienced four major cold phases, occurring around 8200 B.P., 5800 B.P., 3000 B.P. and 350 B.P. respectively. During each cold period the sea level dropped 2-3 m. During the warm intervals the sea level rose again and formed three major Holocene high sea levels which occurred at 10,000-8300 B.P., 8000-7000 B.P. and 6000-5500 B.P. 4) Climatic and sea level changes during the last 2000 years. Making full use of the long and rich historical records and the three ring studies as well, we are now able to reconstruct both climatic and eustatic curves in detail. Eustatic fluctuations indicate that high sea levels occurred in the fourth, fifth and sixteenth centuries with maximum oscillation amplitudes of more than 2 metres. It is noticeable that the synchronous relationship between climatic and sea level fluctuations not only existed with the time scale for 10° years but also for 10-15° years. We find that the climatic and eustatic curves of China fit the Quaternary very well. During the “warm epoch of the twentieth century” the air temperature of 1935-1940 was 1°C higher than during the 1880s and consequently the sea level during 1935-1940 as recorded by the tidal gauge of Wu-Sung, near Shanghai, was 20cm higher than that of 1910-1920. From the study the paper concludes that major global sea level fluctuations of planet earth seem to be synchronous with major tectonic events, while sea level fluctuations in the Pleistocene and minor ones that took place in the Holocene or even in the twentieth century coincide with climatic changes.

VULNERABILITY OF AFRICAN COASTAL CITIES TO THE IMPACT OF INCREASE IN SEA LEVEL RISE: CASE STUDIES OF LAGOS, BANJUL AND DAR-ES-SALAM
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Lagos and Banjul in West Africa and Dar-es-Salaam in East Africa are the heavily populated and industrialised capital cities of Nigeria, Gambia and Tanzania respectively. For example, Lagos has an estimated population of 8 million (out of the country’s estimated 100 million) and 80 per cent of its industries. Given the lopsided nature of urban development in many African countries, most economic and social infrastructure are sited in these capital cities. These include sea ports and harbours, airports, cross country roads, rail terminals, etc.
The common feature of these cities is that they are located on geographically exposed coasts. At present the three cities are affected by coastal erosion and concomitant flooding, the seriousness of which is putting life and property continuously at risk. In Lagos, an erosion rate of 80m/yr has brought high tides to the limits of the main boulevard in Victoria Island along which are located merchant banks, luxury hotels, military installations, oil export handling facilities, radio and television houses, the minting and security printing establishments, research institutes, etc. In Beira, severe erosion is currently undermining coastal fish landing sites, hotels, ancestral cemeteries, in addition to decimating the beaches on which Gambia's tourist industry thrives.

In Dar-es-Salaam accelerated marine erosion and flooding in the last decade have uprooted settlements and resulted in the abandonment of luxury beach hotels (e.g. Tropicana) and the adoption of panic measures to protect other coast based facilities but which have tended to exacerbate rather than solve the problem. A rise in sea level of, say 1m, will worsen the problems associated with erosion and flooding in all three cities. Surface rivers and groundwater aquifers will be made unusable through increased salinisation and increased load of sediment and pollutants. Increased inundation of coastal land will virtually cripple most economic and social structures and activities.

People and businesses would need to be re-located, new infrastructure would need to be provided, and the level of frustration and misery would be high.

Due to the financial disabilities of these countries, the various disruptions to be caused by the projected rise in sea level would lead to a near collapse of social and economic order. Given the near certainty of an accelerated rise in sea level, the only hope left for the administrators of these cities to avoid future chaos is through anticipatory planning and action.

Such should include a phased "disengagement" from the coast where practicable, prevention of new developments in the coastal zone and/or the adoption and enforcement of the concept of set-back lines. In already built up areas of these cities, the emphasis should be on the installation of low cost, low technology erosion and flood defence measures.

PHYSICAL RESPONSES TO SEA LEVEL RISE IN A SANDY COASTLINE: A CASE FOR NORTHERN ARGENTINA

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The 180km long sandy barrier which extends south of the Río de la Plata on the Atlantic shore, offers an interesting case for evaluation and prediction of future changes as a consequence of global sea level rise.

The oceanic shoreline shows dissipative characteristics with a significant littoral drift (more than 500,000m/yr). Several small, tourist-based towns are established on the sand dune fields, totalling about 40,000 permanent inhabitants. The population on a single summer-season day can be as many as 400,000 people. Although it is an accretionary-type coastline, shore erosion occurs in many localities. This is due to beach sand mining, forestry and urbanisation (which reduces the sand contribution into the beach system). Taking into account an estimated rise in sea level of 1.6m/yr, the human factor accounts for most of the changes that occur. However, if sea level rise in the order of 0.5m, 1.0m or 2.0m were to take place as predicted for the next few decades, erosive processes resulting in magnified coastal retreat would be expected. In this situation, the dune-bench system will not behave as an interactive unit as the dune fields will become progressively restricted in width.
A first discussion on *Planning Defence* was chaired by Brent Gerstle. Since historical times, men had to protect their dwellings from meteoric or ocean water adversities. Increase in SL and in frequency and strength of storm surges were recorded in the last century in most coastal areas of the world. This threat forced modern metropolitan and heavily populated regions to plan hard and soft engineering defences.

Because of the long experience acquired in critical regions (such as in the lowlands of Holland) further exacerbations of ocean and land flooding risks should not present an engineering but rather a socio-economical problem, particularly in the early planning of measures to face substantial SLR and its coastal impacts.

Defences from Sea Level Rise and connected impacts have three options:

1) Planning and modifying the land use also by means of local or national legal regulations.
2) Planning the hard defence system such as dykes, embankments, walls, gates which are indispensable in some cases but need preparedness for failure. Many failures occurred in the past with disastrous loss of lives and properties.
3) Planning the soft defence system with nourishment of beaches and building of dunes which has shown to be a most successful approach wherever it was feasible. This option needs to be further studied by scientists and technologists and may become widely used where sediment transport is consistent.

The most interesting example of this technique has been exposed by Waterman in a new masterplan project for Rotterdam. Similar projects are under study for the Mississippi area (Titus).

The second discussion chaired by Tunney Lee dealt with the *Urbanistic Implications of SLR*. Problems on ocean cities always preexisted. An anthropogenic accelerated SLR will certainly exacerbate these problems in decades to come, not in millennia as natural trends of past history have shown. Engineering solutions are not sufficient by themselves. Rotterdam (Klassen) is an example of an old town impoverished by the separation of working and living areas and by the displacement of the growing harbour to the western side of the city. Replanning harmonious new and old parts of cities is needed using a more balanced distribution of prosperity, quality and accessibility of services, residence, business, recreation and culture.

The *Socio-Economic Implications*, were the logical follow-up in the discussion, led this time by Gabriele Zanetto.

Defences and new city planning capable of withstanding the future possible risks of global change involve a great deal of economic issues and other hazard preventive measures.
Solutions have inevitably high costs for densely populated cities. Long-term investments need evidenced good reasons to be sold to the population. As human settlements, cities depend on human habits, structures and behaviours all of which need to follow evolutions under proper guidance and with a sound view into the future. Two thirds of mankind seem to live within 60km from the sea in lowlands, linked to the benefits and risks provided by sea and land waters. Offshore activity and in-land activities involve the integrated ecosystems and natural as well as anthropogenic adversities.

The socio-economic aspects of environmental risks have a dominant part in planning and renewing cities on water. By the economic point of view, at cities or nation level, the best solution is to face the Global Change impacts to act at a global limitation level (Titus). Some intergovernmental actions are being decided, others need the analysis of cost/benefit for each detailed issue. Solutions exist, they must be resolved through careful studies and with responsibility, without undue delays.

The last discussion on the Developing Countries problems was resumed by Stjepan Keckes. The most obvious consequence of the sea level rise will be the flooding and loss of land below the new water line, unless adequate protective barriers are erected. Large coastal cities, coastal industrial plants and constructions (e.g., roads, airports), recreational zones, coastal agricultural lands and wetlands will be in peril. Equally serious will be the intrusion of salt water into the coastal freshwater reservoirs and the elevation of water tables, leading to the salinisation of soils, interfering with present irrigation and drainage systems, and otherwise impairing water quality. Furthermore, salinity of estuaries will increase, tidal ranges in rivers and bays will alter, and the pattern of coastal deposition of sediments carried by rivers will change.

Among other expected consequences associated with the climate changes, those which may be of major importance for the coastal and marine environment, are:

A) Elevated atmospheric and oceanic temperatures: Agricultural crops are highly vulnerable to changes in ambiental temperature and the agricultural practices of some regions may have to be modified considerably to accommodate the new conditions. Zones which were pest free due to the temperature tolerance of some pests (e.g. malaria) may become infested.

Energy consumption of countries in tropical and subtropical zones may be increased considerably in order to meet the airconditioning requirements. Coral reefs are natural protective barriers at low-lying coasts against erosion and waves.

Their distribution is very temperature dependent and may be altered by changes in oceanic temperatures, with concomitant negative consequences.

The primary productivity of the oceans may be increased and trigger significant changes in the food chains, including in the distribution of fishery resources.

B) Episodic and periodic events: Episodic events such as cyclones, hurricanes and storm surges, as well as periodic phenomena such as the "El Nino", are climate driven and may occur with higher frequency, severity and different periodicity. Some of the episodic events may be experienced in geographic areas which are at present free from them.

C) Changes in rainfall patterns: The amount and seasonal distribution of rainfall which is expected to be altered in many parts of the world, will have a major impact on agricultural practices.

The frequency and severity of floods may increase in some regions as a consequence of changing rainfall patterns.

Due to the time scale on which the changes are expected to occur, the natural ecosystems will be able, in most cases, to adapt to the changes and establish a new dynamic equilibrium with the physical factors determining their functioning. These adaptations may, however, involve considerable shifts in the composition of some ecosystems or in their present geographic distribution which, in turn, may affect human activities dependent on their present status.

Man-made environment will be probably more vulnerable and the adaptation to the changes and the measures which may have to be taken to reduce the rate of changes, will be costly.

Mankind's response strategy would require several types of action. Reduction in the emission of "greenhouse gases" would obviously slow down the rate of changes, although they now seem inevitable. The cost of measures to reduce the emissions are estimated as very high, in billions of dollars. Adaptations to the expected impact of the changes will not be less costly.

Although the impact of expected climate changes will be a gradual phenomenon, strategies suitable for the protection of unique social, economic, environmental and cultural conditions require long lead time. The response strategies of the developing countries will be most probably concentrated on a combination of various adaptive options, such as:

A) Maintaining the existing use of imperiled sites by defence measures: This option is costly but feasible in cases when the main impact is from sea level rise. The measures primarily consist of large scale engineering works to erect physical barriers against rising sea levels.

B) Adapting to the changing conditions: Whenever
physical protection of a site is not feasible, solutions will be sought through modification of existing structures (e.g. by raising the level of harbour piers, roads and airport runways) or activities (e.g. shifting to different agricultural practices).

C) Relocation. This may be the most costly and, from the cultural and social standpoint of developing countries, the most disruptive option. Abandonment of coastal cities and cultural sites, many of them century old capitals and cultural centres, may scar whole nations and alter their future socio-economic development. Large scale movements of population engaged in agriculture may be equally disruptive, particularly in countries with strong traditional agricultural practices. Measures which would have to be taken will impose a significant financial burden which most of the developing countries could hardly afford under their present economic circumstances.

The burden of coping with accelerated sea level rise and other consequences of greenhouse warming would fall disproportionately on those countries which are least able to cope with them. The expected climate changes are mainly the consequence of activities carried out by the industrialised countries, and therefore there is a general feeling that these countries have special responsibility to reduce the rate of changes and to assist developing countries in adapting to the changes.
INTERNATIONAL ASSOCIATIONS
Interests and Activities
1. THE CHANGE IN GLOBAL CLIMATE

For about a century scientists have been warning us that the fumes emitted by factories, furnaces and cars would eventually raise the temperature of the earth. It was at the peak of the industrial revolution, in 1896, that Svante Arrhenius calculated that doubling the carbon dioxide in the air would cause the temperature of the earth to increase by several degrees, the level of the oceans to rise and the world’s climate to change, impairing existing agriculture. He was the grandfather of the present Science and Technology advisor of the World Bank.

For three generations we kept busy burning fossil fuels to “develop” the old world, ignoring the claims of isolated scientists.

It has taken that long for us to all begin reading of the “greenhouse effect” in our daily newspapers, and public concern has spurred governments to take the matter seriously.

It is indeed a serious matter, because even a few more degrees in global temperature can have serious consequences: not only the sea level rises, because of the thermal expansion of the waters and the gradual melting of polar ice-caps, but changes occur also in the pattern of precipitations, the rate of evaporation, the relative humidity and wind velocity, the frequency and strength of hurricanes, the amount of cloudiness and insulation, wave movements, water mixing, ocean currents, and crops and vegetation compatible with shifting climatic zones.

A number of sophisticated computer models have been developed to simulate climatic change as the average global temperature increases.

As most scientists are quick to point out, a high degree of uncertainty characterises these models, because all variables seem to change at once, with complicated feedbacks and no simple chain of causality. One does not know, for instance, when the heat stored in the oceans will start radiating off in the atmosphere.

There are differing opinions on the impact of increasing cloudiness, on the extent of territorial dislocation of climatic zones, on the potential shifts in ocean currents, tide levels and wave movement. The timing and magnitude of change therefore remain conjectural.

One does not even know whether the earth climate may change gradually in response to a steady increase in global temperature, or suddenly, through traumatic shifts. We only know for certain that the earth is warming up and that this involves risks which leave little room for complacency and advise prudent action.

Optimistically, we can assume that cleaner forms of energy might be found, but we know that their development will take time, while the greenhouse gases in the atmosphere have a lifespan of 100 or 150 years.
There are of course the advocates of the nuclear option, but this continues to be a costly alternative which presents obvious risks of security and waste disposal.

More environmentally sound practices (such as the conversion to natural gas, hydropower, solar energy, wind energy, biomass energy) can contribute to a slower build-up scenario, but are unlikely to offset drastically the trend of global warming: they can delay its progress but will not simply eliminate the greenhouse gases that have already accumulated over time.

The working assumptions of the United Nations Environmental Agency are necessarily loose. If present trends continue, the world’s economy will grow a lot larger over the next century, at some 2-3% /yr. At this rate, the amount of CO₂ in the air would double from its pre-industrial level by about year 2040 or, according to more conservative estimates, by about year 2070.

The corresponding change in global temperature is expected to range between 1° and 5° degrees Celsius. At the Villach International Conference UNEP experts agreed on a sea level rise of 20 to 140cm in 45 years.

Because of the thermal inertia of the oceans, scientists tend to lean towards the lower value, but: point out that higher levels are also possible, with serious threats to the settled population and economic activities in many coastal regions.

2. EFFECTS OF SEA LEVEL RISE

Among the many consequences of global warning, this meeting focuses on the potential rise of the ocean level which is a particularly threatening prospect for cities and regions located on the seashores. There is by now recorded evidence that the average sea level is rising, even if there is considerable disagreement as to the rate of future variation.

But even discounting the effects of polar ice melting, increasing global temperature can raise the ocean level considerably, simply because warm water takes up more space.

The combination of sea level rises and storm surges can have devastating effects. A rise of a few degrees in sea temperature would increase both the frequency and the destructive power of hurricanes, particularly in the tropics, where warm water reaches deep below the surface and evaporation keeps building up the strength of hurricane winds, which already reach speeds of 200 miles per hour.

Finally, one can also expect major shifts in the patterns of ocean currents. Some scientists go as far as to suggest that ice-cap melting could shift the centre of gravity of the globe, causing gradual tipping. Drastic variations could occur in tidal movements, wave action and river flows, with disastrous impacts on some areas.

The most publicised cases are those of the Maldives Islands, an “endangered nation”, which could be totally submerged, and that of Bangladesh where some 15 to 20% of the population would be dislocated from their farmlands.

Another dramatic example is that of the Nile River Delta where most of Egypt’s population and economy are concentrated. Human and material costs could be very high. The ocean surge of winter 1953, which opened 89 breaches in the Netherlands protective dykes, cost the Dutch government 3 billion dollars just to repair the protective facilities.

Generally, low-lying lands are more vulnerable to sea level changes and increased storm activities, particularly deltas, estuaries, wetlands and coastal plains. Here one can expect the combined effects of erosion, saline intrusion, sea invasion, frequent flooding during storms, increased water turbidity and evaporation.

This may imply loss of farmland, disruption of natural habitats, shoreline alterations, damage to fish nurseries and shellfish beds, upheaval of seagrass, mangrove forests, salinas, sandy beaches. Only if the change is gradual can one hope that living organisms might tolerate moderate temperature increases and adapt themselves to the new conditions. Where the coastline gradient does not shift abruptly, their habitats may shift inland, on new wetlands and lagoons which may be formed.

3. ECONOMIC IMPLICATIONS

It is conceivable that particular sectors of the economy (for instance the construction industry) may reap some benefits from climatic changes.

But one must consider the net sum of all cost and benefits born by the economy as a whole, because the resulting gains to the construction industry in such circumstances, do not represent a creation of new costs and benefits, but merely a transfer of costs and benefits from other sectors.

To consider another example, the tourism industry may experience gains as investment opportunities open up on new beaches created by sand accretion, but may also have to bear heavy costs for replenishment, protection and stabilisation works where beaches are eroded and existing tourist facilities are not yet amortised.

Many economic decisions will have to be taken in uncertain conditions. It will be difficult to estimate whether or not to build, rebuild or strengthen physical structures in order to protect existing coastal settlement and activities.

Waterfront roads, bridges and port facilities will need frequent repairs and adaptation if not full reconstruction. Many municipal water supply systems will need to be modified as the salt-front advances upriver, threatening water intakes.

Coastal aquifers, which have hydrogeological
continuity with the ocean may be affected by sea level rises. Wells may have to be relocated and drinking water may have to be transported by barge to small islands.
The efficiency of many sewerage outfalls and sewage treatment plants may be jeopardised. Residential areas on the seashore may be seriously affected. This does not apply only to fashionable waterfront communities or tourism resorts, but also to large Third World city squatter settlements, which have grown up in areas most likely to be inundated. In addition to the physical dangers, one must contend here with possible outbreaks of tropical diseases as septic tanks and cesspools get flooded, contaminating shallow aquifers.
These are but a few of the possible impacts of climatic changes. Clearly, the more coastal oriented are the economies, the more they will be affected by sea level rises. And, the poorer and smaller the countries, the least they will be able to cope with these challenges both in financial and technical terms.

4. THE SOCIO-ECONOMIC RESPONSE

Global warming is a curse we have brought on ourselves, driving our cars, running our factories, clearing forests, growing rice paddies, spreading fertilisers, raising cattle, turning on air conditioners, using spray-can products.
To implement a drastic change in our lifestyle, to adopt entirely new ways to address people's relationship with nature, as the conservationists advocate, is difficult and expensive.
The size and complexity of our industrialised world is such that even a marginal correction of the present course may be hard to achieve because cars, factories and energy have become an integral part of our own life. And even those scientists who argue for a drastic limitation of emissions admit that this will only slow down the pace of global warming.
All measures currently advocated are basically buying time and risk insurance, in the hope that a minimally traumatic transition can be made and that - as the futurologists have it - we might come up with some technological breakthrough to stall the process of global warming.
Inadvertently, we have changed the chemical composition of the atmosphere, and this is changing the weather. As it turns out this is now challenging our own lifestyle. Of course, the major culprits are the industrialised countries: with only 8 percent of world population they account for 75 percent of the dangerous emissions.
But it must be mentioned also that most of the future increase in greenhouse gases will come from the developing countries as they follow our own pattern of industrialisation.
This poses difficult problems of international equity, because it is morally unacceptable to expect them to avoid our malpractices, as long as we are unwilling to curb wasteful policies in our own countries.
One cannot limit economic growth in the developing countries without condemning the poor to continued poverty. Somehow, the industrial nations must agree to bear the largest share of the burden.
In a world that has become physically as well as economically interdependent, we must face the challenge of global warming together and our remedial efforts must commensurate with our resources and responsibilities.
It is in the nature of human affair, that vested interests should arise every time there is a challenge to the existing order of things.
To achieve international agreement on a drastic reduction of fossil fuel burning is not going to be easy, and might be difficult to enforce even when achieved. It is clear that such a measure cannot impose a disproportionate burden on the developing countries and that the possibility of division of rich nations versus poor nations is great.
Some countries may perceive themselves as potential losers in the process, others as potential winners. Nations with large reserves of fossil fuels like coal may be reluctant to write off their own comparative advantage. Countries with vast potential for increasing harvests through an extended growing season may feel this prospect is worth the risk of global warming.
Still other countries may be paralysed by internal disagreements over the losses and opportunities involved in climatic shifts.

5. THE WORLD BANK POSITION AND INITIATIVES

The idea of shared global responsibilities is embedded in the World Bank's work with 150 member countries. The Bank's commitment is to pursue a balance between the urgent need of economic development in the Third World and the longer term goal of environmental management.
Our challenge is to integrate measures of prudent environmental management into the mainstream of development thinking so that they are not perceived as external impositions but as an internal imperative for both developing and developed countries.
This year the Bank has carried out a thorough review of what is known and what is not known about global warming.
On the basis of this review it has grouped the available options into three major groups: (i) those options which can be immediately implemented in developing countries, because they yield unambiguous economic benefits in excess of their costs (basically energy efficient policies and cleaner technologies); (ii) those options referred to as 'buying insurance policies' (mostly research activities) the costs of which are low, compared to their potential benefits and (iii) those options for which international response and
political action are still uncertain pending universal persuasion that a climate related disaster is imminent or very probable (this category includes the phasing out of coal, a universal freeze or a tax on CO$_2$ emissions, 'clean' energy alternatives, nuclear power etc.)

The Bank's policy agenda concerning environmental matters has been made explicit in repeated public declarations.

It is now reflected in its daily operations and in its active participation in critical international debates. The key positions can be summarised as follows:

A) improving efficient use of energy. In the Bank's estimate developing countries could save up to 20-30% in energy production, transmission and consumption through pricing adjustments, more efficient technologies and improved market information.

B) promoting the switch to natural and other relatively clean sources of energy whenever economically feasible;

C) discouraging deforestation and supporting sound environmental practices;

D) supporting the phasing out and substitution of chlorofluorocarbon gases;

E) encouraging measures of risk reduction, mitigation and emergency preparation against natural disasters;

F) cooperating with multilateral and national organisations and NGOs;

G) representing and assisting developing countries in documenting their development interests in any global debate;

H) assisting developing countries in the formulation of appropriate responses to global warming;

I) introducing environmental impact assessment into the appraisal of Bank supported operations.

6. ENVIRONMENTAL ISSUES
AS AN INTEGRAL PART OF THE BANK'S WORK

In recent years, we have made considerable progress in making environmental concerns an integral part of the Bank's operational activities.

This takes place in several forms:

A) Preparation of Environmental Issues Papers. These are internal discussion documents used as reference in project, sector and macro-economic work. During FY 1989 environmental issue papers were prepared for 70 countries.

B) Preparation of Environmental Action Plans. These are follow-up documents to the Environmental Issues Papers, reflecting a coherent country environmental strategy, prepared in collaboration with the government. Several such documents were produced last year.

C) Environmental Components in Project and Sector Lending. Last year, 85 Bank loans included significant environmental components. In addition we began development of specific environmental projects supported by a Technical Assistance Grant Program for the Environment, financed by the Japanese Government.

D) Carrying Out Regional Environmental Studies. Examples of these are the Capital Cities Clean Up Program, the Mediterranean Program, a study on Asian Watersheds, and one on Agroforestry Practices in Sub-Saharan Africa.

E) Policy and Research Activities. In addition to in-house papers and reports, several books, guidelines and state of the art reviews have been published. Key areas for research are (i) the Management of Natural Resources, (ii) the Quality and Health of the Environment and (iii) the Economics and Institutions for Environmental Management.

F) Evaluation, Training and Information Activities. Independent Audits of Project Performance and Project Completion Reports have now introduced environmental considerations. Training Seminars are offered for Bank staff and an Information System has been established to monitor the environmental impact of Bank projects.

7. WORLD BANK ROLE IN THE INTERNATIONAL CONTEXT

In the environmental area, as in other areas, the Bank's role is to work with its member governments towards a better understanding of the problems, to assess the chains of causality and to assist countries in formulating appropriate policies, besides financing investments. This must be done in cooperation with the governments and institutions of the borrowing countries by clearly identifying with their own interest in sustainable development.

Environmental protection measures are costly in social, political and economic terms. They tend to expand the resources required for sustainable development of the Third World and it is a good question whether developing countries should be induced to borrow at conventional rates for this purpose. While the World Bank makes its participation in project funding contingent upon certain criteria, it must recognise the ultimate right of governments to exercise sovereignty within their own borders. Therefore, the Bank has limited ability to persuade borrowers to invest in environmental improvement measures when the benefits of such measures accrue outside the country's borders.

It is clear that many environmental issues in the developing countries are linked to population pressures, poverty, institutional weaknesses, perverse economic incentives and uncertainties about property rights. Environmental management cannot be separated from social, economic and institutional development planning.

Public attention has often focused on a few visible, controversial projects while overlooking the far more powerful influence of the Bank in addressing environmental problems through policy intervention at country planning level.
At project level, the Bank will not avoid participation in a particular operation just because it is potentially controversial. The deciding factor is whether the net gains from Bank participation can do much to reduce the adverse environmental consequences of a project if not to offset the damage entirely. The World Bank has been urged to do more for the environment. It has been intensifying its efforts in both policy and project work with the developing countries. But one role of the Bank is also to urge the wealthier, industrialised nations to do more themselves.

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Statements, interpretations and conclusions of this paper are the author's own and should not be attributed to the World Bank, its Board of Directors, its Management or any of its member countries.
1. INTRODUCTION

Early in the Mandate of IPCC Working Group II (Impacts), it was recognised that the linkages between the environmental impacts of climate change and the related socio-economic variables were poorly understood. In fact, what little research existed on impacts up to that point had centred mostly on physical responses, with very little emphasis having been given to assessing likely economic or social consequences.

Working Group II also recognised that it would not be able to move very far towards an assessment of these socio-economic impacts in the limited time that was available to complete its work.

Nevertheless, the Working Group wanted to make a start on that objective, so it asked the Organisation for Economic Co-operation and Development (OECD) for assistance.

For its part, OECD recognised the growing environmental (and therefore political) urgency attached to the global warming problem. OECD governments were just beginning to study the question, and analytical tools were in short supply.

It was therefore agreed that OECD would:

a) review the “state of the art” of methodologies for assessing the potential socio-economic impacts of climate change in two key economic areas: agriculture and sea level rise.

b) use this review as a basis for suggesting improvements in these methodologies, with a view to providing general guidance to both OECD and non-OECD governments on how to carry out more detailed impact assessment studies themselves.

The first part of the project involved the preparation of an overview of design criteria that should be included within any socio-economic impact assessment methodology. This was essentially a “scoping” exercise, which laid the groundwork for the more detailed methodological work that was to follow.

Three individual methodological development projects were then defined. Two of these dealt with the agriculture sector (one on agricultural impacts generally; and one on methods for modelling impacts in international agricultural trade).

The third project dealt exclusively with the sea level rise issue. This paper summarises the key contents of the sea level rise report.

It is important to realise that these projects were carried out very quickly and with limited resources. As such, they were not designed to provide the “last word” on socio-economic impact assessment.

To the contrary, they were intended only to provide IPCC Working Group II with a somewhat broader perspective on impact assessment methods than it might have been able to obtain for itself.
2. SUMMARY OF LITERATURE REVIEW

Most of the existing literature on the economic impacts of sea level rise uses one of three basic methodological approaches:

a) studies that are concerned primarily with the costs of adaptation. This type of study defines "impacts" as the costs (rather than the benefits) of adaptation.

The need for adaptation is not questioned. Typically, this approach tends to be taken in areas where projected sea level rise would be catastrophic (e.g. Maldives), or where it would at least cause very significant economic dislocation (e.g. Holland). Usually, politically-determined "adaptation rules" exist in such countries.

b) studies that are confined to impacts that can be observed in functioning markets. Specifically, non-market based impacts (e.g. intangibles) are excluded from this type of study. These models focus on the current economic product of threatened (market-based) resources, and then apply a growth function to these variables in order to obtain a long run estimate of impacts.

c) studies that incorporate both market and non-market types of impacts. Examples of non-market impacts include loss of life, unemployment, etc. Obviously, valuation issues are important parts of this type of study.

It is clear that the "adaptation cost" approach is insufficient because this model is incapable of predicting optimum levels of adaptive response - it is only capable of demonstrating how to achieve a given level of adaptation at least cost.

In short, both the benefits and the costs of adaptation are relevant to the policy decision. The Dutch ISOS (Impact of Sea Level on Society) Model is the most comprehensive example of this type that was reviewed in this project.

Similarly, models which incorporate impacts on the basis of whether or not they are readily measurable in the market place are also insufficient. This is particularly true in the case of environmental resources, most of which are not traded in any market.

All things considered, an approach based on both market and non-market impacts seems most appropriate. To be sure, valuation problems are significant with such an approach, but the operating principle here has to be that both types of impacts are important determinants of the ultimate policy decision. As a result, the conceptual framework suggested in the next section is based on this more comprehensive approach.

3. A PROPOSED METHODOLOGICAL FRAMEWORK

A suggested conceptual framework is provided in Fig. 1. The model is intended to be used dynamically, with feedback loops allowing for changes in emissions; for changes in public adoption policies; and for changes in private adaptive behaviour over time.

The first iteration of the model can be interpreted as the "do nothing" scenario.

Successive iterations allow potential policies to be evaluated on the basis of conditions existing at the time of assessment.

Given the long term nature of the global warming and sea level rise problems, this is an important feature of the model.

Another noteworthy aspect of the framework is that some cells can be determined at a national level whereas others require analysis at the international level. Obviously, adaptive response policy is a national issue, whereas the actual amount of sea level rise experienced by a given country depends on worldwide environmental conditions.

And finally, it is important to remember that there are important lags inherent in most of the linkages between cells in the Model.

For example, preventive policy takes a very long time to work its way back into the dynamic sea level rise scenario.

These time lags are very important because they will generally mean that there is not usually a direct
tradeoff between preventive and adaptive policies. A synopsis of the major cells in the model follows:

3.1. Dynamic Sea Level Rise Scenario

The basic exogenous input to the model is an estimate of the amount of anticipated sea level rise. Note that this estimate can vary by region. Given the scientific difficulties associated with establishing the estimate of sea level rise, a scenario approach (including high, medium, and low assumptions) should be utilised.

3.2. Identification of Primary Impacts

Primary impacts typically include the loss of, or damage to, coastal property; permanent inundation of wetlands; saltwater intrusion of water supplies and agricultural land; impacts on coastal fisheries; etc. These impacts can be either non-stochastic (e.g., permanent inundation) or stochastic (e.g., increased frequency of flooding).

3.3. Adaptive Behaviour/Identification of Secondary Impacts

Here, the framework distinguishes between public sector adaptation (discussed below), and private sector adaptation. The latter is concerned with individuals' and firms' reactions to known or assumed impacts. It is this reaction that causes the level and type of secondary impacts to be modified.

The secondary impacts themselves include such variables as altered infrastructure requirements; loss of income due to periodic closures; etc.

3.4. Quantification and Valuation of Impacts

The long-term nature of the sea level rise problem leads to large uncertainties at this stage in the process. Various types of models already exist for quantifying the results of changes in economic variables. (Input/output models, and macroeconomic models are but two examples).

Geographical Information Systems (GIS) also seem to offer some potential for assisting in the quantification process, as well as for integrating physical impacts with economic ones.

Monetary impacts will obviously be measured in monetary terms. Prices of goods and services foregone are multiplied by the quantities involved to yield an impact "value".

Non-monetary impacts can either be expressed in their own (non-monetary) dimension (e.g., number of lives lost, increased number of unemployed), or "shadow prices" (e.g., opportunity costs, willingness to pay) can be estimated.

Various techniques exist for determining shadow prices, including willingness to pay, contingent valuation, etc. A detailed summary of available benefit estimation methods was recently published by OECD.

3.5. Physical Norms, Risk Limits

At this point, the analyst may wish to impose a physical standard on the model. For example, in the Netherlands, a legal limit exists on the maximum risk of flooding (risks in excess of the 1:10,000 year event are to be protected). Where such a risk limit exists and would be surpassed by the projected impact of sea level rise, no further analysis is necessary. In effect, the policy decision is pre-empted by the existence of the legal norm.

3.6. Economic Assessment of Policy Responses

As indicated earlier, the first run of the model is the "do nothing" scenario. The basic evaluation criterion at the end of each run is a benefit-cost one. In other words, if the projected impacts are greater than the projected costs of adapting to, or preventing, these impacts, public intervention is warranted. If this intervention leads to reduced emissions, the feedback is to future sea level rise scenarios. If the form of intervention is adaptation, the feedback affects future primary or secondary impacts directly.

3.7. Other Issues

The cost-benefit model is best suited to situations involving marginal changes in economic conditions. Clearly, the types of changes being evaluated here are not marginal.

Nevertheless, it is still recommended that countries adopt a cost-benefit approach because:

a) this approach is more easily understood by policymakers;
b) no reliable method exists for assessing relative price changes over long periods of time in any event. It is also useful to recall that policies designed for one problem can impact both positively and negatively on other areas. This dynamic interaction of policies is important, especially for such broad environmental problems as sea level rise.

For example, even in the absence of a sea level rise problem in the Netherlands, there would still be a need to construct higher dykes. It would not be appropriate to attribute the cost of these policies entirely to global warming. Uncertainty manifests itself at at least three different levels in the model: (i) the sea level rise scenario itself; (ii) the quantification and valuation of impacts; and (iii) the implementation stage. Sensitivity analysis (perhaps using Monte Carlo techniques) is one way to assess the importance of these uncertainties. In the end, however, policies
which maintain long term flexibility are likely to be the most practical way of hedging against uncertainty. The choice of an appropriate discount rate is always an issue in cost-benefit analysis, especially where this analysis involves decisions which affect the very long term. Using a low discount rate (perhaps even one as low as zero), gives stronger weight to future events than a high rate does. Thus, it is possible to bias the analysis against future generations by adopting a high rate. Some analysts have therefore suggested that low rates are particularly appropriate for situations involving "irreversibilities" (e.g. permanent inundation). In theory, the social rate of time preference (an indicator of consumer preferences for present-day consumption over future consumption) and the marginal productivity of capital (an indicator of producer preferences for investment) should reach long run equilibrium at the optimum discount rate. However, this long run equilibrium will never be reached because of differing risk levels, tax rates, etc.

In practice, if the funds to be used in a project are derived from present consumption, a social rate of time preference should be used for discounting purposes. If the source of the funds is savings, then market interest rates would be more appropriate. Also, some environmental resources are not reproducible, and are therefore subject to depletion and irreversibilities. It can be argued that discount rates for this type of resource should be lower to reflect their relative scarcity. Similarly, it is reasonable to assume that the aggregate social rate of time preference will not be the same as the rates for individual resources. For all of these reasons, it is suggested that different discount rates should be applied to different types of costs and benefits.

Risk also poses special problems, especially in the low probability-high consequence category. For monetary impacts, it may be possible to value risk using a hypothetical "insurance" premium. In the case of non-monetary impacts, a shadow price can be computed, as discussed earlier. But some will argue against this approach on moral grounds. (Attempts to value human life in monetary terms provide an example of the ethical problems that are involved).

4. SUMMARY

A cost-benefit model, modified to allow for: (i) successive iterations (including feedback loops); and (ii) exogenously-imposed decision rules, seems best suited to the problem of assessing the socio-economic impacts of sea level rise. Such an approach would be politically practical and reasonably cost-efficient. The basic elements of a methodological framework for conducting this analysis were outlined above. In implementing this framework, special attention should be given to such questions as the degree of marginality involved; the dynamic interaction of policies; risk; uncertainty; and the choice of an appropriate discount rate. It is hoped that the existence of this framework will act as a catalyst for more detailed local or regional studies of this important policy problem.

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AN APPROACH OF UNEP TO THE EXPECTED CLIMATE CHANGES

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In spite of uncertainties surrounding our ability to predict with higher precision the changes we may expect in global climate, greenhouse gases seem to have accumulated in the atmosphere to such a level that the changes may have started already and their continuation may now be inevitable. On the strength of presently available scientific evidence, UNEP has adopted the assumption that significant changes in global climate are likely to happen in the not so distant future, resulting in global temperature elevations of 1.5°C by the year 2025 and 1.5°C-4.5°C by the end of the twenty-first century. The expected concomitant sea level rise is 20 and 20-140cm, respectively.

The environmental problems associated with the potential impact of expected climate changes may prove to be among the major environmental problems facing the marine environment and adjacent coastal areas in the near future.

Therefore, the Oceans and Coastal Areas Programme Activity Centre of UNEP launched, co-ordinated and financially supported a number of activities designed to assess the potential impact of climate changes and to assist governments in the identification and implementation of suitable policy options and response measures which may mitigate the negative consequences of the impact. In 1987, Task Teams on Implications of Climatic Changes were established for six regions covered by the UNEP Regional Seas Programme (Mediterranean, Wider Caribbean, South Pacific, East Asian Seas, South Asian Seas and South East Pacific regions) with the initial objective of preparing regional overviews and case studies on the possible impact of expected climate changes on the coastal and marine ecological systems, as well as on the socio-economic structures and activities of their respective regions.

Additional Task Teams for the West and Central African region and for the Eastern African region were established in 1989, and for the Persian/Arabian Gulf in 1990. The establishment of Task Teams for the Black Sea and for the Red Sea is under consideration. The Task Teams are established and work under the overall co-ordination and guidance of the Oceans and Coastal Areas Programme Activity Centre of UNEP. Each Task Team operates under the direct guidance and supervision of a Task Team Co-ordinator appointed by the Oceans and Coastal Areas Programme Activity Centre.

The members of the Task Teams are appointed by the Oceans and Coastal Areas Programme Activity Centre on the recommendation of the Task Team Co-ordinators. In selection of the Task Team members the need for adequate geographic representation and for expertise relevant to the work of the Task Teams is taken into account. UNEP's financial support to the Task Teams is provided through the Oceans and Coastal Areas Programme Activity Centre.

KEY WORDS

Coastal Areas Programmes
Regional Seas Programmes
UNEP's Task Team
The long-term objectives of the Task Teams are:
- to assess the potential impact of climatic changes on the coastal and marine environment as well as on socio-economic structures and activities; and
- to assist Governments in the identification and implementation of suitable policy options and response measures which may mitigate the negative consequences of the impact.

The short-term objectives of the Task Teams are:
- to analyse the possible impact of expected climatic changes on the coastal and marine ecological system, as well as on the socio-economic structures and activities; and
- to prepare overviews and selected case studies relevant to specific regions.

The subjects intended to be analysed and described in the regional overviews include:
- the possible effects of the sea level changes on the coastal ecosystems (deltas, estuaries, wetlands, coastal plains, coral reefs, mangroves, lagoons, etc.);
- the possible effects of temperature elevations on the terrestrial and aquatic ecosystems, including the possible effects on economically important species;
- the possible effects of climatic, physiographic and ecological changes on the socio-economic structures and activities; and
- areas or systems which appear to be most vulnerable to the expected impact.

The overviews are intended to cover the marine environment and adjacent coastal areas influenced or influencing the marine environment of the following regions:
A) Mediterranean Task Team: 17 States covered by the Mediterranean Action Plan of UNEP's Regional Seas Programme (Algeria, Cyprus, Egypt, France, Greece, Israel, Italy, Lebanon, Libya, Malta, Monaco, Morocco, Spain, Syria, Tunisia, Turkey and Yugoslavia) and Albania.
B) Caribbean Task Team: 25 States covered by the Carribean Action Plan of UNEP's Regional Seas Programme (Antigua and Barbuda, Bahamas, Barbados, Belize, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Grenada, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, St. Christopher and Nevis, St. Lucia, St. Vincent and Grenadines, Suriname, Trinidad and Tobago, United States of America and Venezuela) and the Caribbean territories of France, Netherlands and the United Kingdom.
C) South-East Pacific Task Team: 5 States covered by the South-East Pacific Action Plan of UNEP's Regional Seas Programme (Chile, Colombia, Equador, Panama and Peru).
D) South Pacific Task Team: 14 Island States covered by the South Pacific Action Plan of UNEP's Regional Seas Programme (Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, Niue, Palau, Papua New Guinea, Solomon Islands, Tonga, Tuvalu, Vanuatu and Western Samoa) and the South Pacific territories of France, New Zealand, United Kingdom and the United States of America.
E) East Asian Seas Task Team: 5 States covered by the East Asian Seas Action Plan of UNEP's Regional Seas Programme (Indonesia, Malaysia, Philippines, Singapore and Thailand).
F) South Asian Seas Task Team: 5 States negotiating the South Asian Seas Action plan of UNEP's Regional Seas Programme (Bangladesh, India, Maldives, Pakistan and Sri Lanka).
I) Persian/Arabian Gulf Task Team: 8 States covered by the Kuwait Action Plan of UNEP's Regional Seas Programme (Bahrain, Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia and United Arab Emirates).
J) Black Sea Task Team: States which may participate in the Black Sea Action Plan of UNEP's Regional Seas Programme (Bulgaria, Romania, Turkey and USSR).

The regional overviews and case studies are being presented to the intergovernmental meetings convened in the framework of the relevant Regional Seas Action Plans in order to draw the countries' attention to the problems associated with expected climate change and to prompt their involvement in the development of policy options and response measures suitable for their region and countries. The site-specific case studies are presented to national seminars in the interested countries. The preliminary results of the regional overviews of the Task Teams were already considered by meetings convened under the Mediterranean, Caribbean, South Pacific, South-East Pacific and East Asian Seas Action Plans. A special intergovernmental meeting was convened in the Marshall Islands (Majuro, 16-20 July 1989) for the island States and territories of the South Pacific to consider their policy options, suitable response measures and additional site-specific case studies to be developed. A detailed case study on the Maldives was prepared with assistance of the South Pacific and the Mediterranean Task Teams and will probably lead to a large-scale country project.

Once the initial objective of the Task Teams (impact
studies) is achieved, they concentrate on providing assistance to national authorities in defining and implementing specific policy options and suitable response measures.

The development of climate scenarios for the Mediterranean region has been initiated. They are planned to be completed in 1990 and to be used in connection with the revision of the Mediterranean regional study.

On a global scale a review on the interaction of the oceans and greenhouse gases and atmospheric aerosols was completed and published, a bibliography on effects of climate change and related topics was prepared by the Mediterranean Task Team, and the launching of a globally co-ordinated programme for monitoring climate related changes relevant to the marine and coastal environment is being prepared in collaboration with the Intergovernmental Oceanographic Commission and the World Meteorological Organization.

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COASTAL CITIES AND ENVIRONMENTAL HAZARDS

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Excellencies, Distinguished Participants, Ladies and Gentlemen, Foresight and vision are rare qualities in international and public affairs. More often than not, when faced with the probability of pending catastrophes and disasters, the natural human reaction is to take comfort in the fact that the threat is not immediate and put off difficult decisions until tomorrow, despite the fact that tomorrow may be too late and that today's complacency only greatly increases the cost of future action.

This observation certainly holds true when we move to the contemplation of the potential impact of climate change produced by the increase in atmospheric trace gases and the consequent greenhouse effect. Will the international community as a whole, for the threats and risks inherent in this change are global, muster the political will now to allocate the resources and initiate the actions required to mitigate or prevent these threats, whose full impact, if left unabated, will not be felt until the next century?

Such is the challenge that is before us, and that is why the United Nations Centre for Human Settlements (Habitat) is greatly encouraged by and welcomes the initiative of the City of Venice to establish an association of Cities on Water, and the International Centre of the same name.

Certainly cities on water are at a particular risk from the consequences of drastic climate change, and the first and foremost of the potential threats is, of course, sea level rise, the subject of this first International Meeting of the Centre.

Approximately one-third of the world's population lives within 60km of a coastline. In some regions, such as the Caribbean, the South Asian maritime zones, and the South Pacific, 100% of the population lives within this distance from the coast. Settlements located in low-lying coastal areas are vulnerable not only to sea level rises of varying degrees, but also to a combination of other impacts caused by waves, encompassing all kinds of water level fluctuations.

If the projected climate changes occur, flooding due to storm surges will increase significantly; saltwater incursions will increase; coastal erosion will intensify and an even greater number of people will become subject to the hazards of storm surges.

It is estimated that at least 50 million people will be driven from their coastal dwellings by the rising sea in the next century, if no action is taken. Some islands may disappear completely, or at least become uninhabitable, if the sea level rise scenarios become true.

The economic implications of sea level rise are equally dramatic. Given the global tendency of urban and industrial concentration in coastal areas, many investment decisions could be affected by possible sea level rise. Preventive measures to mitigate the impact of such a rise on the economic and social infrastructure already in place would be very costly.
For developing countries the cost could be prohibitive, unless international financial assistance is made available.

Given the massive costs of preventive and mitigation measures, and the social dislocation which these actions may also call for, decision-makers and political leaders in both developed and developing countries will be hesitant to take such steps unless they are absolutely convinced that these actions are unavoidable. This requires first and foremost the establishment of the complete scientific credibility of predictions of sea level rise, including accurate estimates of sea level changes.

This in turn requires data, the precise identification of vulnerable areas and new measurement tools and data collection technologies. Also, much work will have to be done in the field of impact area analysis, including new physical development plans for settlements and action planning for disaster mitigation and prevention.

To make such an enterprise successful certainly will require the co-operation of the global scientific community, governments, non-governmental organisations and multilateral and bilateral assistance agencies. Your meeting here in Venice over the next few days is a step in that direction.

My personal hope is that the International Centre of Cities on Water will become that centre of excellence and research which will take the lead in producing the pioneering work which will allow settlements, both large and small, to face the twin challenges of climate change and sea level rise with a degree of confidence and with the appropriate tools in hand. Certainly Venice is a fitting location for such a Centre, for Venice, as a maritime city, has throughout its history, been more aware than most of the consequences of environmental change and the vulnerability of coastal cities.

Finally, and in conclusion, I should like to assure you that the International Centre of Cities on Water will be able to count on the full support and co-operation of the United Nations Centre for Human Settlements (Habitat) in its search for new solutions with which to face the global environmental hazards of the 21st century.
1. INTRODUCTION

For the World Meteorological Organization (WMO), climate has always been a main subject which includes climate monitoring and a wide variety of research activities. Since the establishment in 1873 of the predecessor of WMO - The International Meteorological Organization - the Organization has always had, as one of its main tasks, the observation and collection of data on climate. The climate programmes of WMO and its 160 Members have been primarily responsible for the present understanding of climate variability and change, and continue to contribute the scientific basis for development of appropriate policies. WMO is very much aware of its responsibilities in matters related to environment as expressed by the Executive Council of WMO at its forty-first session in June 1999:

"WMO's responsibility is to provide the authoritative scientific information and advice on the condition and behaviour of the global atmosphere and climate and the conditions that affect them. To carry out this responsibility, WMO will actively support and encourage the development of environmentally sound policies by the international community to respond to climate change; and to encourage its 160 Members in co-operative efforts and appropriate programmes within their own countries."

2. SOME HISTORY

In 1975, the Seventh World Meteorological Congress, in response to requests made by the UN General Assembly and the UN World Food Conference (1974), adopted the Resolution "Climate Change".

The Resolution required review of available evidence, both meteorological and non-meteorological, on climatic change. The first review was announced at the WMO Symposium on Long-Term Climatic Fluctuations in August 1975. At various stages WMO has also issued a number of statements on carbon dioxide increase and climate change.

The World Climate Conference organized by WMO, in collaboration with other international agencies, provided a comprehensive and authoritative review of climate effects on human activities and an assessment of current understanding of and ability to predict the impact of human activities on the global climate.

The World Climate Programme (WCP) was established by WMO in 1980, in co-operation with other international organisations - especially the UNEP and ICSU (International Council of Scientific Unions). The WCP provides an international infrastructure in the areas of climate data and applications as well as in climate research and the study of climate impacts.
Its main objectives are:
- to apply CLIMATE INFORMATION for the benefit of economic and social activities,
- to improve UNDERSTANDING OF CLIMATE PROCESSES in order to accelerate the:
  - determination of the predictability of climate,
  - development of climate projections and scenarios,
  - determination of the causes and extent of human influence on climate, in order to recommend appropriate preventive or adaptive actions,
  - to MONITOR CLIMATE VARIATIONS OR CHANGES, either natural or anthropogenic, and to develop the capability to warn Governments of changes and their impacts which can markedly affect economic and social activities.

3. CLIMATE VARIABILITY AND CHANGE

Climatologists have studied and described climate variability for ages. A major objective for the WCP is to advise and help society to take this variability into account in planning economic and social activities. In some sectors of the society tie benefits from applying climate, as well as meteorological services in general, have been shown to be substantial. The value of climate data and information as well as of various meteorological services have thus led to new developments within the WMO and its Members represented by the national Meteorological Services. One such development relates to urban planning and building.

The Tropical Urban Climate Experiment is an attempt to focus research and application development on understanding and improving the deteriorating environments in the fast growing urban areas of the tropics. This may very well include aspects related to the impact of potential sea level rise on coastal cities, i.e. the risks for flooding, landslides, etc.

Climate change, due to human activities which cause increasing atmospheric concentrations of greenhouse gases, is now of major concern to national leaders, the general public, the media, scientists and environmentalists.

A major milestone on the issue of Climate Change and Greenhouse Gases was the 1985 ICSU/UNEP/WMO Villach Conference. The conference provided a consensus statement of the scientific community on the probable magnitude of climate warming and its implications. This statement is still of a great extent valid and widely used. In particular it was stated that:

A) If present trends continue, the combined concentrations of atmospheric CO₂ and other greenhouse gases would be radiatively equivalent to a doubling of CO₂ from pre-industrial levels possibly as early as the 2030s.

B) Increases of the global mean equilibrium temperature for a doubling of the atmospheric CO₂ concentration, or equivalent, may be between 1.5 and 4.5°C.

C) Global warming of 1.5 to 4.5°C would lead to a sea level rise of 20-140cm.

4. THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

The Global Climate Change issue is also addressed with high priority through the work of the Intergovernmental Panel on Climate Change (IPCC). The IPCC, which was established in 1988 by the Secretary-General of WMO and the Executive Director of UNEP, was given the following tasks:

A) to assess available scientific information on climate change,

B) to assess the environmental and socio-economic impacts of climate change, and

C) to begin to formulate the types of global strategy and national and international policies that would need to be adopted in order to address this unprecedented and pressing challenge to humankind. These tasks are also requested in the UN General Assembly Resolution 43/53, and a report of the Panel’s activities will be submitted to the 45th session of the General Assembly. The work of the panel draws on the activities of the many scientists and policymakers concerned with the climate change issue and includes a large number of workshops and other meetings. The first assessment report is requested by the governing bodies of WMO and UNEP by September 1990, ready for presentation to the 45th session of the General Assembly and the Second World Climate Conference (SWCC), which will be held in October 1990. This SWCC is expected to be a landmark with respect to the climate change issue.

5. CONCLUSION

WMO as the specialised agency of the UN system is responsible through its 160 members, for international collaboration and cooperation in meteorology and operational hydrology and has responsibility for providing authoritative scientific information and advice on the condition and behaviour of the global atmosphere and climate. As this is a most complex and difficult task both from a scientific and policy point of view, it is of utmost importance that the ongoing assessments within the framework of IPCC are conducted thoroughly and with great care.

The importance of climate and its variation and change to economic and social activities of the society need to be fully appreciated and understood. WMO is fully committed to fulfilling its responsibilities in close cooperation with other organisations within and outside the UN system.
THE CLIMATIC CHALLENGE
AND THE EUROPEAN COMMUNITY

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Mr. Mayor, Ladies and Gentlemen and dear Colleagues, I was invited by Roberto Frassetto to take part in this Convention so that I could explain what the European Community is doing in this field. My thanks to him. At a time when environmental problems come first and foremost for everyone: scientists, Governments and organisations alike, he and his colleagues have launched one of the best initiatives possible in this field. I am furthermore grateful to be here in this wonderful city, as will already be obvious.

I will be brief, because my subject does essentially lie beyond the scope of the programme. I do however think it is important for people to know what the European Economic Community is doing in the field of study related to the activities of the Centre Cities on Water, and in particular to the theme of this Meeting - the effect of the rise in sea level on cities and coastal regions.

In 1979 the European Community launched a programme of climatology that had been on the drawing board since late '76/early '77. Two people present at this Meeting, Prof. Wun-Nielsen and Prof. Puppi were in Brussels ten years ago at a meeting to prepare that very programme. It is with great pleasure that I see them again here at this meeting in Venice, ten years later.

The programme was not approved with great enthusiasm, as the time was not ripe. It was a small pilot programme with a grant of 8 million ECU's (called accounting units in those days) over 5 years. Nevertheless, it was successful and I, personally am proud of it because the idea for the European Community to have a climatology programme was mine. I do not want to boast, but quite frankly, I am pleased to have it known that the idea was an Italian one that started off in Brussels and then grew.

This 5-year programme was especially successful and was replaced by its first reincarnation in '86, due to come to an end in 1990.

This new programme concerns climatology and natural hazards. Climatology and natural hazards because, in the meantime, ideas had changed, and it was held that the study of climate could not be separated from that of other associated phenomena such as forest fires, landslides, the instability of natural slopes, or hydrological phenomena such as flooding and so on.

The idea was to bring to the attention of the European Community - and consequently the national governments who approve the Commission's proposals - that the environment cannot only be seen as the victim of human activities, the object of pollution such as is produced by industrial development, but also as a source of risk for man. Some of these hazards can, of course, be traced back to man, because, in managing his environment badly, he creates conditions which then have repercussions on him.
The most comprehensive example is the one under consideration here: a change in climate caused by the build-up of carbon dioxide in the atmosphere that can have a negative effect on man.

For the most part, Community environmental programmes developed up until then had normally been programmes in which the environment was considered as an essentially passive receiver of the polluting substances that man poured into it (polluted water, polluted earth, polluted air).

The environment as something that is living and reacts on the basis of its own mechanisms to man-made ones, and that thus can become a source of hazard for man, is an idea that has arisen in the course of the programmes I have had the honour to run in Brussels.

Our intention was also to take account of the more specific problems of countries such as these in the Mediterranean area. There, in addition to the classic problems due to pollution, there are others caused by the special nature of the natural environment - countries such as Italy, with its wealth of landscapes, culture, art and human heritage.

There is a dimension in all this that should have been taken into consideration in the development of the new type of environmental programmes. There are countries which, even though wealthy, are afflicted by problems that differ widely from those of the northern European countries.

Problems related to geographical position thus climate, problems concerned with the geological, orographical, hydrological structure, problems about location with respect to the tectonic situation, earthquake phenomena and thus with all associated problems that are not only scientific and technical but also of a human nature: the impact on the people; what can it mean for example, for a community, to live in a high earthquake risk area: one by one all of these concepts become of prime importance.

The present programme that will theoretically terminate at the end of '90 (the last one I mentioned) is practically dead and buried.

For a start, the funds have run out (the programme had a budget of approximately 17 million ECU). Then, on November 21st, the Council of Ministers of the European Community approved a third programme of climatology and natural hazards to run until the end of '92.

This new programme has a budget of 40 million ECU - so you can see what progress has been made.

But the progress is more an appearance than a reality because, as it is a fusion of two programmes - one of climatology and the other of natural hazards - a budget of 20 million per programme is relatively poor with respect to the problems to be faced. In any case, let's hope for the best in the future.

I am not going to describe the contents of these programmes, as I have already covered them roughly. Further details can be provided later if necessary.

You may be interested to know how these programmes are put into practice. With the Chairman's permission I will provide these details: first of all an announcement is published in the Official Gazette of the European Community. It comes out in all the official languages of the European Community. The announcement relative to the EPOCH programme appeared on August 3rd, with the deadline of November 30th.

We receive offers and projects of an international nature - because we only accept projects that involve collaboration with several different European laboratories. Then follows a process of evaluation, at the end of which the proposals accepted are awarded research contracts to which the European Community contributes a maximum of 50% of the total cost.

As well as this, we have numerous meetings to promote contacts with and between the people who work under contract. At these meetings we also try to involve people who do not hold a contract with us, with the aim of expanding the circle of this activity of coordination as far as possible.

We have also set up a School of Climatology and Natural Hazards that holds annual one week-10 day courses on various subjects, for students from all over Europe - we have had had for example one course in Athens on earthquake risk, in Florence on climate change, and we will be holding one now in Lisbon on the instability of natural slopes, landslides, etc. In spring we will hold a course in France about the change in climate in the context of global environmental change.

These are just a few examples. One of our best results are the strong links that have been forged between European researchers, links across the borders that did not exist once. Research is stimulated, as well as collaboration, and this is where I believe the Community programmes have been particularly successful.
The recent concern that sea levels will rise by 0.5 metres or more in the next few decades as a consequence of greenhouse warming, has drawn attention to what Coastal Engineers know is already an ongoing problem. The coastal zone is a dynamic region of tides, currents and mobile sediments. Protection against erosion or siltation may require expensive preventative measures. Although sea level rise cannot be isolated from other effects on coastal dynamics, there are strong reasons why the global concern over possible increases must be addressed by a global response as well as by more detailed studies at a local level.

It is usual to divide sea level measurements and studies into global, regional and local scales. For someone whose land or house is flooded the problem is local and immediate. But these local problems are best understood in the context of long-term global developments. Proper design against local hazards requires the long-term collection of sea level measurements over decades and ideally over centuries. We are told that Peter The Great made the first readings of water level in Leningrad personally, to emphasise the importance which they had for the future development of the city.

Each individual City on Water must make its own observations and be prepared to sustain these on a permanent basis. Local effects such as channel dredging and subsidence of low-lying alluvial land must be detected. Projections of likely future changes also demand studies of changes in global sea level which may result from the melting of grounded ice or from the expansion of ocean waters due to heating. The Intergovernmental Oceanographic Commission coordinates the Global Sea Level Observing System which consists of an international network of sea level measuring stations. GLOSS provides high quality standardised data from which valuable sea level products are produced for international and regional research programmes, as well as for practical applications at a national and city level. The Global Sea Level Observing System has to serve many purposes. It has to cover the entire spectrum in time and space from short lived tsunami to the changes related to tectonic processes. Characteristics of the network must include permanence, high vertical precision and stability, and the flexibility to develop as the requirements evolve.

Many of these gauges are already operating but many need upgrading in terms of levelling accuracy, documentation, telemetry and time taken before the data becomes available for analysis. About one hundred new sites are proposed, many on ocean islands which are the best places for ocean monitoring. The network as planned is shown in Fig. 1.

As data products are made available and analysed,
the correlation of mean sea level to climatic phenomena will become clearer.

This, along with advancement of technology, should result in the eventual upgrading of all stations to near-real-time delivery of data.

The elements of GLOSS are:

1) The global network of permanent sea level stations for obtaining standardized sea level observations; this forms a primary framework to which regional and national sea level networks may be related.
2) Data collection for international exchange with unified procedures which may include near-real-time data collection. Near-real-time data collection allows immediate evidencing of gauge malfunctions so that repairs can be made.
3) Data analysis and product preparation required for scientific and/or practical applications. Analysis of long-term series of sea level data will allow the detection of trends not only in the mean levels, but also in the statistics of extreme events.
4) Assistance and training for establishing and maintaining sea level stations as part of GLOSS and improving national sea level networks.
5) A selected set of GLOSS tide gauge benchmarks will be accurately connected to a global geodetic reference system so that vertical movements of the land can be separately identified from changes in the mean sea level. The development of a fully coordinated observing system will take time even though many of the component parts are already in place in a national level.

It will also need resources beyond the modest sums which the IOC can make available. Further support, either through donations to the Trust Fund, or in kind would allow key activities to proceed;
1) Establishment of further gauges through supply and equipment and expert assistance.
2) Upgrading and continuing operations of existing gauges.
3) Development of coordination through publication of regular newsletters, brochures and technical reports.
4) Setting up further training courses in measurement, analysis and interpretation for both developed and developing countries.
5) The operation of a small team of sea level coordinators each operating at a regional level as part of a global
team. Direct measurements of sea level by tide
gauges will in future be supplemented by
measurements from satellites.
The challenge is to develop an integrated system of
measurements which match the long-term stability
of direct measurements with the more general ocean
coverage which satellites afford.
It is essential that the GLOSS network develop
globally, and that it has expression at regional and
local levels. Resources must be available to measure
future changes of sea level as a vital component of
civic planning.
Resources must also be made available to sustain a
strong permanent global system.
Without these measurements, planning for the impact
of sea level rise will be speculative and potentially
misdirected.
1. INTRODUCTION

Global climatic changes, whether natural or as a result of human activities, can have far-reaching consequences. One such change, of considerable importance, is the rise of the mean sea level due to possible global warming associated with the so-called greenhouse effect, the related melting of polar ice and the expansion of the ocean waters. Estimates based on numerical models describing the consequences of increases in the greenhouse gases in the atmosphere, suggest that the rise could be from 20cm to 200cm over the next century.

If this were so, large areas of the globe, particularly land masses in the Northern Hemisphere would be at risk, with serious consequences in terms of flood control, surface and groundwater level management, and disturbances to the ecological balance.

The recognition of this possible threat has led to a dramatic increase in measurement activities worldwide in the last few years.

Traditionally, sea level height data are collected by a network of observatories located on coastlines and equipped with tide gauges. About 1300 such stations exist worldwide. Our knowledge of sea level changes over the past 100 years has depended solely on tide gauge measurements, although the geographical distribution of historical sea level records has not been ideal and they are unreliable.

Nowadays, through the elimination of many disturbing meteorological and oceanographic factors, the annual mean can be determined much more accurately; on a local scale even in the mm-range. The mean sea level thus obtained represents an approximation to a zero-level reference surface.

As the term “tide” indicates, the dominating signal that is measured by these instruments are the sea level variations caused by the tides.

The sea level variations can be as much as some tens of metres within a 24-hour period. There are other sea level disturbances caused by currents or temperature changes in the water that make it extremely difficult to find in the irregular down-and-up motions an average value for the so-called Mean Sea Level (MSL).

The MSL is defined as the average of all the instantaneous sea surfaces over a sufficiently long period of time. The mean sea level thus obtained represents a reference surface good enough to observe the larger oceanographic phenomenon.

When it is realised that the measurement points on the Earth’s surface are moving because of the tidal deformation of the “rigid” Earth (about 50cm variations within a day), it is easy to understand how difficult it is to make reliable measurements.

Since we are dealing with a global phenomenon rather than with a local effect, it is necessary to provide all observers with a common stable reference benchmark.
Not long ago, it was an acceptable assumption that the undisturbed surface of the oceans represented an absolute reference level for height measurements since it was understood that the mean sea level was the best physical approximation of a gravitational equipotential surface, the geoid.

Today, we know that the MSL at the tide gauges can differ from an ideal surface of the open oceans by a few metres and consequently, all measurements made with respect to such a mean sea level have a substantial error in relation to a real static reference surface, especially from one ocean to another, as well as along coastlines of the same ocean.

Some geodesists even consider the determination of the "permanent sea surface topography" the most important unsolved problem in geodesy (K. Wagner, Assisi, 1988).

So, if we want to make precise height measurements, we have to determine with high accuracy a stable, static surface. Such a surface exists in principle, if we introduce the idea that a motionless uniform ocean on a rotating Earth takes the shape of the equipotential surface of the Earth's gravity field, the geoid.

Since it reflects the very irregular shape of the Earth and the distribution of masses inside the planet, it takes the form of a body which is characterised by a large number of bumps and depressions of different sizes. Fig. 1 is only a very simplified representation of its large-scale features.

The problem is then to measure the geoid or positions with respect to the geoid and use this datum to arrive at the mean sea level.

Space techniques have the capability not only to establish the required static reference surface but also to perform the necessary complementary measurements on a global scale.

The stringent accuracy such measurements must achieve are possible. The first goal to be addressed is the ability to bring together the height coordinates of all tide gauges into one geodetic "datum".

This goal can be accomplished by using space techniques to determine precisely the absolute and relative positions over long distances. A convenient method is to instal at the tide gauge stations, receivers of the Global Positioning System (GPS) and link these facilities geodetically to fundamental sites on tectonically stable points (Fig. 2).

Exclusively space-based approaches appear to offer very attractive and, possibly more economic solutions to the requirements of setting up a uniform tide monitoring network to obtain standardised observations, procedures for near-real-time data collection, data analysis and connecting a selected set of tide gauge stations into a global geodetic reference system.

Possibly the most promising approach is sketched in Fig. 3, where we can distinguish four surfaces.
Fig. 3. Sea Level Rise Observed by Space Techniques

Fig. 4. P.R.A.R.E.: Precise Range and Range Rate Equipments
Fig. 5a. GPS stations network for the Venice Altimeter Calibration
Fig. 5b. The Venice CNR Platform for the Calibration of the ERS1 Altimeter
The orbits of satellites are determined from tracking the spacecraft through ground stations at known positions. The dominant error in this operation is the uncertainty of the gravity field, i.e., insufficient knowledge of its irregular structure.

On the other hand, it was the observations of the perturbations of the satellite's orbits (caused by an uneven gravity field) which allowed a progressively more detailed description of the shape of the geoid. In order to interpret distances measured by spacecraft sensors in terms of ocean topography, it is important to measure the vertical position of the satellite above the sea surface by radar altimetry to the decimetre level, or better. Such a stringent goal requires a network of very precise tracking stations distributed regularly over the globe.

The importance of a more precise determination of spacecraft orbits was confirmed when the first spaceborne altimeter was switched on in 1973 on Skylab. The coarseness of the tracking systems available kept the absolute accuracy of altitude measurements to the 5m-range, and the precision which the altimeters could achieve was wasted for many years until continuing refinements in tracking techniques and orbit computations enabled both, altitude above ground, and above the Earth's centre, to be determined with comparable accuracy.

It is therefore not surprising that spacecraft equipped with altimeters also carry ultra-precise microwave tracking systems which determine, in combination with a suitable network of ground stations with well-known position coordinates, positions of the satellite and, consequently, its orbit.

The Precise Range And Range-rate Equipment PRARE on board ESA's first remote-sensing satellite ERS-1 will use the most advanced concept ever built for precise satellite tracking: a dual frequency, two-way microwave tracking system (Fig. 4).

In order to exploit the even higher precision of modern laser tracking systems, such satellites frequently carry retro-reflectors for ultra-precise tracking with laser stations.

The laser-reflector on board ERS-1 may seem an inconspicuous payload element, but it is extremely important. One of its functions is to calibrate the absolute accuracy of the Radar Altimeter. For this purpose a site near Venice has been selected as the central point for such calibration sessions to be performed by a network of five laser stations (Fig. 5).

3. REFERENCE ELLIPSOID

The Earth's surface may be closely described mathematically as a rotational ellipsoid. It is therefore well known and no measurement is required. By convention, its dimensions are chosen so that they fit the geoid as closely as possible.

However, since the variations in geoid surface elevation across the globe are of the order of 100m, this fit is far from perfect. An ellipsoid that fits very well, for instance, in Europe, does not necessarily fit in Africa. The reference ellipsoid is an arbitrary surface which has no fundamental physical meaning.

4. THE SEA SURFACE TOPOGRAPHY

The height of the ocean surface above the geoid (Hs) represents the sea surface topography. This surface differs from the geoid because of tides, currents, wind stress, salinity and temperature variations. Sea surface topography plays an important role as a meaningful signal in oceanography, in particular in ocean circulation studies.

However, when determining sea level, the fluctuating sea surface topography is undesirable noise. The direct use of the observed momentary sea level as a means of deciding the geoid is therefore not possible, and until recently the geodetic measurements using shipborne gravimetry or satellite altimetry ignored sea surface topography, accepting errors in the metre range. Satellite altimetry nevertheless furnishes useful data, in particular over the open oceans. Together with an accurate determination of the satellite's orbit, the vertical position of the open ocean surface can be established with respect to the Earth's centre. Or, in other words, the fluctuating part of the sea surface topography can be computed using only the satellite orbit and altimetry information.

Today, satellite altimetry can be considered the workhorse of physical oceanography. Fig. 6 is one typical result of sea surface topography as derived from earlier satellite altimetry data.
5. THE GEOFID

As already explained, the geoid is defined as the equipotential surface that would be assumed by a still, uniform ocean after removing the time-dependent effects of external forces such as those due to tides, currents, storm surges, wind and atmospheric disturbances. Thus, if the ocean and atmosphere were motionless, the geoid would coincide with mean sea level. Since by definition the force of gravity is everywhere perpendicular to the geoidal surface, a map of the geoid is related to the Earth’s gravity field; it represents an equipotential surface of the gravity field.

So, if we can measure the geoid, we observe a gravity field quantity which can be related to the mathematical gravity value of the reference ellipsoid. Because of its stable form the geoid is the ideal global reference surface for heights. One way, though very time-consuming and limited in coverage, would be by integrating marine gravity potential data obtained from ships, if they were uniformly available globally.

Another method, exploited since the first successful measurements from Skylab in 1973 and GEOS-3 in 1975, is satellite altimetry. In the following, the two principal space techniques for supporting the monitoring of changes in the World’s ocean height, Altimetry and Direct Gravity Field Mapping, are described and examples for implementation of them in Earth observation programmes of ESA are given:

Satellite altimetry (Fig. 7) is a technique whereby a satellite sends a pulsed radar signal vertically downward to the Earth’s surface (oceans or continents) and records the time of arrival of the echo reflected back from the ground. From this round-trip propagation time we can calculate the distance between the spacecraft and the ground.

The unique characteristics of satellite altimetry are:

- the high degree of accuracy to which measurements can be made by today’s and tomorrow’s instruments: a typical example of this extraordinary product of engineering skill is the altimeter that will be carried on board ESA’s first Remote-Sensing satellite ERS-1, which will measure the 800km distance between the satellite and the oceans’ surfaces with an accuracy of 10cm, day and night and in any weather condition.

Fig. 8 shows ERS-1 as it will circle the globe as from the end of 1990 onwards, with its altimeter antenna pointing vertically downwards. This performance corresponds to one-second averages of the measurements, which is equivalent to an along-track spacing of target points of about 7km.

ESA is currently planning for a follow-on satellite to ERS-1 and for a series of polar orbiting platforms, all equipped with altimeters with increasingly improved performance specifications. This programme can therefore offer:

- continuity for altimetric data at least until the next century. ERS-1 will be launched at the end of 1990.
- the ability to collect these measurements globally over relatively short time intervals (Fig. 9).

Fig.10 shows the dense coverage obtained by ERS-1 during a period of 35 days.

The lines on the map represent the ground projections of the satellite’s orbit during this period. Since the
orbital plane is inclined with respect to the Earth's axis, ascending and descending paths cross each other at certain points which are therefore even more frequently covered.

If we can determine at the same time the vertical position of the spacecraft with reference to the Ellipsoid or the Earth's centre, we can, in principle, determine the geoid over the oceans to an accuracy which corresponds to the remaining oceanographic "noise" in the altimetry signal.

This "altimetric" geoid is affected by errors in all three principal measurements:
- spacecraft tracking
- altimetry
- gravity field (GEOID).

The most intriguing uncertainty by far lies in the knowledge of the geoidal height N.

Space techniques can provide an elegant solution to this problem.

If we could determine the Earth's gravity field in space with very high accuracy, and if one could extrapolate that field to an equipotential surface
average gravity value for each of the 65000 1° by 1° surface elements of the entire globe.
To come back to the causes of the anticipated sea level rise, it is appropriate to speak about these factors, the more so as ERS-1 instruments are considered capable of measuring such parameters. Major changes in the volumes of the polar ice sheets will affect both sea level and climate.
Increased melting from the surface of the ice sheets and from numerous icebergs in Arctic and Antarctic waters (Fig. 12) will have a strong impact on the oceanic circulation and on the heat exchange between ocean and atmosphere.
The potential amplification at high latitudes of future climatic warming due to increased concentration of “greenhouse” gases in the atmosphere makes it essential to assess the present mass balance of the Arctic and Antarctic ice sheets in order to predict probable ice sheet responses to the large temperature increases predicted for polar regions.
The Radar Altimeter and the Synthetic Aperture Radar of ERS-1 will enable ice sheet characteristics to be observed continuously and, as a near-term application, the corresponding global changes and, in the end, the Sea Level Rise to be monitored.
It is clear that space techniques can be very down to Earth.

Fig. 12. Antarctica: Sea Ice Evolution

with adequate accuracy, then we could compute the geoid height \( N \).

6. DIRECT GRAVITY FIELD MAPPING

The mathematical tools exist, and the measurement device is being conceived as the payload of the proposed future ESA mission ARISTOTELES, a mission to determine the Earth’s gravity field globally and precisely with uniform quality (Fig. 11).
The technique used is gradiometry, i.e., the measurement of the smallest acceleration differences inside a dedicated spacecraft in a very low (200km altitude) polar orbit. A satellite in such a low orbit will have only a limited lifetime due to the drag forces of the high atmosphere, but it is sufficient to map the Earth’s gravity field with the highest possible resolution and accuracy during a six-month mission. Highest possible resolution means that we have an
The following city officials expressed their point of view on the role and goals of the proposed Centre.

Prof. Sevenard of the Leningrad delegation supported the creation of a permanent Association of cities on water. Joint efforts of city officials with scientists engineers and industries will enlighten the understanding of problems and of their solutions. "In view of the present and pending problems, we look forward to an active cooperation in an international sound structure as soon as possible. It is unwise to delay this plan but it is also dangerous to be too hasty. We think however, that today is not too late nor too early.

Ten people could form the directory, 50% of which could be changed every 3 years. Rights and duties of the directory and the rules of the Association of the participating cities should be established with some flexibility. The first duty of each member is to furnish objective information following a defined list of topics. The centre, with automatic elaboration of information, should be able to disseminate it and answer questions posed by the members of the Associations. The future possible connection with the UN activities should be considered early."

Prof. Klaassen official of Rotterdam, suggested other topics to be dealt by the Association which, with this meeting, has already made an important step towards common efforts: the transportation function, in particular the development of inland waterways and inland shipping and the role of the water in the quality of life in the city.

Furthermore, the value of lowlands protected by dykes is increasing regularly and needs greater measures of safety. Rotterdam is ready to be active in the Association and recommends that the Centre contributes to the coordination of all the existing centres which collect data by centralising a network of information activities.

The official of Amsterdam, Mrs. De Voer, clarified that the global problems require global approaches and global solutions. It is very important to work together on problems as cities, also as a way to influence the national governments to deal with worldwide legislations, particularly in the pollution problem which cannot be solved by fragmentised approaches.

Dr. Ascher, representing Hamburg, confirmed the need for a Centre as proposed by Venice, which should acquire and assimilate the products of different existing activities in the world of national and international character dealing with climate and economy. "The city of Hamburg has to decide today but we are not yet sure what we shall decide. We have to reconstruct our defence works, to deepen navigable waters, but empoldering of low-lying land is not possible and we cannot move the city. It is a circle of the devil as the Germans say."
However, it is difficult to believe that precautions may totally eliminate the potential danger to life for any city as closely dependent on tidally influenced waters as Hamburg is.”

The representative of Boston, Mr. Adel Foz, emphasised the range of solutions to deal with Sea Level rise impacts and hard and soft technologies. The Associations have the privilege to bring forward problems and arguments so that we can learn from each other and create opportunities to begin finalising some joint research topics.

“We are very happy to become part of your group in order to sponsor joint research and improve everybody’s knowledge” says Prof. Lee of the Massachusetts Institute of Technology, Boston.

“I wanted to make a proposal for the group’s consideration as to what the goals and broad objectives of the Centre might be. I thought that there were three things that came out of this meeting: one was knowledge, second was local decisions and the third was flexibility.

Underlying all of those things was a theme that came through very clearly: it was how to reconcile global concerns and local actions. The statement I would like to make is: we (meaning the Centre) will work to improve and disseminate knowledge of the world, at all scales and all kinds: that means scientific, technical, socio-economic.

So that localities can make the best informed local decisions to improve the lives of their people, and that the actions are made with the utmost flexibility in the face of everchanging knowledge and conditions of all kinds: environmental, economic, social, political and technological. This is proposed to you, for your discussion and for consideration by the Centre.”

As representative of Osaka, Dr. Tamai confirmed that the outcome of this meeting also concerns a city which has long experience in facing land subsidence and storm floods and which is making a substantial contribution to the Global Research Program with research centres and universities. He will convey the result of this meeting to the Lord Mayor for an active participation the Centre’s activity.

The representative of Rio de Janeiro, Mr. Siqueira Castro, expressed great interest in the proposal of Venice and will bring the intent of including Rio in the Association to the attention of its mayor.

The Lord Mayor of Cork, Mrs. Ahern, expressed her pleasure and interest in participating in this illuminating meeting and in the future of the Venice Centre. Cork, built on several islands like Venice, has now reclaimed the channels, filling them as roads. The city, 18 miles from its port, suffers from effects of storm floods 2 to 3 times a year. “We are ready to benefit from long-term solutions elaborated by the International Centre. We will be behind and stay with the Centre’s organisers all the way”.

The Mayor of Orbetello, Mr. Fommei, said that his small city, built on a lagoon Tuscan’s coast, is similar to Venice. The importance of this meeting and of the Centre, among other things, is the opportunity to bring together the people who live on water. The local administrations represent the needs and problems of the social medium, above the bureaucratic problems. The Centre should have a cultural aim, in addition to the technical-scientific ones considering customs, way of life and traditional ties with the sea.

The Mayor of Marseille, Mr. Vigouroux, remarked on the important aspects of the similarity of the problems exposed by the experts but also the diversity of the solutions case by case.

This is a good motive for associating and discussing experiences with politicians.

“The pollution of the Mediterranean and of its coastal waters is the present main concern of Marseille, not subjected to land subsidence. However, all problems are interconnected and in view of the possible long-term effects of SLR, despite its present uncertainty, we intend to be informed.

The policy makers have great responsibility in spending large sums of the people’s money and need a well debated motif to act. If the Association proposed in Venice succeeds in creating the proper information, Marseille will be glad to be part of it.”

Trieste’s Mayor, Mr. Richetti, emphasised again the important role that the Centre must acquire as a link between the populations which have a connection with the water. This does not mean to bypass regional and national authorities.

The interdisciplinary point of view is also basic in the relationship between cities and environment.

“The sea and waterways are also the way to exchange culture and trade with the East, in the case of the Mediterranean Sea.”

Dr. Gerstle, representing Sydney, said that the two main issues which can be dealt by the Centre are:
1) updating information on the state of the art in predicting climate change and its effects;
2) dealing with the problem of management of the information: science is needed to back information.

The management of science to the best profit emerges from international discussions and agreements.

The issue of uncertainty in predicting models is not unique and must not interfere to prevent mitigation of potential damage. Uncertainties are the rule in all policy making and are the reason why insurance policies exist.

Wisdom suggests action in a position of uncertainty and preparation to fine tune decisions when more accurate information is available. Action can take place in a rational and sensible way, not attributing excessive weight to the problems.

The fact of uncertainties will always, to a certain
extent, be passed down to the people who are gaining the benefits.

The core function of the Centre of Cities on Water is to get the best possible informations from the world of predictions as it becomes available. It should be centrally localized so that information and know-how from one city or place can be transferred to another city which has its own specific character and problems.

Non-governmental, university and industrial groups should participate in the Centre's activity. This would provide a further network for collection and dissemination of information.

Another topic is pollution, which is becoming a worldwide problem which necessitates creative and advanced techniques to be solved.

Pollution control is dealt with in different ways, few of which are motives satisfaction. A great deal of interdisciplinary research and technologies need to take place and common efforts are needed.

"I would like to recommend as a role of "Cities on Water", to concentrate in a medium and longer term goal, of becoming the forefront in the information clearing house for these kinds of techniques."

The Mayor of Rijeka, Mr. Luzavec, expressed his interest in becoming a member of the Association although at the present time flood risks, given the stability and the rocky character of most coasts, are not felt in Yugoslavia.

Dr. Him, representing the officials of Hong Kong, remarked on the importance of the past as a lesson for what can happen in the future.

Loss of lives and economic damage remind decision-makers to act preventing future hazards. Subsidence and sea level control is an essential issue for Hong Kong and the use of space technology may eliminate present problems.

"The proposed programmes of the Centre "Cities on Water" are of great interest for us. Unfortunately, even with a verified evidence of risks, it might be difficult to counteract economic interests which create business by selling vulnerable lands which are due in time to subside."

The Mayor of Venice resumed the suggestions made for the objectives of the Centre: it was pointed out by some speakers that politicians have often made wrong decisions in the past, such as allowing for construction in areas at risk, like on the coastlines of Australia or in Venice, where the dredging of new canals for the shipping traffic, 30 years ago, turned out to be a mistake when the project was completed several years later.

With the proper technical and socio-economic approach, it seems possible for future settlements in flood risk areas to be planned and built with new rules and adaptive techniques as is done in seismic areas, perhaps thinking of amphibious cities or areas.

This is a challenge for planning experts.

The re-utilisation of existing but obsolete structures such as old harbours, and the analysis of the ecological and chemical problems must be considered in harmony with the land surrounded by water.

The new Centre that we are proposing should gradually become the forum for an exchange of ideas, experiences, projects of all experts who deal with land, cities and marine and river waters.

The important aim is to communicate the elaborated information to the respective regional and national governments. The way of the City, as a medium to attract the world's attention of the world, is to be pursued.
CONCLUSIVE REPORT AND RESOLUTIONS

1. In the last two days we have seen that Cities on Water have many existing problems, e.g. flooding, subsidence, erosion, salt-water intrusion, pollution, storm and wave climatology. We also saw that the range of tides worldwide is increasing. Although there is uncertainty as to the rate of increase in sea level rise, as a greenhouse warming effect, there is common ground that some change is likely and that any changes will only aggravate the present problems of these cities, within a few decades.

The participants also reported on many efforts in local data gathering although better information is still required. Worldwide efforts to collect information, such as with satellites, must be encouraged; data must approach absolute values and must be made available.

2. The absolute present and future growth of the population worldwide is focusing on the coastal and deltaic zones because they are attractive and productive. These areas are important for agriculture, fisheries, industry, commerce, tourism and seaport and airport activities. The majority of the world population lives within a few km of the sea coast.

The necessity to defend these resources and investments has resulted in structures like dykes, sea-walls, tide barriers. Such structures are very expensive to construct and maintain, and need to be continuously upgraded as standards of safety are more closely defined. Continuous investments are required for maintaining and managing these facilities. There was consensus that “hard” engineering structures were not the only effective solutions to protect coastal cities. A flexible approach allows progressive, and often less costly adjustment to the effects of a rising sea level.

This is particularly true in developing countries which require special consideration and assistance to protect their population and other resources. It is vital to help them have the opportunity and the support to reach their own decisions.

3. To be effective action must be taken locally, keeping in mind the principle “think globally and act locally”. Therefore, through education it is necessary to raise awareness of the local population and of their decision-makers to plan and to take responsibility for the solution of local problems and local impacts of global issues.

This awareness must be based on the best worldwide scientific and technical information and integrated into locally gathered and constructed models of natural and socio-economic processes. The plans and actions must be based on local conditions and should include considerations such as local way of life, social structure, cultural heritage, financial resources, and political institutions.

4. The Centre “Cities on Water”, in cooperation with international agencies, could play an important role in supporting cities and other governmental and non-governmental bodies in finding solutions to these problems. Examples of such a role include: dissemination of objective scientific information; coordination of local and worldwide data gathering; conveying special working groups on specific issues; acting as a clearing house for expertise, information and case studies, organising university courses.

5. Finally: the impacts of climate on cities is a vast topic that should be included in the assessment being prepared by IPCC. The socio-economic problems of Cities on Water, in relation to Climate Change, must concern the European Community.
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<thead>
<tr>
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<tr>
<td>ASLR</td>
<td>Absolute SLR</td>
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<tr>
<td>ECMWF</td>
<td>European Centre for Medium-range Weather Forecasts</td>
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<tr>
<td>ERS-1</td>
<td>European Remote Sensing</td>
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<td>ESA</td>
<td>European Space Agency</td>
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<tr>
<td>DEO</td>
<td>Directory of Earth Observation</td>
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<td>FAO</td>
<td>Food and Agriculture Organization</td>
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<tr>
<td>GIS</td>
<td>Geographical Information System</td>
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<tr>
<td>GLOSS</td>
<td>Global Sea Level Observing System</td>
</tr>
<tr>
<td>GPS</td>
<td>Geo Positioning System</td>
</tr>
<tr>
<td>HABITAT</td>
<td>UN Centre for Human Settlements</td>
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<tr>
<td>HWL</td>
<td>High Water Level</td>
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<tr>
<td>ICSU</td>
<td>International Council of Scientific Unions</td>
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<td>IOC</td>
<td>Intergovernmental Oceanographic Commission</td>
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<tr>
<td>IPCC</td>
<td>Intergovernmental Panel of Climate Change</td>
</tr>
<tr>
<td>ISOS</td>
<td>Impact of Slop Society</td>
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<tr>
<td>MSL</td>
<td>Mean Sea Level</td>
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<tr>
<td>MSLSR</td>
<td>Mean Sea Level Rise</td>
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<tr>
<td>OCA/PAC (UNEP)</td>
<td>Ocean and Coastal Areas/Program Activity Center</td>
</tr>
<tr>
<td>OECD</td>
<td>Organization of Economic Cooperation and Development</td>
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<tr>
<td>PRARE</td>
<td>Precision Range and Range Rate</td>
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<td>Relative Sea Level Rise</td>
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<tr>
<td>SL</td>
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<tr>
<td>SLR</td>
<td>Sea Level Rise</td>
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<tr>
<td>SWCC</td>
<td>Second World Climate Conference</td>
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<tr>
<td>TRUCE</td>
<td>Tropical Urban Climate Experiment</td>
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<td>UN</td>
<td>United Nations</td>
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<td>United Nations Environmental Program</td>
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<tr>
<td>WCP</td>
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What is the International Centre “Cities on Water”

The International Centre “Cities on Water” is the Association set up in Venice on March 1989 by the Venice City Council, the University (Ca’ Foscari), the University Institute of Architecture (IUAV) and the Consorzio Venezia Nuova.

It promotes and carries out the collection of data and information, studies and research activities on the problems and experiences of cities that are strongly characterised by their relationship with water.

Why this Centre?

The Centre was set up for two main reasons. The first is that recently town-planning experts have been devoting more and more attention to the problems of the city/water relationship.

This relationship, fundamental for the very birth and development of urban centres, has suffered increasing deterioration, with the consequent provocation of considerable unbalances and dangerous effects.

Water must therefore no longer be considered as the enemy to fight or the danger to avert; rather it must become the major resource for the improvement of the city’s living standard.

The second reason is that, despite the different situations involved, an exchange of information on the experience acquired in various urban environments can be extremely useful in dealing with the problems of cities that are linked to water (on marine coasts, lagoons, bays, estuaries, rivers, gulfs etc.).

Why in Venice?

Of all the cities built on water, Venice is the one with the most fascinating history and can certainly be considered as their symbol.

Now its very survival is endangered and it has become the object of an important safeguard program including the re-establishment of environmental equilibrium, with measures requiring substantial financial efforts as well as advanced knowledge and technology.

Studies and tests under way in Venice can be of great interest for the other cities on water as, in turn, experiences acquired elsewhere can be extremely useful for Venice.

This is why Venice, the city on water “par excellence”, is becoming a centre where information, studies and experiences concerning these cities can be exchanged and compared.
PROMOTERS

Promoters for this Centre are:
- The Venice City Council, whose Mayor is the President of the Board of Directors of the Centre.
- The University of Venice (Ca’ Foscarri), the main academic institution of the city.
- The University Institute of Architecture of Venice (IUAV), one of the most important architecture and town-planning institutes in the world.
- Consorzio Venezia Nuova, a consortium of public and private Italian firms which has been granted the sole concession by the Italian Government for the design and execution of works to safeguard Venice and its lagoon.

AIMS

The Centre has two specific aims. The first is to become a permanent reference point for the exchange of information on methods and techniques for the analysis, diagnosis and treatment of common problems, experience already or still being acquired and on the appraisal of completed projects.

The second aim is to promote studies and research to be carried out by Universities and Scientific Institutes on subjects that might be of interest to all cities on water. The Centre intends to support local administrations, which are usually responsible for formulating and implementing policies for the physical safety, rehabilitation and development of urban areas as well as for the organization of transport. The information collected by the Centre will be available to all private or public users on request.

ACTIVITIES

The Centre carries out the following activities in fields of priority concerning cities on water:

a) collection of data;
b) information service;
c) publication of a newsletter;
d) planning of research projects;
e) seminars;
f) conferences (International Meetings).

All activities of the Centre will be scheduled on a long-term basis, with plans prepared and approved by the appropriate organs of the Association.

The collection of data, the information service and the research activities will mainly concern the following subjects:

- characteristics and typology of cities on water;
- water quality (pollution and treatment problems);
- water level control (problems related to the defence against water);
- waterfronts (reutilisation of abandoned port and industrial areas);
- transport organisation
- protection of valuable areas (historic and architectural heritage);
- productive use of water (for leisure activities for example);
- water management (bodies in charge of the management of water resources).

ORGANISATION

The Centre was established as an Association on March 22nd, 1989; with its operating rules drawn up by the Board of Directors.

In addition to the charter members, the Association can be joined by private and public bodies, after their application has been accepted by the management body of the Centre according to the procedure laid down.

The organs of the Association are the following:
1. the General Meeting (which is summoned at least once a year);
2. the Board of Directors and its President, the Mayor of Venice;
3. the Scientific Committee (which provides suggestions for programs).

The management of the activities of the Centre is entrusted to a Director; a Secretariat is responsible for maintaining contacts with Members and for supplying information as requested.

SOURCES OF FINANCING

The Centre carries out its activities mostly with contributions, both financial and technical-scientific, supplied by the promoters. Other financing comes from public and private institutions that support the initiatives of the Centre (research, seminars, meetings).

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INTERNATIONAL CENTRE
'CITIES ON WATER'

Antonio Casellati
Mayor of Venice, President (1989)

Paolo Ceccarelli
Director of the University Institute of Architecture of Venice (IUAV), Vice-President

Giovanni Castellani
President of the University of Venice (Ca' Foscari), Board Member

Luigi Zanda
Chairman of the Consorzio Venezia Nuova, Board Member

Rinio Bruttomesso
Director

First International Meeting
IMPACT OF SEA LEVEL RISE
ON CITIES AND REGIONS

Venice, Palazzo Grassi, 11-13 December 1989

under the Patronage of
President Francesco Cossiga
of the Republic of Italy

ORGANISATION

Prof. Roberto Frasetto, Scientific organiser
Arch. Rinio Bruttomesso, General organiser

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UNEP (United Nations Environment Programme)
OECD (Organisation for Economic Cooperation and Development)
UNESCO
WORLD BANK
ECC (European Economic Community) - DG XII
ESA (European Space Agency)
IOC (Intergovernmental Oceanographic Commission)
WMO (World Meteorological Organization)
EPA (Environmental Protection Agency)
IGU (International Geographical Union) Commission on Marine Geography
EGS (European Geophysical Society)
PRINTED IN JANUARY 1991
FOR MARSILIO EDITORI®, VENICE
BY LA GRAFICA & STAMPA EDITRICE S.R.L. VICENZA