REVIEW OF SCIENCE, TECHNOLOGY AND POLICY FOR RIVER AND COASTAL FLOODING

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ABSTRACT

This paper looks at the causes and impacts of two natural disasters, river and coastal flooding, through reviews of papers written by people living worldwide and from our own experience of living and working in Bangladesh. We offer no apology for referring frequently to Bangladesh as, more than any other country in the world, it has learned to endure the consequences of these twin events which occur with dreadful regularity. The less well-known fact is that Bangladesh also suffers from water shortage and droughts in its seven month dry season

The paper considers the concepts of vulnerability and hazard, and the changes in our perceptions of them in the light of global climate change. Experiences with physical protection measures, assessing risks and improving warning capacities in the major flood events of recent years are discussed, and strategies for basin wide water resource policies reviewed.

The paper concludes by pointing out the benefits which have accrued in richer countries from investments made long ago over many decades in flood control infrastructure, and the advantages of investment in prevention rather than cure for the people still at risk, many of them living in the poorer countries of the world.

1. FLOODING AS A NATURAL HAZARD

Flooding from rivers is a natural phenomenon that can occur in great and small rivers, and in wet and dry climates and affects great numbers of people around the world. Four main types of flooding are recognized these ones·

- Local drainage congestion. This occurs when run-off from local intense rainfall exceeds the capacity of natural or artificial drainage canals, causing them to back up or overflow. The rainfall can be due to an intense storm, cyclone or hurricane.
- Flash flooding: Flooding which occurs in smaller rivers in response to rainfall on an upstream catchment, with a very sudden rise in water level. Frequent in plains areas close to hilly areas, or in desert wadis.
- Major river floods: Flooding as a result of prolonged rainfall in the river catchment, causing a large but relatively slow-moving wave to descend the river, overtopping its banks as it moves downstream
- Surge-induced flooding: Sudden and violent flooding when strong winds cause the sea-level to rise locally due to low pressure and shear forces on the surface, and drive it into a confined area where a steep fronted wave develops, often moving as a tidal bore many kilometres up estuaries.

The first three types of flooding can occur anywhere where there is rainfall or a major river Surge, the other topic of this paper, is much more localized, affecting only those who live in coastal areas, where the rather specialized conditions behind this phenomenon are created and in the lower reaches of rivers draining to these coasts. However, as a natural disaster, surge is the killer. River floods can cause huge economic losses, but do not kill people on the scale of the 300 000 people who died in 1970 on the shores of Bangladesh. In the decade up to 1996, 245 000 people died from floods throughout the world, but 140 000 of these deaths occurred in a single surge event, again in Bangladesh, in 1991.

The impact of flooding tends to be described in numbers of events, in flood damage and in numbers of deaths. The following table clearly shows that in Asia, we do pay not in dollars, but with our lives. A better measure might be damage expressed as a proportion of GNP but even this does not reflect the real impact. When a family is warned to evacuate in the face of an impending flood in a rich country, it drives off in the car and files an insurance claim for US $3 000 for carpets and repainting A family in a poor country clings to a tree as the family pair of bullocks are drowned and the few possessions worth US $300 are washed away, and retreats to the nearest urban slum, never to return. What value is placed on a livelihood lost ?

Continent	Number of floods	Damage in million US $	Deaths	Damage ($M) per flood	No of deaths
per flood					
Africa	124	1 576	6 200	13	50
Americas	270	24 656	7 249	91	27
Asia	432	135 509	227 612	314	527
Europe	100	88 568	3 878	886	39
Oceania	56	349	416	6	7

Source· Miller, 1997

As we distinguish surges from tides, so we distinguish flooding from seasonal inundation. The regular pattern of astronomical tides lead to a rhythm of life for coastal people to which they are well adjusted and the terms high or spring tide hold no fears for them. Contrast this with the terror they experience as winds of over 200 km/hr accompany the gradual build-up of the sea's energy, which suddenly releases itself in the fury of a tidal bore, 7 m high, sweeping over the flat coastal wetlands and destroying life and property in a few hours. Similarly, the seasonal rise and fall of even the largest rivers can be watched with equanimity by people who have built their houses on platforms or protected areas, laid in stocks of food and planted crops which are adapted to the event. It is only when the rivers rise to an exceptionally high level, or exceptionally quickly, that the life-giving flow become a destructive force. Our people have two words, *bonnya* and *plabon*, for these two events.

Tales of floods and the fury of the sea are deeply embedded in the history of many regions of the world and we must accept that the hazards of floods and surges have been with us as natural phenomena since the dawn of civilisation. However, the development process gives us the potential to minimize their damaging consequences, either by reducing the hazard itself or our vulnerability to its effects There are, however, many feedback paths, so development itself often increases the hazard and those who reduce their vulnerability by protecting themselves may, in the process, increase the vulnerability of others. As with so many other activities, the richer have the opportunities and choices, while the poorer have to make do with that they can afford. In a world that claims to recognize the rights of all to basic freedoms, we much seek win-win solutions, both within and among nations.

2. VULNERABILITY

In general, riverbanks and shorelines are good places to live and civilisations have tended to grow and develop in their proximity. Even now, relatively few major towns develop far from either (Johannesburg may be the biggest exception). Flood plains are fertile areas and good crops can be grown there. Crops damaged by flood tend to be followed by bumper yields the next season and low-input agriculture is clearly a good use of flood plains. However, as investment in seeds and crops increases, vulnerability to flood hazard increases.

Urban areas also develop near rivers and coasts, often for historical reasons related to transport This trend continues as people with the available means enjoy living near water. Whereas the original site may be in a naturally well protected area, expansion leads to urbanization of more exposed areas, and increases the population at risk. High value commercial and industrial developments increase the vulnerability of the settlement.

The general trend in societies with increasing populations or increasing standards of living is increasing vulnerability of life and property to the hazards of flood or surge.

3. HAZARD

Primary flood-inducing events are well-known and are addressed under the topics of tropical cyclones and severe local storms. Translating these events into estimates is the domain of hydrology and hydraulics, using the tools that have been developed in the last 100 years, based on the original hydrodynamic equations of St Vennant Using either the characteristics of the catchment, or more recently the capability for pixel analysis provided though the data management capability of Geographic Information

Systems (GIS) combined with kinematic wave theory, estimates can be made of the effects of the passage of a flood of a event of given probability.

These analysis have to be kept continuously up-to-date as land use and floo plain configurations change and the channels change both in plan geometry and in cross-section, due to the continuous processes of erosion, accretion and sedimentation. Suites of programmes, now widely available both in the public domain and in more sophisticated form within specialist institutes, allow modellers to calibrate the models to observed conditions at the boundaries and gauging stations, and then extrapolate with new boundaries or river configurations. The transport of sediments, pollutants and salinity can be modelled by post-processing of the output files, thereby facilitating the study of the impacts of changes in conditions due, for example, to climate change.

4. TRENDS AND CLIMATE CHANGE

Despite the worldwide concern over global climatic change, there is little evidence of a change in the frequency and severity of primary flood-inducing events such as rainfall and cyclones. However, general circulation models do predict that there will be changes in patterns such as monsoon intensity and duration, as well as increased frequency of days with heavy precipitation (Huq *et al.*, 1999). Such predictions tend to be revised fairly frequently as more parameters are introduced, such as the effect of sulphate aerosols, and it is necessary to view them as potential scenarios rather than forecasts. Under these scenarios, we can expect both flash floods and seasonal floods to increase, but not necessarily in a uniform fashion. Scenarios for northern India, for example, indicate more intense annual floods but little change in lower frequency flooding (e.g. 1:20 years flood), for which much non-critical flood protection infrastructure is designed.

What effect this will have on flood design infrastructure depends on how rigidly economic principles are followed. Engineers design embankments to minimize the sum of capital cost, operation and maintenance costs and expected annual damage, all capitalized at a certain discount rate which is intended to reflect the opportunity cost of investment capital. In developed countries with low interest rates in the 2-3 per cent range, the long-term benefits of protecting against future conditions will figure significantly in the equation. In poorer countries, development agencies typically require public infrastructure investment to show a return of 12 per cent, and potential benefits accruing gradually over 25 years and beyond are heavily discounted. Unless the poorer countries depart from currently accepted advice and abandon these high discount rates for investment in flood alleviation infrastructure, they will be left with only the "poor man's solution" of flood-proofing This is particularly ironic given that the causes of climate change arise within the richer developed world.

Although there is little evidence that the incidence of cyclones that give rise to surges will increase, many cyclones die before reaching landfall. One effect of a rise in sea surface temperatures will be that a proportion of those that die under present conditions will retain enough energy to reach land, and one recent estimate was that the incidence of surge-inducing cyclones could increase by 30 per cent (Ali, 1999) as a result. Areas affected by storm surges include India, Bangladesh and Myanmar around the Bay of Bengal; Germany, Netherlands and England around the North Sea; and China.

Sea-level rise will increase flooding in estuarial areas of rivers and could have effects further inland due to a regrading of river beds. The effect of a sea-level rise of 0 5 m in the Bay of Bengal would be to raise the bed of the Brahmaputra by 15 cm for a distance of at least 200 km from the coast (Halcrow, 1995).

Countries with extensive areas of land close to sea-level have tended to build coastal polders to protect farmland and this complicates the assessment of the impacts of sea-level rise on flooding and waterlogging. These polders are drained by tidal sluices and pumps such as the famous Dutch windmills. Where drainage is by pumps, sea-level rise will increase drainage pumping costs, but only gradually and not by very much Where drainage is by tidal sluices, the sluices will gradually go out of operation as the tide-locked period increases, requiring more or larger sluices. Re-investment is unlikely as the economics of farming have changed since many of polders were built. Governments around the North Sea are rethinking policies in view of high maintenance costs and, indeed, the last polder of the Zuyder Zee in the Netherlands was never drained. In areas around Chesapeake Bay, polders are already being demolished as environmental costs are weighed against the limited benefits they now bring (Stevenson, 1999).

In Bangladesh, most of the area less than 1m above sea-level is already empoldered, but very few polders have pumped drainage as very large capacities would be required to drain monsoon rainfall. The result has been extensive water-logging, a situation which will be aggravated but not necessarily extended. The response has been a change from rice farming to shrimp cultivation in many areas, a change that has brought about economic gains to a minority and losses to a majority, leading to severe social impacts.

Sea-level rise will, for many decades, be small in relation to surge and wave run-up, so the direct effect on the design height of embankments and structures such as the tidal barriers on the Thames will be small. However, there are situations where indirect effects are significant. Wave run-up is affected by the depth of water on the foreshore and greater depths mean that waves reach embankments without having dissipated energy in the approach, thus releasing more energy against the structure. In other situations, the dominant direction of the incoming waves may change due to changes in diffraction caused by the change in wave velocity associated with increased water depth and a corresponding change in the direction of waves reflected by marine structures. Studies using numerical and physical models will be needed to assess these effects in individual cases and may well lead to design modifications other than raising structure heights.

5. PROTECTIVE MEASURES

The two major structural measures used to control floods are reservoirs and dykes. Reservoirs (and detention ponds) formed behind dams and embankments hold water back at the peak of the flood for later controlled release. Dykes confine floodwaters into the river and parts of its flood plain reserved for that purpose

A 1:100 year flood may be typically 2 to 6 times the magnitude of the mean annual flood (MAF), a 1:1000 year flood 3-15 times MAF. To be effective, flood control dams have to be large, and and are in consequence, expensive. To cover the cost, they are frequently designed for multi-purpose use. for irrigation and hydropower, and often during project life the structure is operated to raise revenue. As one South African writer observed:

> "Due to the trauma of water managers in seeing crucially important dams reaching levels of less than 20 per cent during drought situations, their inclination is to operate dams as full as possible" (Sweigers, 1997).

For efficient hydropower, reservoir levels are kept high and flood control benefits accrue only at the start of the wet season. Larger reservoirs can be very effective in controlling flash floods, which tend to have a small volume but a high peak that can be attenuated with little rise in reservoir level. Very large reservoirs can regulate for hydropower and flood control simultaneously by smoothing seasonal flows over several years and have the added advantage that they take centuries rather than decades to silt up, even in areas of high sedimentation such as the Himalayas.

The High Aswan Dam in Egypt provided a good example of flood control in 1988. After eight dry years, the reservoir level was close to minimum operating level when the Blue Nile flooded. Although the flood caused major problems when it swept through the suburbs of Khartoum, on arrival at Aswan a few days later it merely replenished vital storage instead of sweeping through the streets of Cairo as in former times. Nevertheless, the reservoir is operated entirely for irrigation benefits, even hydropower being generated as a secondary benefit.

Embanking has been practiced on river like the Po and the Yangtze for centuries, and the tradition has been continued on rivers like the Mississippi in conjunction with flood storage reservoirs.

The 70 800 km^2 basin of the Po lies largely in Italy, but also drains parts of France and Switzerland. Over 1 000 km of levees have been constructed over the last 500 years but, despite continuous improvement, they still do not provide complete protection from floods. Failures of flood control dykes and levees may occur through mechanisms such as:

- simple overtopping, when the cumulative level of the flood and wave run-up cause water to spill over the crest;
- erosion, when the velocity of water at the toe of the embankment removes material from the embankment or the bank on which it is founded;
- seepage, when water seeping from the river through the embankment emerges above ground level on the landward side, causing the back face to start collapsing, and;
- piping, when water flows through or under the embankment in pipes of weak sandy materials, animal burrows or holes left by old tree roots.

All are still common, the last two being particularly dangerous because of their relatively sudden development. Piping can cause failure within 45 minutes of fine sediment appearing at the toe of the embankment (Govi et al, 1996). In 1994, almost all the 86 km valley floor of the Tanaro tributary was flooded, and pulse flooding occurred in downstream reaches when logjams of trees and debris against bridges suddenly collapsed

The "Great Flood" of 1993 on the Mississippi also led to the collapse of a large proportion of the levees constructed since the eighteenth century to contain floodwater failed, flooding some 6 Mha of farmland and 50 000 homes in hundreds of towns (Ingram, 1996), some of which may never be rebuilt. The levees nevertheless prevented damages of US $11.6 billion, against total losses estimated at US $ 15-20 billion (Miller, 1997).

In China, the Yangtze River has been bounded by levees for centuries but progressive siltation has caused the bed to rise 5 m above the surrounding plain. When these levees burst, as they did in 1996, they caused the worst flooding for decades, with 10 Mha of farmland flooded, 5 million homeless and losses of some US $20 billion.

The evidence suggests that structural protection can confer only partial safety for people inhabiting the flood plain and must be combined with other measures for flood management to be effective. When protection fails, damages can be increased because of the increased investment made by those living behind the embankments. Current opinion in Bangladesh is that that full flood control is neither practicable nor, indeed, desirable for rural areas on environmental grounds. However, the benefits of urban protection were obvious to many city dwellers in Dhaka when, in 1998, river flood levels rose to the same levels experienced a decade earlier, but large parts of the city were protected by embankments built since that time.

6. RISK ASSESSMENT

The components that the engineer has to consider when designing for flood risk include the water level with a given probability of occurrence, afflux due to changes in physical surroundings, wave run-up, and settlement of the construction and its foundations. Other events may also occur, such as tsunamis, low-frequency oscillations in large lakes or inland seas and collapse of ice or mud dams. Some are interdependent, others not, but in the assessment of risk all may need to be considered.

Methods for the statistical analysis of river floods were introduced into hydrology in the 1920s (Kite, 1963) and the distribution functions developed over the next 30 years are still used today, with variations in fitting methods Other techniques, such as the unit hydrograph and non-linear catchment routing methods have also been developed to estimate floods. Combined with estimates of extreme rainfall, these techniques can be used to estimate "maximum" events. These are used in the design of critical structures intended to "never" fail (probability of events 1:100 000 years or greater). There are fundamental philosophical objections to the concept of a maximum event and economic design principles require costs to be justified through risk assessment.

The estimation of the risk of surge events is more complicated as there are several factors to be taken into account, such as atmospheric pressure, wind speed and direction and time of landfall in relation to the astronomic tide.

Independently maximising each of these may lead to over investing in structures, which may need to be long and contiguous to be effective. The 1800 km long coast of China is exposed to tropical cyclones in the south and extratropical cyclone in the north and different fitting parameters are required for fitting statistical models in each zone.

Computer-based deterministic models are also needed, especially for the prediction of specific events in real-time. Methods used in China are reviewed in a 1994 WMO paper (Guo Dayuan *et al.*, 1994), which points out the need for models to be tailored to the data and financial resources available. Complex models can certainly provide improved accuracy, but only if funds are available for installation, and operation and maintenance of the sensing equipment.

As noted earlier, computer models are also used to model hydraulic processes but, in many cases, physical models are required to confirm findings. Few major flood control structures are built these days without physical models to examine some aspect of their behaviour, whether it be the influence on currents, scour or wave regime. Both fixed and mobile bed models are used, often requiring large amounts of space in speciality laboratories in many parts of the world.

Hybrid models, which combine features of both physical models and computer simulations, are also being used to assess the interactions of complex events. The Hybrid Simulation Model (Barthel, 1991) developed at the Hydraulic Laboratory in Ottawa is one such example. Such models are particularly important in view of the work done in Australia (Neilson *et al.*, 1991) on wave set-up, which show large differences between the results of theoretical models and actual measurements.

7. WARNING CAPACITIES

For many people and many situations in throughout the world, the cost of controlling floods is simply too high to be affordable, or the side effects of the works required too damaging to the environment. The options are then to avoid habitation and development of flood prone areas or to devise means to warn people of impending floods.

The evidence worldwide is that people will not abandon flood prone areas, whether they are in the flood plains of the Mississippi, the mountains of Honduras, or the tidal mud flats of the Bay of Bengal. Consequently, the task of the water resources planner is to find ways to make life liveable in the flood plains, even if there is considerable risk to life and property. The greatest contribution the Government can make is to enable people to save their lives by warning them of impending floods, and facilitating their evacuation to temporary safe havens.

There are several components of this activity. Forecasters must be able to make reasonably accurate forecasts with an appropriate lead time; the information must be relayed in a reliable manner to the people likely to be affected; and the people must have a clear idea of what they should do to protect themselves when warned.

Flood plain maps, which show the area at risk of flooding with a given probability, provide the most advance warning. Typical maps in use in Canada and the USA are based on a flood with a return probability of 1 per cent (1:100 years), routed through the current configuration of the flood channel and plain. Variants include maps that show flooding at a given time of year, such as harvest time for a major crop, with a 20 per cent risk, appropriate to agriculture. Such maps allow people to improve their own decisions about their investments, whether in a factory or an earth mound on which to build their houses. Flood plain zoning goes one step further and imposes regulations on the types of activity which can be carried out in vulnerable areas. This can be unpopular, and can lead to legal action where it limits profitable developments.

Flood forecasting for rivers can use radar reflections from raindrops to estimate rainfall intensity a few hours ahead and routing models to generate real-time forecasts, which can be updated and recalibrated as the storm event develops. Such systems are in widespread use in countries that can afford them. The system on the Rhine (Wilke, 1996) includes no less than 19 flood forecasting centres distributed over 5 countries. Other systems use satellite information relayed to ground stations in near real-time. One such system, developed in Cairo for the Nile (Barrett, 1995), uses satellite observations of cloud temperature readings over the upper catchment. These are calibrated with data from a few synoptic stations in Ethiopia and Sudan and used to generate estimates of the flood volume in the Blue Nile and Abara Such systems are much more affordable and appropriate for larger rivers with slower response times.

Political difficulties may surround the exchange of the data needed and this is an area of greatest need in integrated river basin management. Despite meetings over many years between experts from India and Bangladesh, the release of the data from the upper catchment of rivers like the Ganges and Brahmaputra, needed to make predictions 72 hours ahead on the major rivers, has still not been agreed, despite the major benefits this would bring.

An integral part of the system is the telemetry network needed to transmit the data reliably from the sensors to the modelling centres. Here again satellites play a major role, although other ingenious methods are also used, such as meteor burst telemetry, which uses the ionised particles in the trail of small meteorites as a reflector for radio signals.

The key issue is how much time is needed to prepare and disseminate a forecast, and for people to react. Floods on the lower reaches of large rivers and cyclone-induced surges can be predicted, but the accuracy diminishes rapidly with increases in lead time. The flood warning agency has to be careful not to issue false warnings, which not only cause unnecessary disruption but also reduces the credibility of the agency and could lead to later warnings being ignored.

In poorer countries, there are few options for people without motorized transport. They can go to cyclone shelters, stand in the wind and the rain on embankments, or stay and pray for deliverance. It is a sad reality that mothers with teenage daughters will sometimes chose the third option rather than risk harassment in the shelters.

Nevertheless, the programme of construction of shelters on the cyclone prone coast of Bangladesh is held to be the major reason why the death toll of 140 000 in 1991, horrifying as it is, was less than the 300 000 in 1970. Conditions of wind and tide were similar and there had been a 50 per cent growth in population. The reduction in the number of deaths was, in part, because of improved warning systems and the fact that people had somewhere safe to go.

8. BASIN-WIDE WATER RESOURCES AND LAND MANAGEMENT

Within the river basin, there is little to be done to reduce the intensity of rainfall or cyclone events. However, flooding is often exacerbated by human use and abuse of the land and it may be possible to do much to mitigate the intensity of flood hazard or the vulnerability of human activities.

It is now commonplace to advocate policies for integrated basin-wide measures to harness water resources and improve land management practices, particularly afforestation of the uplands and control of agriculture. These are seen as complementing structural measures such as dam and embankment construction. A typical flood plain management strategy is shown in Table 2.

Neat presentations of integrated strategies can all too easily conceal some very hard choices. What may be a satisfactory solution for some may be a much less satisfactory solution for others. Almost all structural measures require land to be acquired, and that can mean a dramatic change of life for those affected. The problem is made considerably worse if compensation is slow or important aspects of community social life are destroyed, such as the networking arrangements upon which many people in developing countries depend

Structural measures also have environmental impacts. The protection of arable lands by ring dykes in Bangladesh has impacts upon fish stocks, which are the main source of protein for its people. Some rivers have silted up and waterlogging is widespread in heavily empoldered areas. Any new dam anywhere in the world is the immediate target for activist groups campaigning on social or environmental issues. Such concerns are legitimate but must be related to the actual needs of each country to reconcile conservation and development objectives.

Table 2. A typical flood plain strategy

STRATEGY 1: REDUCE FLOODING	Dams and reservoirs High flow diversions Dykes, levees, flood banks Land treatment measures Channel improvements On-site detention
STRATEGY II: REDUCE SUSCEPTIBILITY TO DAMAGE	Flood plain regulation Development and redevelopment policies Flood Plain Zoning Design and location of facilities Housing, sanitary and building codes Land rights, acquisition and open space Subdivision and other regulations Redevelopment or permanent evacuation Flood Proofing Flood forecasting and warning systems
STRATEGY III: REDUCE THE IMPACT OF FLOODING	Information and education Tax adjustment Disaster preparedness Flood emergency response Disaster assistance Post-flood recovery Flood Insurance
STRATEGY IV: Restore and preserve the natural and cultural resources of the flood plain (Source: Modified from Thomasm (1995))	Flood Plain and wetland regulations Tax adjustments Information and education Other administrative measures

Deforestation may not be the primary cause of flooding or sedimentation in mountain areas as orogenic processes have a major role to play. Deltas of the Nile, Irrawaddy and Ganges were built up from several kilometres of sediment millennia before deforestation was rife. Equally, reforestation may not be the panacea for those whose livelihood depends on what they can grow in a season, rather than tree crops that take 10 years to mature.

Dykes and levees can raise river bed levels, entraining a costly process of operation and maintenance. They can increase the cost of flooding by encouraging inappropriate structures to be built within areas which people mistakenly believe to be secure. Furthermore, the loss of storage within the protected area can only aggravate the problem for those living in unprotected areas; and in certain places retribution takes the form of deliberate breaching of embankments by those who feel they have been victims of development.

Thus, each of these strategies will require an evaluation of the winners and losers in the process. In principle, a process of negotiation is possible between landowners whose activities will tolerate a higher degree of flooding than those of others. French law, for example, now requires that flood management be dealt with at the catchment level and this has led to the possibility of a negotiated solution based on an objective evaluation of the level of flood hazard and of flood vulnerability for each parcel of land. Ways to treat the difference in value of these parcels as a tradeable commodity is currently under research (Gilard, 1996).

The problems are difficult to manage even at a national level. At an international level they become even more difficult and there are relatively few examples of works built in one country for the benefit of another. Indeed, around the Aral Sea countries, the break-up of the Soviet Union has led to increased difficulties as dam releases upstream on the Syrdarya have been increased for power generation despite the consequences in term of increased flooding downstream (Konovalov, 1996).

Increased regional cooperation and improvements in integrated river basin management go hand-in-hand, each acting as a catalyst for the other. Within Europe, the EurAqua network, founded in 1992, is examining the question on the

"Prevention and management of crisis situations: Floods, droughts and the institutional aspects" and, using the Rhine as the cornerstone of policy, has identified ten points to be followed in practical flood-related management (Lullwitz, 1996). Other forums such as the Mekong Secretariat and the Ganges-Brahmaputra-Meghna Track II initiative are pursuing similar basin-wide goals.

9. RESEARCH AND CAPACITY BUILDING

Investments in flood control works are huge and it is vital that they be made correctly. Worldwide, about 20 major dams collapse each decade. In a survey by the US Corps of Engineers, one-third of 9 000 US dams in high-hazard areas were tentatively classified as unsafe, but the cost of bringing them up to current safety standards is prohibitive. River embankments regularly fail in a variety of modes, sometimes with considerable loss of life. They then have to be reconstructed, often in a hurry, before the next flood season, leaving little time for thorough investigation. Maintenance costs are also high, particularly for embankments on major rivers.

Good design is essential, and elaborate test beds mounted on centrifuges are now being used by US Bureau of Reclamation to examine failure modes and assess solutions. Other problems can arise on rivers such as the Ganges and the Brahmaputra, where scour depths of up to 60 m are recorded. A recent failure was attributed to mass movement of sand fill with small amounts of silica, following very rapid scour hole development at the toe of the launching apron within a few weeks of construction.

Food forecasting and flood warning systems are expensive, but considerably less expensive, and costs are falling as remote sensing systems and telecommunications costs fall. This allows for improvements not only on the forecasting side, but also in the dissemination of information. As real incomes rise around the world, more and more people have access to radio and television, more roads are built, and more safe havens can be provided.

There are still major uncertainties about the combined effects of wind, surge and river flow. In 1998, we in Bangladesh experienced the most severe long duration flood in our history, a flood aggravated by a significant rise in sea-level (compared with the astronomical tide) in the Bay of Bengal for a 40-day period. The cause has yet to be identified

The likelihood of a major pay-off from increased research is high, particularly if this is linked to field trials of promising solutions. Recent years have seen greatly increased use of complex geotextiles in river and marine embankment works. These expensive materials are fabricated to exact specifications according to the geotechnical properties of the soils and exposure to abrasion. Other materials, blending artificial fibres with natural ones such as jute, could reduce costs and offer environmental advantages. In Bangladesh, we have been building pilot projects with costs from $300 to $10 000 per metre and annual maintenance costs of 5 to 20 per cent but, even so, have no guarantees we can keep our major rivers stable. Research into new and cheaper solutions is desperately needed.

10. OPTIONS FOR FLOOD MANAGEMENT AND CONTROL

Options to reduce damage by flood may be summarized as:

- Keep the flood away from people — control or reduce the flood, through structural and catchment management,
- Keep people away from the flood — use flood zoning and judicious practices in the flood plains, and help them find shelter when floods occur

The costs of the first option are huge and, if some of the possible scenarios for global climate change materialize, will increase rather than decrease. As recent floods in Europe and the USA have shown, even the richest countries of the world are unable to construct works that provide full protection. But it is the failures that make the headlines, the exceptional circumstances when floods exceed design standards which are a compromise between a desire for complete safety and limitations on the budget available to pay for it. The successes go unrecorded when, year after year, all but the most extreme floods are contained. In these years, economic activity continues and expands, creating the wealth to repay the earlier investment.

The investment costs of the second option are rather less, although the toll in human misery is greater, and this tends to be the poor man's solution However, one great turning point may be approaching, as the growth rate in the populations of LDCs slows to the point (as in Bangladesh) where rural growth rates are outstripped by urban migration. As a result, the pressure to live on the flood plains may reduce, or at least stop expanding, and judicious policies may finally be given a chance to work effectively. However, lower investment brings lower returns and the penalty is reduced economic activity at a time when expansion is needed.

However, in the developing countries today, we are being advised to adopt a third option "clean-up afterwards", — i.e., to use all means possible, including insurance and post-flood assistance and rehabilitation, to get people back on their feet. Countries hit by flooding depend on each other for post-flood recovery and one of the more encouraging sights of the twentieth century has been the willingness of governments to come to the assistance of those in need. Offers of help by countries with military personnel and equipment, NGO's and relief organizations and dispersal of food, medical supplies and shelter are greatly welcomed. These cement understanding and humanitarian concepts and will probably always be a necessary part of the solution. The post-flood rehabilitation in Bangladesh this year has been enormously aided because of the timely assistance which enabled people to replant immediately after the floodwaters receded and bring in a bumper spring rice crop.

The flood-affected nations, and the people directly affected, must be grateful for assistance in the clean-up option, but how much better it would be if money which seems to flow so freely after a disaster has hit could be made available before hand. Used wisely to invest in either of the first two options, it would show a far higher rate of return, improve standards of living and the quality of life for people now reduced to depending on others to survive the hazards of flooding.

These arguments point to the potential benefit from investment into improved designs and warning systems and to the need for strengthening the capacity of organizations to manage the entire flood mitigation and preparedness process. Such investment needs to be on a broad front, for people living in all countries, not just those in developed countries. Let us remember that "rich man's solutions" were being built 100-200 years ago in countries which were no richer then than poor countries are today. The difference is that, then, there were no rich countries telling them what they could or could not afford. They were simply building for a better future, and their children, and their children's grandchildren, are the beneficiaries. We, in this generation, are trying to improve our management of natural disasters, and we must create a comparable legacy for our own children.

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