research paper

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After the Bangladesh Flood Action Plan: Looking to the future

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The main objectives of the Bangladesh Flood Action Plan (FAP), to protect the country from river floods, were not achieved, for several political, economic and institutional reasons. Demographic and economic changes in the following 20 years have increased Bangladesh's exposure to damaging floods. The country's newly elected government is committed to providing flood protection and surface-water irrigation as a means to achieve national foodgrain self-sufficiency. Therefore, the feasibility and affordability of comprehensive flood and water management systems need to be re-examined. The technical assessment must take into account the finding that severe floods in Bangladesh are caused mainly by heavy rainfall within Bangladesh as well as the increased flood and cyclone risks associated with global warming. An institutional assessment should examine practical means to overcome governance constraints and to increase local responsibility for managing flood protection and irrigation projects. If such projects cannot be provided, alternative measures must be sought to provide security for lives, livelihoods and economic production. These could include 'flood-proofing' urban and rural settlements, development of improved crop varieties, and more efficient use of irrigation and fertilizers. Measures to expand other sectors of the national economy would also be needed to generate the exports and incomes required to purchase increased food imports.

Keywords: Bangladesh; floods; flood protection; irrigation; polders

1. Introduction

Bangladesh has changed greatly since the Flood Action Plan (FAP) was conceived 20 years ago. This paper reviews important changes in demography, economic development and government policy relevant to flood security that took place after the end of the FAP study period. It also reviews the technical and institutional considerations that Bangladesh needs to address in order to meet its current and future development needs, paying particular attention to water management needs and constraints affecting agricultural production. The paper is based on the author's long experience in Bangladesh: see editorial box. The views expressed in this paper are the author's own; they must not be construed as representing the policies or strategies of either FAO or the Government of Bangladesh.

1.1. Looking back

FAP was formulated at the request of the Government of Bangladesh with the objective of fully embanking the country's major rivers (World Bank, 1989). The plan arose out of the Flood Policy Study (UNDP, 1989), which envisaged that flooding behind embankments along the main rivers would be managed by means of sluice gates (controlled flooding) or, additionally, by a system of secondary embankments (compartmentalization). These policy and plan objectives were not achieved. In part, this was because regional studies showed that economic returns from protecting agricultural land against periodic damaging floods were, at best, marginal. It was also because of opposition from civil society activists to the top-down, institutional hegemony they associated with existing large-scale structural projects and a perceived

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lack of attention to social and environmental issues. Major aid donors were also reluctant to fund further flood control and water management projects without issues of governance being addressed and without reform of the relevant government agencies (Brammer, 2004). For a recent review of governance issues in Bangladesh, see Taslim (2009).

Following the FAP studies, the Government of Bangladesh carried out a comprehensive review of national water policy in 1997–1998. This led to the National Water Management Plan (WARPO, 2001; Brammer, 2004), which gave priority to small-scale flood-proofing over major flood protection projects. No programmes to implement the flood-proofing proposals were included in successive 5-year plans, but the Disaster Management Bureau and the Surface Water Modelling Centre were strengthened, more cyclone shelters were built and the Centre for Environmental and Geographic Information Services (CEGIS) was established. The people and economy of Bangladesh remain as exposed to floods today as they were before the FAP was initiated, as illustrated by the serious floods that occurred in 1998, 2000, 2004 and 2007. However, the government's capacity to issue flood warnings, to provide relief and rehabilitation measures, and to model river behaviour and potential environmental changes with global warming has improved. The World Bank and the Asian Development Bank have projects supporting good governance and institutional reform in the water sector, but neither bank has major flood protection or surface-water irrigation projects in its current programmes.

1.2. Looking forward

Attitudes to providing flood protection in Bangladesh have changed in the past two years. A strategy document prepared for a joint meeting of the Governments of Bangladesh and the UK on climate change in September 2008 proposed, among other measures, the construction or strengthening of flood embankments in the coastal zone and along the country's major rivers against the projected rise in sea level and increased frequency and severity of floods and cyclones with global warming during the 21st century (GOB, 2009). The new government of Bangladesh, which came to power in late 2008, included statements in its political manifesto (Awami League, 2008) that it aimed 'to make Bangladesh self-sufficient in food by 2013. . . . Projects will be undertaken for river dredging, water conservation, flood control, prevention of river erosion and protection of forestry. . . . Initiatives will be taken to implement the Ganges barrage project to expand irrigation facilities, prevent salinity and to solve the problem of scarcity of sweet water in the Sundarban region.' Subsequent policy statements added provision of surface-water irrigation.

The time is opportune, therefore, to take a new look at needs, opportunities and constraints regarding Bangladesh's exposure to floods. Lessons learnt from experience on the FAP need to be taken into account (Brammer, 2004). So do demographic and economic changes that have taken place since the end of the FAP and new environmental needs that have been recognized (described below). The objective of this paper is to indicate subjects that need to be addressed in considering the provision and operation of major water-control projects related to Bangladesh's changed needs since the FAP was formulated. A final section reviews alternative flood security and development options that will need to be considered if such projects cannot be implemented on the scale required to meet flood protection and food production needs.

2. Technical considerations

2.1. Changed background

Bangladesh's population (now c. 150 million) has increased by c. 50 million since the FAP was formulated in 1989–1990, and it is predicted to increase by a further c. 50 million by 2030.[1]

TABLE1 Irrigated area and rice production in Bangladesh in 1989–1990, 2003–2004 and 2007–2008

Year	Area irrigated (000 ha)			Rice production (000 M tons)		
	Tubewell	Other modes	Total	Boro	Aus + aman	Total
1989–1990	1,782	1,245	3,027	6,033	11,677	17,710
2003–2004	3,714	1,221	4,935	12,838	13,352	26,190
2007–2008	n.a.	n.a.	n.a.	17,540	11,309	28,849

Notes. 1. Sources: 1989–1990 and 2003–2004: BBS (1993, 2007). Data for 2007–2008: FAO (2008). n.a. = not available.
2. 'Tubewell' includes shallow and deep tubewells (+other minor modes). 'Other modes' includes low-lift pump, canal and traditional modes.
3. Rice as brown rice (not milled). Milled rice = 2/3rds brown rice.

Foodgrain production in the past 20 years has increased roughly in parallel with the growing population, largely due to the expansion of tubewell irrigation (Table 1). Irrigated dry-season *boro* rice production now exceeds that from *aus* and *aman* rice in the monsoon season.

There has also been a considerable expansion of the urban population: 26.6 per cent of the country's population was classified as urban in 2007 (United Nations, 2007) vs. 15 per cent in 1981 (BBS, 1993). Urban expansion is taking place rapidly (3.5 per cent per annum), not only in the major cities but also in many rural towns. Urban populations include a rapidly growing middle class with much higher expectations regarding quality of life than existed when the FAP was formulated. There have been greatly increased investments in industry, services and communications, both in urban and in rural areas, such that, despite the considerable increases in agricultural production in the intervening years, the agriculture sector now provides only 19 per cent of GDP (World Bank, 2009) vs. 37 per cent in 1989–1990 (BBS, 1993) (the agriculture sector includes forestry, fisheries and livestock as well as crop production). The widely developed mobile telephone (cell phone) network has greatly improved marketing for farmers and the provision of commercial services generally, and it has also greatly facilitated disaster preparedness and response. Bangladesh is, in effect, a different country from that which was considered when the FAP was formulated 20 years ago.

This changed and dynamic situation needs to be recognized in formulating future flood control and water management plans: plans need to look forward, not be based on past needs and outlooks. The rapid growth of Bangladesh's population and economy means that many more people and much greater economic assets are exposed to damaging floods than in the past. Additionally, while the growth of groundwater-irrigated rice production in the dry season in the past 20 years has reduced the importance of crop losses by damaging floods in the monsoon season, the limits to further expansion of tubewell irrigation are approaching and there are concerns about its sustainability (see below). Therefore, as national foodgrain demand increases with the growing population, monsoon-season crop production will, again, become increasingly important. The economic benefits of providing flood protection thus need to be reassessed, and so do the social and political benefits.

Subsequent to the time of the FAP, it was recognized that severe floods in Bangladesh are not primarily caused by overbank flow from the rivers. Messerli and Hofer (2007)[2] showed that damaging floods in Bangladesh are caused by heavy rainfall over Bangladesh itself occurring at times when the rivers are running at high levels, which thus prevent drainage of water from adjoining land areas. This finding – which is consistent with the author's soil observations (Brammer, 2004) – requires that Bangladesh's flood protection and management strategies be re-examined. What purpose, it may be asked, do flood embankments serve if the land behind them will still be deeply flooded when there is exceptionally heavy rainfall in the country?

2.2. Polders

In fact, embankments do provide protection against 'normal' floods along the country's major rivers and against flash floods along the country's smaller eastern rivers. Embankments built alongside tidal rivers under the Coastal Embankment Project also protect adjoining land from flooding with saline water, except where they are deliberately breached by shrimp farmers or are damaged by storm surges (the embankments were not designed to protect land against storm surges of more than moderate height). But if protection is to be achieved against the high floods that periodically destroy large areas of *aman* rice, seriously disrupt communications, commerce and industry, and degrade living conditions for many millions of both rural and urban populations, the concept of compartmentalization deserves re-examination.

In the FAP, it was envisaged that compartments behind the main embankments would retain water in upstream floodplain areas and thereby prevent or reduce the flooding of areas downstream (particularly Dhaka city). The practicality needs to be examined of turning such compartments into polders from which ponded rainwater could be pumped over the embankments into adjoining rivers, as is practised in the Chandpur and Meghna-Dhonagoda irrigation project areas (the Chandpur project area is in the north of agroecological region 17 in Figure 1; the Meghna-Dhonagoda project area is in the central part of region 16). As in the two latter polders, pump drainage would enable high-yielding *aman* to be grown in the monsoon season on land where, because of deep flooding, either a low-yielding deepwater *aman* crop is presently grown or the land is left fallow during the monsoon season. Soil surveys showed that normal flooding depths exceeded 90 cm on 32 per cent of Bangladesh's floodplain area (Brammer, forthcoming).

Provision of surface-water irrigation to such polders would not be necessary because of the widespread availability of groundwater for irrigation in most floodplain regions of Bangladesh. This would greatly reduce the capital and operational costs of such projects, because tubewell irrigation is much less costly (to government) than providing surface-water irrigation, which also involves acquisition of farmers' land for distribution canals. The only reservation in this regard is that the shallow aquifers that are generally used for tubewell irrigation are contaminated with arsenic in some areas, and irrigation with river water might need to be considered among a range of alternative mitigation options (see below).

The greatest need for pump-drained polders is on the Jamuna Floodplain in the former Jamalpur, Tangail and Dhaka districts, and on the Ganges River Floodplain adjoining the Jamuna-Ganges confluence in the former Pabna, Faridpur and Dhaka districts (see Figure 1). However, the easiest place to test the technical feasibility of this concept and determine its economic and social benefits would be on the Old Meghna Estuarine Floodplain adjoining the Chandpur and Meghna-Dhonagoda project areas in greater Comilla and Noakhali districts. There the land is more uniform and level than on the Jamuna and Ganges floodplains; there is no problem of river-bank erosion (as there is in both the Chandpur and Meghna-Dhonagoda project areas); there is a network of internal drainage canals; and local people have witnessed the benefits of pump drainage on security of agricultural production and quality of life in the adjoining polders. Since there are significant differences between physiographic regions in relief and flooding characteristics, each region should be assessed individually in considering the country's flood protection needs, opportunities and constraints.

2.3. Gorai diversion

The Gorai-Madhumati river system provides most of the fresh-water flow into the western part of the Ganges Tidal Floodplain. Rivers in the west of this region become saline in the dry season. Tubewell irrigation is not a feasible option in this area

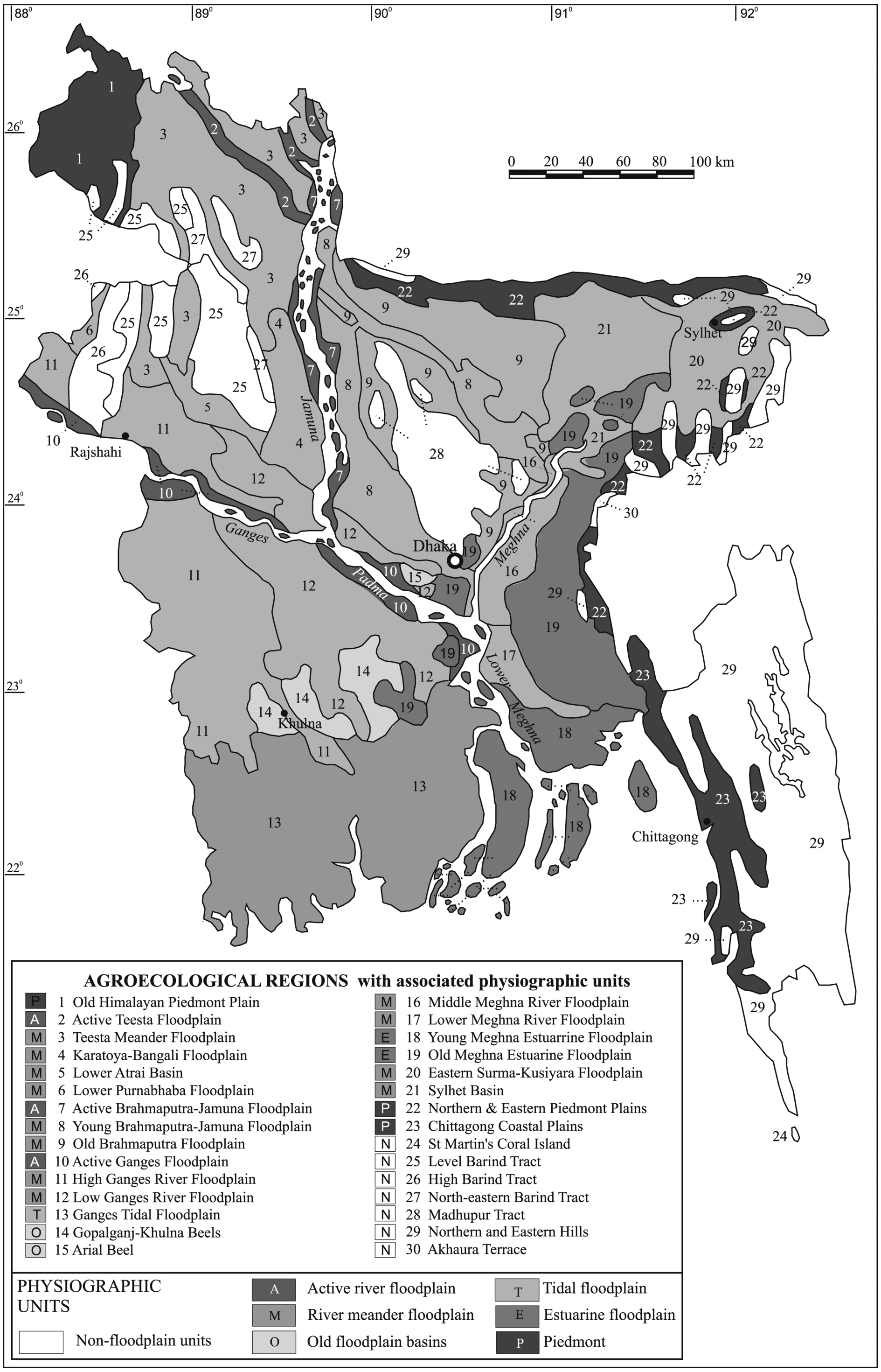

FIGURE 1 Bangladesh agroecological regions
Source: Brammer (2004).

because the upper aquifer is saline and there is a risk that the non-saline deep aquifers presently used to supply water for domestic and industrial use might be salinized by the draw-down of water from upper layers. Hence, irrigation with surface water is required if a rice crop is to be grown in the dry season (monsoon rainfall is sufficient in this area to wash salt out of the soils so that one or sometimes two monsoon-season rice crops can be grown, using salt-tolerant varieties in some areas).

However, over the past several decades, the salt-water front in tidal rivers in this region has gradually moved inland, especially in the west, due to reduced flow in rivers entering the region from inland. The latter has mainly been attributed to – and has certainly been aggravated by – the diversion of Ganges river water at the Farakka barrage in India (Mirza, 2005). This structure has reduced dry-season flow of water into Bangladesh and thereby into the Gorai-Madhumati river system. However, the Farakka barrage is not the only cause: any diversion of water from the Ganges and Brahmaputra-Jamuna rivers for irrigation or other purposes will reduce the flow of fresh water reaching the coastal regions in the dry season; so also, in principle, must the draw-down of regional groundwater tables by dry-season tubewell irrigation (although there are no data on this).

Considerable government and donor funds have been spent on dredging the entrance to the Gorai river each year, with varying degrees of success (the entrance to the Gorai river lies on the boundary between regions 11 and 12 south of the Ganges river in Figure 1). The government is currently examining the feasibility of building a spur into the Ganges river at the Gorai offtake to divert more dry-season flow into the latter river. This is intended as an interim measure until a proposed Ganges barrage is built to divert more water into the Gorai river. But here the Government of Bangladesh faces two serious dilemmas.

- The statement in its manifesto referred to above indicates that the government intends that water diverted into the Gorai will be used both for surface-water irrigation and to hold back the salinity front in tidal rivers downstream, with the additional objective of sustaining the mangrove-forest environment in the Khulna Sunderbans. But data given in the FAP4 regional study report showed that, without augmentation, there was not enough water in the Gorai river to be used for both purposes (FPCO, 1993): water extracted from the Gorai-Madhumati or tidal rivers for irrigation will decrease the water flow available to hold back the salinity front. This dilemma – which has political as well as economic and environmental dimensions: for example, where should the water diverted into the Gorai be used? – will need to be resolved before diversion works can be properly planned and evaluated.
- An additional dilemma is provided by uncertainty regarding the future availability of Ganges flow below the Farakka barrage. Mirza (2005) estimated that dry-season Ganges flow at the Farakka barrage declined by 15 per cent between 1947 and 1998; and it seems probable that this trend will continue, and possibly accelerate, as increasing amounts of water are withdrawn from the Ganges system for irrigation and domestic and industrial use in upstream states of India. Conceivably, water might not even reach Farakka in the dry season in a few decades' time.[3]

These dilemmas need to be addressed and taken into account in water resources planning. The government proposes to supplement flow into the Gorai river by transferring water from the Jamuna river into the Ganges above the proposed Ganges barrage. An alternative might be to divert water into the Gorai-Madhumati and tidal rivers system from somewhere below the Jamuna-Ganges confluence. However, preliminary studies made under the FAP4 regional planning study (FPCO, 1993) indicated that the provision of diversion headworks on Bangladesh's unstable major river channels would be technically difficult and very costly to provide and maintain, as experience with the Ganges-Kobadak and Chandpur irrigation projects has shown (the Ganges-Kobadak Irrigation Project area is in the north of region 11 on Figure 1).

2.4. Climate change

In the past two decades, there has been increasing concern about the possible impacts of climate change on Bangladesh in the 21st century, in particular about the projected rise in sea level, increased monsoon rainfall and increased frequency and intensity of floods and cyclones.[4] Strategies to address these concerns are described in GOB (2009). However, the flood and water management suggestions made above need to be examined regardless of such possible changes. It does not matter much to people living in flood-prone areas whether their lives and economies are disrupted once in 5 years or once in 3 years. They want assurance of security every year. Moreover, the demographic, economic and environmental changes that are taking place in Bangladesh, described above, are taking place at a much faster rate than are the changes likely to result from global warming, with mean temperatures increasing by 0.02°C a year and sea level rising by 3.4 mm a year (Allison et al., 2009). The current priority focus on climate change must not be allowed to distract attention from addressing Bangladesh's urgent present needs.

2.5. Arsenic contamination

The rapid expansion of small-scale irrigation that occurred after the government liberalized the market for shallow tubewells (STWs) in 1987–1988 was not FAP-related. However, the rapid increase in food production that this policy enabled took the pressure off the demand for flood protection to safeguard agricultural production that had existed up to the time of the FAP. Unfortunately, the STW irrigation strategy is now threatened by the recognition within the past 10 years that the shallow aquifers tapped by STWs are contaminated with arsenic in some floodplain areas, to the extent that soils and crops (especially rice) are being contaminated. This could have detrimental impacts on foodgrain production, farmers' incomes and family health (Brammer and Ravenscroft, 2009). The scale of this contamination and its socio-economic impacts have not yet been assessed, and there is as yet little official or public awareness of this problem. However, the widely recognized problem of arsenic contamination of drinking water supplies (which are also mainly derived from the shallow aquifer) suggests that irrigation water could be contaminated in several parts of Bangladesh, especially on the Ganges River Floodplain and the Old Meghna Estuarine Floodplain (see Figure 1). Possible mitigation measures, which have not yet been adequately tested, include the substitution of surface-water supplies for irrigation (Brammer, 2009). The limitations of this option are discussed below.

2.6. Surface-water irrigation

It is the present government's policy to promote surface-water irrigation. The feasibility of this policy awaits detailed technical study. Easily available surface-water sources in small rivers and *bils* (natural lakes) have already been fully exploited using small low-lift pumps. Diversions from the country's major rivers, as practised in the Ganges-Kobadak irrigation project, are technically difficult and very costly because of problems of unstable river banks and annual siltation of intake canals. Experience to date has also shown that farmers are unwilling to contribute meaningfully to irrigation costs (Brammer, 2004). In addition, further withdrawals of water from the rivers would have adverse environmental impacts downstream by allowing salt water to penetrate further inland in coastal districts, a situation aggravated by the uncertainties regarding Ganges water flow in future decades, described above. These uncertainties regarding the future availability of irrigation water to support further expansion of crop production reinforce the importance of reviewing the feasibility of providing flood protection and pump drainage in order to expand and safeguard monsoon-season crop production.

3. Institutional considerations

3.1. Policy review

The main obstacles to implementing the flood management proposals studied under the FAP were not technical. They were economic and institutional: the high costs of implementing, operating and maintaining major flood control and water management projects along Bangladesh's unstable river channels; the priority given by the Bangladesh Water Development Board (BWDB) to new constructions over adequate operation and maintenance of existing projects; inadequate Ministry of Finance funding for such work; allegations of widespread corruption; and lack of popular participation (Brammer, 2004). The Water Resources Planning Organisation (WARPO) and BWDB also strongly discounted the potential for groundwater irrigation, in part to enhance Bangladesh's claim on Ganges water flow for irrigation and for salinity control in negotiations with India, but also in response to the demands of a strong civil engineering lobby for continued priority to be given to lucrative construction projects. These constraints and attitudes will need to be addressed and be overcome or changed if a viable flood and water management system is to be provided and sustained to meet Bangladesh's current and future needs.

The question arises: can Bangladesh afford to provide and maintain a comprehensive flood and water management system involving the complete embankment of its major rivers, the Coastal Embankment Project polders and heavily subsidized (and conceptually outdated) surface-water irrigation projects such as the Ganges-Kobadak and Tista barrage projects? (The Tista Barrage Project area lies in the north of region 3 in Figure 1.) Bangladesh is not a rich country, and it cannot forever rely or depend on foreign donations to support its aspirations and needs. But while looking at the affordability of a country-wide flood-management system, the costs – social as well as economic; international as well as national – of Bangladesh *not* having such a system also need to be assessed. This suggests the need for a comprehensive policy study to review what it might be feasible to aim for, and to recommend the financial and institutional changes needed to implement and sustain realistically framed environmental interventions and adaptations, whether with or without flood embankments. Such a study would need to be much broader in scope than the Flood Policy Study that preceded the FAP (UNDP, 1989), examining financial, institutional, social and environmental aspects as well as engineering aspects.

3.2. Institutional review

An institutional review could usefully start by examining why the country's 2001 National Water Plan remained largely a pious wish list and by identifying the measures that would need to be taken to reduce the possibility that a revived or revised national plan would meet a similar fate. The implications of continuing 'business as usual' practices need not only to be appraised: the implications of continuing such practices also need to be propagated to politicians, government officials, business interests and the public in order to increase their awareness of their responsibilities if they want to be protected against floods. It is not only a change in government policy but also a change in political, official and public attitudes that is required.[5]

The review could also usefully examine what means could be taken to increase local responsibility for managing and operating flood control and water management projects. Those responsibilities should include contributing meaningfully to the costs of providing the social and economic benefits that people living in the command areas gain from such projects. It might be easiest to make a start, on a pilot scale, with local management of one or more individual polders in the Coastal Embankment Project area (the Coastal Embankment Project area occupies most of region 13 in Figure 1 and coastal parts of regions 18 and 23). Failure to manage an individual polder satisfactorily in this area would affect only the population living in that polder. Local management boards could employ their own technical staff. However, there would also be a need for larger management boards which, inter alia, might be responsible for monitoring river flow and salinity, dredging rivers where necessary, providing technical advice and arbitrating in cases of inter-polder disputes. The eventual aim should be for regional and local boards to manage and maintain the whole Coastal Embankment Project, with the area subdivided into convenient, contiguous units. Very probably, central government would need to subsidize such boards, but hopefully on a gradually declining scale. However, the aim should be to devolve responsibility for operation and maintenance to local boards as a means to transfer taxation to those receiving direct benefits from successful project operation and thereby decrease the present burden on central government finances.

Similar measures need to be considered for transferring operation and maintenance responsibilities to local management boards for such projects as the Ganges-Kobadak, Chandpur and Meghna-Dhonagoda irrigation projects and some small flood control projects: that is, projects where failure to manage them satisfactorily would not have direct, adverse, knock-on impacts on people living outside the project area. One probable benefit of farmers being required to pay more for surface-water irrigation in the Ganges-Kobadak and Tista barrage projects would be a decision to switch to providing their own tubewell irrigation, groundwater being readily available in both these project areas (an alternative that was not recognized when these projects were conceived many decades ago). Abandonment of surface-water irrigation in these areas would considerably reduce the central government subsidies that are currently needed to support these projects. There would undoubtedly be BWDB and local political opposition to closing these projects, but local objections might be overcome by the provision of a one-off subsidy for farmers to install STWs in arsenic-free areas and deep tubewells in arsenic-affected areas.

3.3. Water management boards

The operation and management of flood embankments along the country's major rivers would probably need to remain a central government responsibility. However, the policy review recommended above could usefully examine the possibility of establishing separate, local, management boards for each major flood embankment (such as the Brahmaputra Right Embankment) to take over operation and maintenance functions from BWDB. The creation of pump-drained polders behind river embankments, as suggested above, would – if found to be technically feasible – enable local management boards to be established in different sections of major river embankment project areas. That would, in turn, facilitate the introduction of local payment or taxation systems to contribute to overall project costs, including proportional contributions by urban, industrial and commercial beneficiaries as well as farmers.

3.4. National water authority

There would remain the need for an overall national water authority to assess both national and regional flood and water management needs; to monitor river flow, water quality and embankment security; to arbitrate in conflicts of interest between adjoining regional water boards; to commission new studies or emergency works where needs are identified; to report annually to government on the status of flood and water management in the country; and to recommend any changes considered necessary to improve national flood security and water availability. Monitoring could usefully include an annual review by CEGIS of changes in river banks that threaten flood embankments so that timely countermeasures can be planned and provided. Additionally, and for the same purpose, WARPO and CEGIS should monitor sites of possible river avulsions, such as that of the Jamuna river into the Bangali river, which threatened to occur in the 1987 and 1988 floods (Brammer, 2004). Other sites on the Tista, Brahmaputra and possibly other rivers also need to be monitored where an avulsion into former or new channels could occur during a catastrophic flood (Brammer, forthcoming). Responsibility for national planning, monitoring and evaluation would remain with WARPO, with BWDB acting as its operational arm responsible for project design and construction, and for executing emergency works.

The policy review recommended above could usefully include a review of the institutional arrangements for flood and water management in other countries in order to benefit from experience gained and lessons learnt in those countries. External models may not apply directly or wholly to Bangladesh's environmental, political, cultural and economic situations, but they could provide a useful starting point for selecting alternative measures that might be appropriate for testing in Bangladesh.

4. Fall back strategy

4.1. Implications and options

What are the implications if major flood-protection projects are found to be technically infeasible or unaffordable, or if international donors are unwilling to fund the capital works on the scale required? Large areas of Bangladesh would then remain exposed to recurrent damaging floods, and the number of people and the value of economic assets affected would increase with time. Environmental changes associated with global warming in the 21st century could gradually aggravate that situation. Continuing insecurity of growing conditions in the monsoon season would discourage farmers from investing more in high-yielding crop production. Together with recurrent crop losses, that would prevent the government from achieving its objective of attaining and sustaining national foodgrain self-sufficiency from 2013. The policy review recommended above would need to examine what alternative options are available that could provide greater security to lives, livelihoods and economic development in flood-prone and cyclone-prone areas, and also provide employment and food security for the whole population.

The National Water Policy prepared by WARPO in consultation with many other government agencies and NGOs reviewed flood-related options in 1998 (Brammer, 2004). Inter alia, it advocated strengthening the early warning system for floods and cyclones; motivating rural people to raise house plinths above flood levels; providing cyclone and flood shelters; raising land levels in urban areas (as a cheaper alternative to providing pump drainage); raising road and railway embankments above flood levels; establishing zoning regulations for locating new industries; and desilting river channels to improve drainage. It also advocated that farmers adjust cropping patterns (which were already well adapted to floods and flooding) and that dry-season irrigation be expanded (which was already in rapid progress via private investment in STWs).

4.2. Structural options

In view of the limited implementation of that policy (except for the expansion of tubewell irrigation) and the considerable expansion of population and economy that has taken place in subsequent years, the National Water Plan adopted in 2001 needs to be re-examined to assess the extent to which it meets present and future social and economic needs. Would it now, for instance, be more cost-effective and practical to embank the more highly developed cities and rural towns and provide pump drainage than was considered economic 10 years ago? What institutional measures could be introduced to fund, construct and maintain flood shelters in all flood-prone rural areas within a realistic (but short) time frame? Such structural flood-proofing measures are needed in all flood-prone areas to reduce human distress during floods and to facilitate the provision of relief as well as of health and other essential services. They are needed anyway in a national embankment strategy for areas that cannot be protected from floods, such as river *chars*, deep basin areas such as the Sylhet Basin, and tidal and estuarine floodplain areas exposed to storm surges.

Flood-proofing of urban areas could reduce the disruption of industrial and commercial activities during major floods. So could flood-proofing of major road and rail communications by raising embankment levels, increasing the capacity of bridges and culverts to allow more rapid passage of floodwater, and providing adequate funds for maintenance. For rural roads, the provision of reinforced flood passages in appropriate places instead of bridges and culverts could reduce impedance of flood flow as well as capital and maintenance costs. Cost–benefit analyses are needed to assess the economic value of providing such flood-proofing measures in particular areas.

4.3. Agricultural options

In agriculture, research is in progress to breed high-yielding rice varieties that are more flood tolerant, salt tolerant, drought tolerant, arsenic tolerant or early maturing. Early-maturing *boro* varieties are being developed to reduce exposure to loss by early floods, and *aman* varieties are being developed that can tolerate submergence for up to 14 days during a high flood period or can be planted later, after the high-risk flood period has passed (Asaduzzaman, 2009). However, flood submergence and a shorter growing period will reduce potential yields; there are limits to the amount of salt or arsenic that plants can tolerate; and high-yielding *aman* varieties are only likely to be suitable for areas that normally are only shallowly flooded but that might be flooded more deeply for a period of one or two weeks at high flood stages. High-yielding *aman* rice varieties are unlikely to be made available within the foreseeable future for the 32 per cent of the country's floodplain area that normally is flooded more deeply than 90 cm.

Elsewhere in agriculture, more can be done to increase crop yields and production by more efficient use of fertilizers – for example, by fertilizer placement – in both the monsoon season and the dry season. There is also still scope in some areas for further expansion of tubewell irrigation in the dry season, and existing irrigation equipment could be used more widely to reduce drought losses in monsoon-season crops. More could be done, too, to increase crop yields and reduce farmers' costs by improving irrigation efficiency; such measures could reduce the build-up of arsenic in soils and uptake by crops (Brammer, 2009). Outside agricultural production, increased foodgrain storage capacity is needed to help support the prices farmers receive for their crops in high-production years and to hold reserve stocks for use when floods (or other natural disasters) reduce national production below supply needs.

4.4. Ensuring food security

The measures for agriculture described above are unlikely to increase rice (and other crop) production sufficiently to meet the government's objective of achieving national self-sufficiency by 2013 and sustaining it thereafter as Bangladesh's population continues to grow at c. 2 million each year. This implies that, in the absence of further flood-protection interventions, the government must seek to increase both economic returns and employment opportunities in other sectors of the national economy in order to pay for the food that will need to be imported to meet the growing demand. In turn, that will need greater government and private investments in education and skills development to support the generation of increased industrial production and commercial and other services on the scale and within the time frame needed. The latter investments are needed, regardless of flood protection and flood-proofing considerations, to enable Bangladesh to compete in world markets with countries such as India and China.

This review illustrates the scale and multifaceted nature of the dilemma faced by the Government of Bangladesh in deciding where best to invest its limited financial resources in order to provide the country's present and future populations with a more secure and satisfactory quality of life. The same dilemma faces donor governments and NGOs seeking to assist the government and people of Bangladesh in addressing existing and future environmental and demographic problems.

Notes

1. Interpolation of data for the 1981 and 1991 Bangladesh population censuses gives a population of ca 98 million in mid-1989. Estimates of the current population range between 148 million (BBS, 2008) and 160 million (World Bank, 2009). Predictions for 2030 range between 190 million (BBS, 2008) and 203 million (UNDESA, 2008).
2. The authors' names are given in the reverse order in the edition published by FAO, Rome.
3. Successive Ganges water treaties are reviewed in Swain (2004). The impacts of the Farakka barrage on Ganges river flow and morphology are reviewed in Mirza (2005).
4. The 2007 IPCC report states that most, but not all, climate models for the South Asian region predict increased rainfall during the pre-monsoon, monsoon and post-monsoon seasons and decreased rainfall in the winter season (Cruz et al., 2007). These models cannot yet simulate the Indian monsoon satisfactorily, so there is great uncertainty regarding the predictions.
5. This is the view of a westerner. An anthropologist (Maloney, 1988), explaining Bengali patron-subordinate *mores* 20 years ago, was not optimistic that such institutional changes could be made. That analysis deserves revisiting to examine to what extent experience, education and urbanization might have changed attitudes in the intervening years.

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