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Maximisation of Joint Benefits from Multiple Resource Use in Bangladeshi Floodplains

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NRSP Production System

Land Water Interface

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The entire report (FTR as well as detailed research results) are presented as one single volume here. Chapter 1 is the FTR, chapters 2 to 7 present detailed research results.

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Glossary of abbreviations, acronyms and Bengali terms

Aman	Rice grown during the monsoon and harvested after the monsoon.
B. Aman	a crop of *aman*, sown by broadcasting the seed. Normally local varieties and more flood tolerant.
Aus	Rice planted before the monsoon and harvested during the monsoon.
AEZ	Agro-Ecological Zone
Beel	Shallow floodplain depression with an ephemeral or perennial waterbody
Boro	Rice cultivated in the dry season; usually an irrigated crop.
BRRI	Bangladesh Rice Research Institute
CBFM	Community Based Fisheries Management
CPR	Common Property Resource / Common Pool Resource
DFID	Department for International Development (formerly ODA)
DoF	Department of Fisheries
FAP	Flood Action Plan
FCD	Flood Control and Drainage
FCD/I	Flood Control and Drainage/Irrigation
GIS	Geographic Information System
GoB	Government of Bangladesh
HYV	High Yielding Variety
ICLARM	International Centre for Living Aquatic Resources Management
IRRI	International rice Research Institute
Katha	Brushpile, fish aggregating device
Khal	Channel or canal, often connecting a *beel* to a river
Kharif	the wet season. Sufficient soil moisture from rain and flooding to support non-irrigated agriculture
Khas	Land (and waterbodies) owned by Government, usually leased out
Kua	Excavated area (sump) in a waterbody, used for aggregating fish
LWI	Land / Water Interface
Mouza	the smallest administrative unit in Bangladesh
NARS	National Agricultural Research System
NGO	Non-Governmental Organisation
NRSP	Natural Resources Systems Programme
ODA	Overseas Development Administration (now DFID)
OVI	Objectively Verifiable Indicators
Pagar	Excavated ditch, used for aggregating fish
PRA	Participatory Rural Appraisal
Rabi	the dry season. Crops depend on moisture stored in the soil from the monsoon, or on irrigation.
Sharia	Quranic law
T. Aman	a crop of *aman*, sown by transplanting seedlings. Normally HYV varieties and less flood tolerant.
Thana	Administrative unit between a Union and a District

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Chapter 1: Final Technical Report

1.1 Executive Summary

The purpose of this project was *'Improved technical understanding and integrated management of floodplain habitats developed and promoted'*.

To achieve this the project undertook desk-based simulation modelling of a set of management strategies that have wide relevance across the floodplains of Bangladesh. The modelling exercises brought together previously generated data, parameters and knowledge from the agriculture and fisheries sectors within an integrated framework. This was complemented with secondary socio-economic information to provide fresh insights into how these strategies may be positioned in order to optimise their role in improving floodplain livelihoods. A suite of modelling approaches were utilised or developed for this purpose: (i) A dynamic pool fisheries model with a hydrological component, (ii) GIS modelling connecting plot level cropping with socio-economic information, and (iii) A mathematical programming model optimising the productive use of land with joint consideration of the two sectors given a set of hydrolgical, biophysical and economic constraints. These were used to investigate the following strategies: (i) fisheries closed seasons (ii) fisheries closed areas, (iii) Limiting water abstraction for winter rice irrigation, (iv) higher dry season water retention, (v) managing early flood risk by non-structural means and (vi) early flood season sluice gate management.

Results indicate that in most cases, scope exists for significant benefits to be reaped from relatively small modifications or sacrifices. For instance, higher dry season water retention in the 6773 hectare site modelled could produce almost 20% higher fish catches, benefiting the entire spectrum of floodplain poor who at least seasonally depend on fishing, at the cost of only 16 hectares of land taken out of winter rice production. In this instance, the gains from fish catch improvement in taka outstrips the loss in agricultural returns by as much as 34 times, indicating very substantial benefits may potentially be reaped from relatively minor modifications.

Results also reveal a common thread running through most of the investigated strategies that could provide a cornerstone for future action research. Managing dry season rice production in low and very low land, either by enabling an earlier harvest than is currently typical for these plots, or preferably by moving such land out of rice production altogether, is capable of helping solve a range of widespread problems investigated in this study. This is because the complex systems interlinkages across time and space in the floodplains depend particularly critically upon this key aspect. Rice production in very low land results in maximisation of water drainage at the end of the flood season, increased surface water abstraction from nearby waterbodies to irrigate the rice crop, and pressure on sluice managers to keep gates closed in the early flood season so that the lowland rice crop may be protected prior to harvest. This combination of drainage maximisation, dry season water abstraction and early flood season sluice closure caused by lowland rice production deprives the fishery of water and blocks migration routes for fish, resulting in significant productivity loss. One of the keys to management then lies in freeing some of the low land of winter rice production. A four-pronged strategy combining cropping pattern management, sluice gate management, land retirement/increased water cover, and fishery effort control is recommended.

When taken into consideration in tandem with consensus building approaches developed by another recent NRSP-LWI project, this research produced here provides a link between understanding produced by previous research and action research for the future.

1.2 Background

1.2.1 Overview and researchable constraint:

80% of Bangladesh is a floodplain of major and minor rivers. These floodplain lands sustain a rural population that is predominantly poor, with over 50% classified as functionally landless (owning less than 0.2 ha of land). With the population expanding at the rate of 2.2 million a year, and continual subdivision of landholdings due to the *sharia* inheritance system, ever-increasing numbers of rural households find themselves in a state of landlessness.

The extreme scarcity of land implies that the importance of the safety-net provided by ecological reserves, particular the rich local fisheries, cannot be overemphasised. Apart form the large numbers of professional fishers whose livelihoods are tied to the health of the fishery, even for the broader group of predominantly agricultural households with marginal and small land holdings the fishery provides an important seasonal supplement to incomes and diets. The seasonal dimension to rural poverty in Bangladesh has received significant attention in the past decade, characterised by the recognition that even households that are above poverty line calculations based on annual income levels can be destitute for significant periods within the year (Sen, 1995). Driven by the annual hydrological cycle, the floodplain resource base fluctuates between being terrestrial or aquatic over the year, resulting in temporal shifts in the use of the same resource base as private property (cropping) or as a CPR (fishing). While the *Boro* (dry season rice) crop sustains labour demand and rural incomes from November onwards until May, few agricultural opportunities are available after *aman* (flood-season rice) planting in June, and fishing from the flooded land becomes an important component of livelihoods across the household wealth spectrum.

There is therefore a clear need for floodplain development policy based broadly on the integrated development of the agriculture and fishery sectors. However, policy has tended to focus largely on agricultural growth. This is manifested in the construction of large-scale flood-control structures based to a significant degree on the premise that a drier floodplain in the flood season will facilitate the replacement of *broadcast-aman* rice by the higher-yielding but less flood-tolerant *transplanted-aman*. The long-run trend, however, has been for the rice economy to be increasingly centred on the dry-season *boro* crop. Thus even the potential agricultural benefit from large-scale flood control has been questioned in some quarters, particularly in relation to the expenditure incurred on this strategy. (Soussan and Datta,1998). The negative impact of flood control on fish catch, due to lowered water levels on the floodplain (FAP17, 1994) and blocked migration routes for fish (Halls, *et. al.*, 2001) is now well documented.

The large-scale flood-control strategy is largely irreversible, and its meso-level effects have been extensively researched and quantified by the numerous Flood Action Plan (FAP) studies[1]. However, the tradeoff between the two sectors extends to the micro-level, often characterised by agricultural interests controlling water levels on the floodplain at the expense of the fishery. One important instance of this is the abstraction of water from dry-season surface water bodies for irrigation of the winter rice crop, to the detriment of the fishery (Barr, 2000). Another is managing sluice

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[1] Although the negative impacts of this strategy have received the most attention, it must be mentioned that various projects have also had significant positive impacts. Also, concerted efforts are being made to control the negative externalities, *e.g.* designing fish passes and fish gates set into flood-control structures.

gates in a manner that dries up land for rice, but deprives the fishery of water. Such tradeoffs, although well recognised by stakeholders in Bangladeshi floodplains and widespread in the country, have received comparatively little research attention until recently. However, once constraints imposed by extant flood control structures are accepted as given, it is through informed management of these micro-level parameters across the country, and enabling 'win-win' scenarios, that action researchers can hope to improve the livelihoods of large numbers of floodplain poor. Most of the strategies investigated in this project are thus important from the point of view of future floodplain management, but are also under-researched.

There is particularly little *quantified* information available. Quantification of such tradeoffs and the management strategies available to ameliorate such problems is important for policymakers and action researchers. For one, quantification may enable an appreciation of the seriousness of the problem that anecdotal evidence or qualitative methods such as PRA's may not provide. For another, quantified counterfactual simulations of the sort produced in this research can help policymakers and action researchers narrow down and better define their strategies in contrast to a field trial and error approach based on the same general principles.

1.2.2 Previous research:

Given the traditional setup of the NARS in Bangladesh, there is a voluminous literature on farming systems (Siddique, *et. al.,* 1994, Roy, 1996, Razzaque, 2001), concentrating on the farm unit and the crop, livestock and aquacultural activities located within it. This literature has generally divorced itself from other activities that households may be engaged in to make a living, such as fishing (Barr, 2000). Typically, these describe the components of various farming systems, model linkages, or describe optimal systems given geophysical constraints such as land elevation. A large literature on inland fisheries has similarly developed (Aguero, 1989; Tsai and Ali, 1997; IUCN, 1993), reporting on various biological, institutional and management aspects of floodplain fisheries. The focus in this literature is largely on the professional fishermen, discussing gears commonly used, patterns of effort and exploitation, measures of the health of the fishery, administration of the fishery, and potential management strategies. The agricultural sector and agricultural activities of households are usually discussed only peripherally in this literature.

The livelihood portfolios of the vast majority of the floodplain poor contain elements from both sectors, however (FAP 17, 1994), with dependence on specific sectors varying seasonally and according to household wealth status. Thus the bipolar model of farming vs. fishing can be misleading, and there is usually no zero-sum game where floodplain livelihoods are concerned. Thus when agricultural interventions or activities negatively impinge on the fishery, the negative impacts will be felt not only by the professional fishers, but also by the seasonal and opportunistic fishers who make up the bulk of the floodplain population. A systems-based understanding is thus required, which links time-varying household activities and socio-economic information with the physical resource base and its multiple functions. A start was made in this regard by NRSP-LWI project R6383 (Barr, *et. al.*, 1996), which produced a conceptual model linking fishermen types with household land ownership types (a proxy for wealth), and the type of natural resources that these households depend on for their NR-based livelihoods. Another NRSP-LWI project, R7565 (Barr, 2000) took this agenda further, by collecting detailed biophysical and socio-economic data over an entire year for two floodplain sites in Bangladesh, and integrating the data into a Geographical Information System (GIS). Analysis revealed an intricate pattern of household activity closely matched with temporal variations in the resource base. A number of ‘entry points’ and opportunities for intervention were identified, including management of early flood risk, and resolving conflicts between water use for irrigation and for the fishery. However, social structures, livelihood profiles, and cropping and fishing patterns were found to vary substantially between sites. Thus, echoing the conclusions of FAP17 (1994), it was concluded that much caution must be exercised when generalising about floodplain resource use and livelihoods trajectories in Bangladesh. Another NRSP-LWI project, R6778 (Soussan, 2000), investigated water-management strategies in Bangladeshi floodplains using participatory methods. A major conclusion of this research was that water *scarcity*, rather than abundance, characterises the principal livelihood constraint. Given the multifunctionality of the water resource for floodplain dwellers and the ever-increasing pressure exerted by the growing population and upstream demand, there is a major scarcity problem in the midst of seeming excess availability.

Concomitant with these recent developments in understanding floodplain livelihoods and systems linkages, research has also been undertaken to improve the understanding of biological processes underlying floodplain fisheries in Bangladesh[2]. DfID-FMSP project R4791 (Heady, *et. al.*,1995) undertook fieldwork in the *haor* region of Bangladesh, collecting information on several biological and socio-economic parameters. These were combined in a fisheries management simulation modelling exercise to investigate the effects of interventions such as gear bans and closed seasons. A further project, R5953 (Hoggarth and Halls, 1997) delved deeper into the migration, reproduction and dry-season survival strategies of river fish, and the implications for management. A PhD thesis written in support of this work (Halls, 1998) developed a simulation model combining a hydrological module with a dynamic-pool fisheries model. One of the major conclusions of this research was that dry-season water maintenance is critical from the point of view of the health of the fishery. This resonates with the findings from the participatory livelihoods research of Soussan 2000, which accords a central role to the maintenance and sharing of water in the determination of livelihood sustainability, albeit from a different perspective.

The research conducted in the past decade has thus led to a greater *understanding* of the problems investigated in our study, particularly of the constituent biophysical elements, and the interplay between household activities and the resource base. This study aims to contribute to the link between *understanding* and *implementation*[3], by providing model-based simulations of various scenarios. There does exist a small literature using simulation modelling in Bangladesh floodplains. R4791 has simulated various fisheries management options, as discussed above, although without explicit consideration of hydrological parameters. Various FAP studies have utilised detailed hydrological models to analyse specific FCDI projects. De Graaf *et. al.* (2001), combine hydrological, fisheries and agricultural modules to optimise water-management strategies in the Compartmentalisation Pilot Project (CPP)[4] area. However, their objectives pertain to the special problem of water management under compartmentalisation schemes, rather than the more generic and widespread

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[2] While considerable resources have been spent over the years in agricultural research in Bangladesh, capture fisheries research has been relatively under-funded until recently, especially in light of its importance in floodplain livelihoods. Thus there have been more critical gaps in the fisheries literature.

[3] Indeed, the mechanics of how implementation may be best achieved given the oft-conflicting interests of various groups of floodplain residents has also now been researched. NRSP-LWI project R7562 (Barr, 2002) has examined consensus-building methods for integrated floodplain management at the micro-level in Bangladesh.

[4] The CPP is a large-scale flood-control project that is experimenting with the concept of ‘controlled flooding’ by compartmentalising the flood control structure.

hydrological issues that this research examines. By examining these widespread, but largely under-researched, problems and appropriate management strategies, and by combining hydrological, fisheries and agricultural modules with socio-economic information, this research hopes to inform future implementation exercises from a holistic perspective.

1.2.3 The demand for the research

Demand for this project was identified at three levels;

- From outputs of previous projects.
- From Government of Bangladesh (GOB)
- From development organisations working in Bangladesh

Outputs from Previous projects:

The stream of research funded by DfID has established an understanding of various elements of floodplain production. It remains for the elements to be brought together in research combining considering the two broad sectors (agriculture and fisheries) jointly, and focused on scenario-based prediction. As project R6383 (Barr, *et. al.*, 1996) states: "...further research is recommended which aims to develop more diversified production strategies for producers dependent on both the terrestrial and aquatic resources of the floodplain". Project R7656 progressed considerably in building further data and understanding to enable predictive assessment. However, it is freely admitted in Barr (2000) that although that project had intended to undertake modelling-based interdisciplinary analyses, time considerations and the complexity of the issues did not permit much progress on this front. This project is intended to fill that gap.

Previous projects have also called for additional work on the *specific* management scenarios investigated in this project. Based on field observations and problem census findings, project R7656 states regarding needs for future research, '*…there remains a need to quantify the impact on fish stocks of beels drying out due to the use of low-lift pumps (LLPs) drawing water to irrigate boro crops'* (Barr, 2000). The problem censuses from the study sites of this project also find that risk of early flooding damaging the boro crop is perceived by floodplain residents as a primary livelihood constraint, yet the scope for mitigation of these risks by non-structural methods has not been researched. Having noted that dry-season water maintenance (through sluice gate management) is key to the health of the fishery, Halls, *et. al.* (2001), in an output from DfID-FMSP project R5953, note that the feasibility of this strategy needs to be explored taking account of the needs of the farming sector during this period.

Development organisations working in Bangladesh:

The World Bank, in its 1998 report on water management in Bangladesh includes among its recommendations for planning, "*Consolidating existing approaches to water resource analysis and developing new tools and techniques for this purpose*", and "*Consolidating earlier National Water Plan reports, regional Flood Action Plan studies and supporting studies, subregional studies, investigation and pilot programs output, and other independent studies…*". Several consortiums and major conferences/networks bringing together academic and action researchers on Bangladeshi floodplains have called for more research on the shared use of floodplain resources. For instance, the periodic wetlands conference organised under the auspices of IUCN, the world conservation network, has been stressing the need for research on integrated wetlands management in Bangladesh (IUCN, 1993).

GOB: The National Water Plan adopted by the Bangladesh government has committed itself to managing water policy in a manner that takes account of all sectors and the needs of all floodplain residents. It notes that '*In the past, many beels have been drained through engineering interventions and turned into cropland for immediate gains. …they have destroyed the fish and aquatic vegetables that thrive in these wetlands and are important in the diet of the rural poor*' (Ministry of Water Resources, 2000). In the 'Research and Information Management' section of the plan, the increasing demand for research to support the complex multi-sectoral management problem is noted.

During the course of this research, further anecdotal evidence of demand became available. Officials in the Ministry of Fisheries opined that, while field observations and qualitative research had established important problem areas in integrated floodplain management, quantitative evidence that could provide helpful measures of benefits or tradeoffs was scarce.

1.3 Project Purpose

The project purpose as defined in the logical framework was:

"*Improved technical understanding and integrated management of floodplain habitats developed and promoted.*"

The underlying premise was that several biophysical elements of floodplain production were by now sufficiently researched. The links between livelihood activities of various categories of floodplain dwellers and the natural resource base had also been studied. Methodologies to enable building of institutions to enable consensus are also available. Given this background, the purpose of this project could be further elaborated as follows:

- To bring together information from past work and add value to this previous technical understanding by considering management issues in a multisectoral framework.

- To help bridge the gap between understanding and implementation/intervention by adopting an interdisciplinary simulation modelling framework.

- To provide quantified information on the likely effects of alternate management strategies to future action researchers and floodplain policymakers.

1.4 Research Activities

The project was conceived of as predominantly desk-based interdisciplinary research based on modelling, as outlined in the call for this project. Most members in the team of researchers had been previously involved in research on development issues in Bangladesh, albeit largely within disciplinary categories. A significant part of the project activities thus concentrated on bridging the disciplinary gaps through continued dialogue and discussion. With previous projects having established an *understanding* of the key elements, this project looked to build on the understanding and proceed towards *prediction*, based on simulation of baseline and counterfactual simulations of key management strategies.

The principal disciplines involved were:

- Fisheries biology and management
- Farming systems
- Economics
- Hydrology

Three factors made this task particularly challenging and time-consuming:

(i) Firstly, most extant models have been built from disciplinary standpoints. Building brand new interdisciplinary models from scratch, without sacrificing too many critical disciplinary details was clearly not feasible given the short time-horizon of the project[5], and the limited time available from disciplinary specialists. For instance, any management option focused on dry-season water levels and the effect on the fishery could not afford to ignore the effect on fish recruitment. Modelling recruitment is however a very challenging task, and there are no simple ways to incorporate such effects in new models built from scratch.

(ii) As a desk-based project, we were constrained by data available from previous research. Thus the modelling had to adapt to the available data, instead of the usual approach of collecting data specifically to enable a certain kind of modelling. As the project progressed, the inadequacies of data collected by previous projects in relation to the kinds of models we were attempting to build became more apparent.

(iii) The available data were from varying sites and time periods. The biophysical elements and social relations within Bangladesh vary so substantially over time and space that fitting pieces from various projects proved very difficult. For instance, detailed biological data on the fishery are available from FMSP project R5953. However, no socio-economic data were collected as part of that project. NRSP project R6756 provided a stream of socio-economic data, but the fisheries data were limited to household involvement in fishing, and consumption of fish. Neither project's data could be fitted to the other, even though the geographical distance between the sites is not enormous. The fish catch patterns and the importance of fishing in the portfolio of households is very different in these two regions, as evidenced by cross-country data collected by FAP17 (1994).

1.4.1 Exploration

Prior to the actual implementation of modelling, it was important to determine: (a) What management options to focus on. A vast array of strategies has been proposed for the enhancement of floodplain livelihoods in Bangladesh. These range from the multitude of region-specific agricultural technology packages to fishery enhancement options to flood control structures. (b) What analytical models were available at hand to build upon. As discussed above, it was decided that the building of multi-sectoral analytical models from scratch was clearly infeasible given time and budget constraints. (c) What socio-economic and biophysical data were available from the

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[5] Although at least one such attempt was made with systems dynamics modelling, discussed below.

various DfID, bilateral and multi-lateral projects that have been undertaken or are in progress in Bangladeshi floodplains.

Broad-based collection of documents and datasets commenced with the project team pooling the document and dataset collections of individual team-members. After an initial review of these, the principal investigator and the research assistant proceeded to Bangladesh to collect additional secondary data and information. Most prominent NGOs working on floodplain issues in Bangladesh were contacted in order to appraise them of the project's objectives, seek their opinions regarding what management strategies they considered key, and obtain documents and datasets that they were willing to release to us. Some governmental and quasi-governmental organisations were also approached. Upon return to the UK, review of the collected material commenced. Part of the interim project meeting that brought together all collaborators was devoted to finalising the list of management options that would be modelled.

The process resulted in the following final list of modelled strategies:
(i) Various fishery closed seasons.
(ii) Fishery closed areas.
(iii) Limiting irrigation water abstraction from dry-season waterbodies.
(iv) Maintaining higher dry-season water levels.
(v) Short-duration crop varieties to mitigate early flood risk.
(vi) Various sluice-gate settings in the early flood season.

Several factors were involved in arriving at this final choice:
(i) Some of the options (closed seasons and areas) had been indicated to us as priority ones at the project proposal review stage.
(ii) Precursor projects had identified key interventions based on field work observation and problem censuses/participatory appraisals. For example, R7868 had found that beel water abstraction was posing a significant threat to the fishery at its project site. A problem census at the site had also indicated that rice crop damage due to early flood risk was seen as a significant problem by the majority of participants.
(iii) The options modelled had to be feasible given the constraints imposed by the models, datasets, tools and expertise available within the team. For instance, project R6755 had established that deterioration of drinking water quality was a significant impediment to the well-being of residents at its project sites. However, none of the models available to us were capable of simulating alternative water quality scenarios in a sensible way.
(iv) The emphasis was on options that had reasonably broad relevance across the floodplain areas of Bangladesh, and were capable of being addressed by action research. Thus attention was restricted to micro and meso-scale, rather than macro-level interventions such as changes in national policy parameters. The initial project plan had included modelling of various embankment options. The general opinion among project members was however that modelling the effects of large-scale flood control structures would only be of limited use to action research plans. In any case, such options have been extensively modelled under the various FAP studies. What is rather more amenable to short and medium-run control is sluice-gate management. Hence sluice management options took the place of original plans to model the presence or absence of embankments.
(v) Attention was restricted to options for which our modelling could provide insights in addition to what is already evident. For example, a lack of input availability is a fairly common problem faced by poor floodplain farming households in Bangladesh. Better provision of inputs would have an obviously

salutary influence on their livelihoods. However, modelling is unlikely to provide any useful new lessons in this regard. In contrast, simulation of beel water abstraction on the fishery enables a quantitative appreciation of the seriousness of the problem, especially for policy-makers who are part of this project's intended audience.

(vi) Consultations with NGO and research organisations in Bangladesh also helped shape the final list.

1.4.2 Review of Literature

For each modelled strategy, a comprehensive literature review was carried out. Rather than present this information as a stand-alone review document as originally intended, we have chosen to weave it into the individual segments of the detailed research report pertaining to individual strategies.

1.4.3 Modelling

The exploratory stage resulted in the finalisation of a list of management strategies to be modelled. The exploration also made it apparent that building on existing models and expertise would be the most practical approach given the constraints and complexities involved. There was also a realisation that creative modification of existing models would indeed be sufficient to achieve the required simulations.
The modelling process was originally conceived of as achieving integration between bio-physical simulation processes with socio-economic data.

Modifying the FPFMODEL: The FPFMODEL is a dynamic pool fisheries model based on detailed population modelling for a key species, *Puntius Sophore*, in the Pabna Irrigation and Rural Development Project (PIRDP) area. This model was originally developed in Halls (1998) as an offshoot of the DfID-FMSP project R5953, 'Fisheries dynamics of modified floodplains in Southern Asia'. A hydrological module within the model connects the weekly water heights observed at sluice gates with the area and volume of water on the floodplain, which in turn has an iterative interaction with the fish population.

The various management strategies listed above were simulated as follows:

(i) Fishery closed seasons: Single-monthly, bi-monthly and seasonal (three-month) closed seasons were all simulated by setting the fishing mortality variable specific to the time period to zero, and generating estimates of recruitment, yield-per-recruit, initial loss of production relative to no closed season, and equilibrium yield and production. Although overall productivity of the fishery is important, the seasonality of livelihood profiles in Bangladeshi floodplains makes the monthly distribution of annual production a very important aspect. Hence, predictions were made on a monthly basis for this research.

(ii) Fishery closed areas: The yield effects of various sizes of dry-season fishery reserves were simulated by assuming that the estimated proportion of the population caught during the dry-season varies linearly and inversely with the reserve area. This enables us to investigate an 'optimal' size for fishery closed areas.

(iii) Water abstraction: In order to simulate the effects of water abstraction for dry-season rice irrigation, and the consequent effects on the fishery, 'typical' irrigation schedules were established. By 'removing' those irrigation water amounts at those specific times from the baseline volumes observed in the dry season water bodies in the PIRDP study site, and modelling the link between the 'new' water levels and the fish catch via the FPFMODEL, abstraction effects were simulated. The simulation proceeded by assuming one hectare was irrigated in this fashion, then two hectares, and so on until the water levels are reduced to an extent where recruitment failure occurs and the fishery collapses. A potential solution to the abstraction problem is diversification out of winter rice production, a strategy that is receiving much attention in agricultural policy circles in Bangladesh for various reasons. Most alternative winter crops have lower water requirements than rice, and hence such diversification is one of the few routes available to ameliorate the abstraction problem. Therefore simulations similar to that for winter rice described above were generated for wheat and onions, two alternative winter crops that could be promoted in the modelled region.

(iv) Higher dry-season water retention: Inherent in the FPFMODEL is a link between dry season water heights at sluice gates and area and volume of water in various dry season waterbodies. This feature was exploited in this segment of the study to explore higher dry season water retention (by blocking drainage at the sluice gate) and consequent effects of the fishery as well as winter rice cultivation. Any change in the water height at the sluice gate correspondingly translates into changes in water depths in each water body. Given estimates of the areas of various water bodies, it is consequently possible to calculate how much extra dry or flooded land results from a change in sluice gate water heights. Estimates of extra flooded land enable estimation of lost rice production. The FPFMODEL estimates increased fish yields. Intersection with prices and costs enabled an appreciation of the magnitude of the gain to the fishery *vis-à-vis* lost agricultural possibilities.

Complementing FPFMODEL simulations with livelihoods/socio-economic information: No socio-economic data were available for the specific site to which the FPFMODEL is calibrated. As discussed before, it was determined that using socio-economic data from floodplain areas in other regions (such as those from R7868) would be pointless, due to the extreme site-specificity of hydrological, biological and socio-economic parameters in Bangladesh. Fortunately, some socio-economic data were available for an area *adjacent* to the FPFMODEL site, from the FAP17 database. Although this provided a solution to our dilemma, it was nevertheless less than a perfect one, since the sites were close-by, but not perfectly aligned with each other. Additionally, the data pertained to different years, and the sampling strategies, etc, were completely different[6]. Given this constraint, it proved impossible to make a *direct* connection between the biophysical simulations and socio-economic data, in the sense of being able to provide simulations of changed livelihood profiles simultaneously with simulations of changed biophysical outcomes[7]. Instead, the project adopted the strategy of using the livelihoods information to evaluate the socio-economic desirability of alternate outcomes predicted by the biophysical model.

GIS Modelling of mitigating early flood risk: Project R7868 had collected data on a set of biophysical and socio-economic variables in the Charan beel area in Tangail district, that had been assimilated into a GIS, with linkages established between households and plots. This provided an opportunity for this project to simulate the effects of early flood arrival on the Boro crop, using a 'temporal shift' GIS tool to advance the baseline flood arrival date by one and two weeks. By manually establishing transplanting and harvest dates based on available data from the area, and combining the simulations of water levels with crop damage parameters,

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[6] This aspect is discussed at length in the detailed research report.

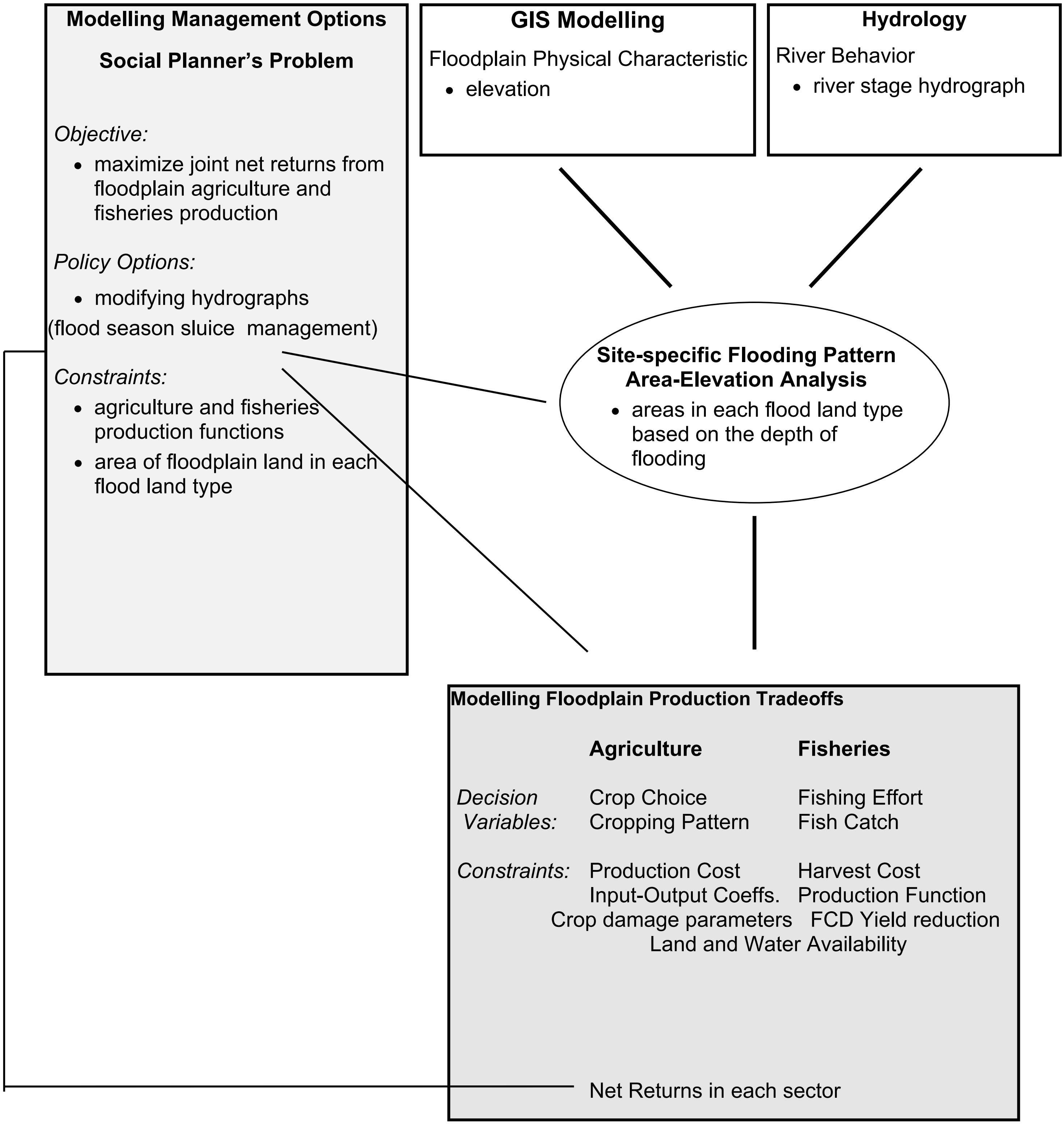
approximate plot-level damages were calculated. Linking plot-level damages to socio-economic information enabled the generation of insights on the vulnerability of poorer households to early flood risk. Data on rice varieties at the plot level were analysed to estimate whether there was scope for managing early flood risk by using shorter-duration varieties.

Modifying the Floodplain Management Model (FMM) to simulate alternative flood-season sluice-gate control strategies:

The FMM, a mathematical programming model combining the agricultural and fisheries sectors in Bangladesh, had been developed in Islam (2001). This provided the basic framework for this segment of the study studying various alternative sluice settings in the early flood season. The model was extensively redesigned for this purposes of this study. Firstly, the model was re-calibrated to data from a different geographical area. Secondly, the model was modified here to examine short-term water control strategies rather than to debate the actual value of flood control structures themselves as in the original study. Thirdly, the fisheries specification was changed significantly, with basic relationships re-estimated using fresh, extensive data available from the Compartmentalization Pilot Project (CPP) (De Graaf, *et. al.*, 2000). Fourthly, important features missing from the original model, such as parameters relating to crop damage and fish yield reduction due to blockage from FCDI structures, were explicitly included.

Previous research has found that typical sluice gate operation in Bangladesh is conducted predominantly to benefit the agricultural sector, usually to the detriment of the fishery. Its eventual effect can be viewed as a process of delaying and smoothing flood hydrographs. Based on this characterisation, several alternative hydrographs representing alternative settings (closure based on various ‘target water levels’) were investigated. A particular point of interest was to examine the extent to which lost agricultural benefits were counterbalanced by gains to the fisheries sector when more ‘fish-friendly’ settings were put in place.

A schematic of the details of the FMM developed is given in the diagram below.


Modelling Management Options
Social Planner's Problem
Objective:
maximize joint net returns from floodplain agriculture and fisheries production
Policy Options:
modifying hydrographs
(flood season sluice management)
Constraints:
agriculture and fisheries production functions
area of floodplain land in each flood land type
GIS Modelling
Floodplain Physical Characteristic
elevation
Hydrology
River Behavior
river stage hydrograph
Site-specific Flooding Pattern
Area-Elevation Analysis
areas in each flood land type based on the depth of flooding
Modelling Floodplain Production Tradeoffs
Agriculture
Fisheries
Decision Variables:
Crop Choice
Cropping Pattern
Fishing Effort
Fish Catch
Constraints:
Production Cost
Input-Output Coeffs.
Crop damage parameters
Harvest Cost
Production Function
FCD Yield reduction
Land and Water Availability
Net Returns in each sector

1.4.4 Unsuccessful endeavours

Given the data limitations and the complexity of the scenarios, some modelling endeavours (that significant amounts of time were spent on), could not be successfully completed.

- Systems dynamics modelling: Early on in the project, it was recognised that systems dynamics modelling was one of the few avenues available to capture the complexity of floodplain resource use in Bangladesh. Recently, software such as SIMILE^{tm} have become available, that provide powerful diagram-based languages for designing models, including system dynamics and object-based concepts. Large-scale modelling projects such as the DfID-funded Agroforestry Modelling Environment (AME) (Muetzelfeldt and Taylor, 1997) have successfully integrated human-decision making at the micro-level in developing countries with local biophysical elements, enabling complete simulation of counterfactual situations. An effort was launched within this project to investigate if SIMILE could be fruitfully used for some of the options we wished to investigate. However, we could not proceed beyond a skeletal model because of (i) remaining critical data gaps, and (ii) the realisation that building a fully-fledged model would take resources (particularly time) far beyond what was available to us.

- Social Accounting Matrix (SAM): A SAM is a village-level accounting system that connects various economic activities in the form of input-output tables. With the inter-relationships thus captured, it is possible to analyse the effects of exogenous shifts (say, a change in rice price) upon the entire village. This project originally had a plan of decomposing meso-level modelling simulations into village-level effects by employing a SAM based on data from R7868 (Charan beel). However, once again the approach had to be abandoned after a start was made, since the data proved significantly short of what was originally expected. R7868 collected several streams of data, but the socio-economic data were mostly of a qualitative nature, of limited use in such modelling.

1.5 Outputs

1.5.1 Reflections on achievement of intended outputs

The project logframe described a single intended output:

A set of recommendations and guidelines for future action research in Bangladeshi floodplains. The guidelines will be based upon an evaluation of alternate technical (management) strategies in terms of economic (returns/wealth) criteria, livelihood effects, and institutional constraints to implementation.

This anticipated output has been largely achieved, although the modes of evaluation of alternative management strategies have differed from case-to-case. The evaluation criteria have inevitably been determined by the kinds of data available to us, the nature of the specific management strategy, and the nature of the models available for us to build upon. For instance, in the GIS modelling of early flood risk mitigation at the micro-level (chapter 6), the availability of plot level socio-economic information in addition to biophysical parameters such as plot elevation enable us to make a direct connection with household-level vulnerability to early floods. The simulation of flood-season sluice-gate control strategies is however, a regional problem, and an entire affected area of 14,301 ha is modelled using a regional programming model. No appropriate household level information could be located in this area. In addition, socio-economic variability at the micro-level is so large that it became gradually apparent to us that any attempts to link regional parameter changes to information from a particular village or community was unlikely to have any merit at all[8]. The evaluation has thus been *ad-hoc* from strategy to strategy.

On reflection, it is also realised that the originally intended goal of 'providing guidelines to action researchers' was considerably naïve. 'Guidelines' implies a standard document that can be used in field activity and replicated across space in a reasonably routine fashion. The evaluations in research projects such as ours are typically based on data pertaining to a single region. Spatial/temporal variations in both biophysical and socio-economic parameters across Bangladeshi floodplains are so large that only the broadest results can be reasonably expected to carry over to other regions[9]. Therefore, we have reinterpreted 'guidelines' as 'lessons learned', and have presented findings on the basis of this perspective.

Given the constraints with respect to data and personnel (detailed in section 4), it is felt that the project has successfully achieved its broad goals, especially in light of the enthusiasm with which the results have been received during dissemination. Certainly it can be said that no stone has been left unturned during the modelling process, even if some methodologies did not succeed eventually.

1.5.2 Research results

Research result summaries are presented option by option, and the narrative relies on bullet-point lists and graphs/tables to facilitate easy absorption. Detailed research reports for each modelled option are in chapters 2-7.

<u>Closed seasons (chapter 3)</u>

- In contrast to an earlier study, our simulations have indicated substantial gains to be reaped from effort control regimes in the floodplains of Bangladesh. In the case of closed seasons, estimated gains range from 25% to 138% annual yield increases, depending on the timing and length of closures. Increased recruitment is key to benefits provided by effort control.

- Longer closures provide increased benefits, but the simulation results indicate that the marginal benefits to increased closure length tapers off rapidly. In light of this, and given the fact that management difficulties are likely to increase rapidly while participant enthusiasm drops off as closure length increases, closures longer than two to three months do not appear to be attractive.

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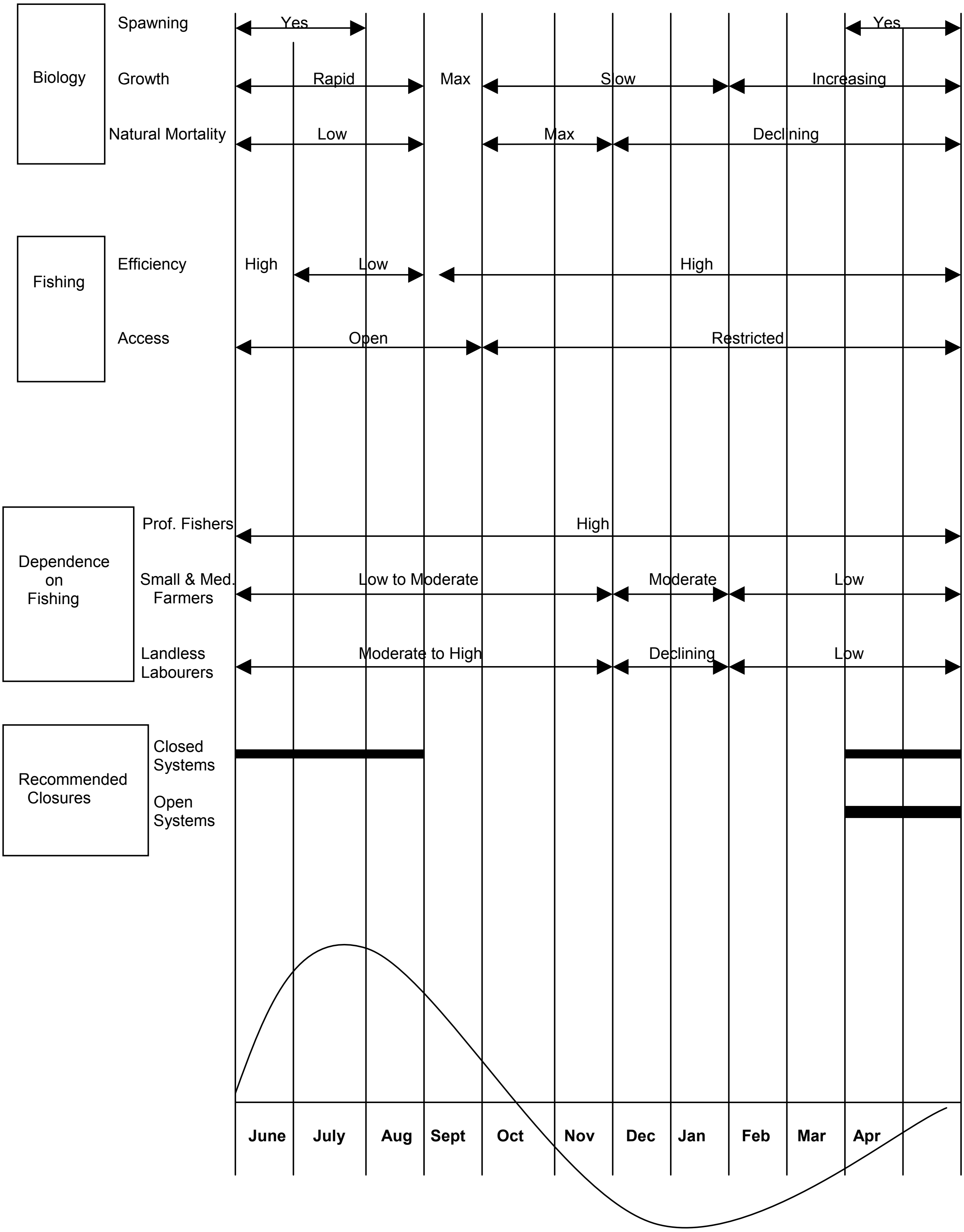
[8] Although, this conclusion was arrived at only after exploration of several possible ways of enabling such a link. Two of these are described in section 4.4 above.

[9] This problem has also been faced by other research projects in Bangladesh. For instance, the socio-economic component of FAP17 (the Fisheries FAP) aimed to study the effects of flood control by comparing pairs of villages inside and outside flood control schemes that had similar geophysical characteristics. However, even where geophysical characteristics were the same, the effects of flood control on floodplain livelihoods could not be isolated because of randomly varying patterns of access at the village level. Therefore, the comparisons had to be abandoned (FAP17, 1994).

- Several closed season combinations are found to provide significant benefits. However, the optimal timing for instituting closed seasons has to carefully balance biological parameters with the livelihood constraints of various floodplain resident categories. A pictorial encapsulation is given below.

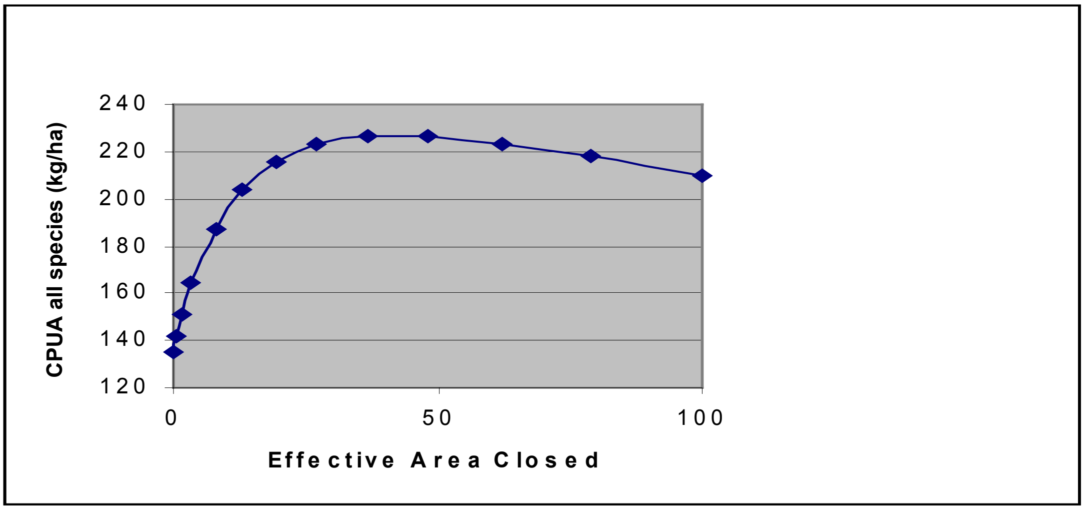


- In the PIRDP area, peak season fishing is inefficient, but is very important to a range of floodplain household groups, including the relatively poor F2 (fishing as predominant source of income) fishing households and the landless labourers. During drawdown, fishing is efficient and continues to be an important part of the livelihood portfolios of most groups. Additionally, fishing is complementary to the winter rice planting activity at this time. In the early dry season, access to most household groups is restricted, and much of the catch is taken by landowners draining pits on their land. In the late dry-season, fishing involvement for most household groups except professional fishers is negligible. This is the spawning period for floodplain fish, and simulations indicate that the bulk of improved catches arising from effort control in this period would flow in the flood season period when there is the greatest want. A closed season during this period, possibly accompanied by kua draining restrictions in previous months, could form an effective basis for an effort control regime. In closed waterbodies, additional closure in the early flood season would provide additional benefits in yield-per-recruit.

Closed areas (chapter 3)

- Closed areas are an alternative way of instituting an effort control regime, with the advantage of being more easily visible and understandable, and therefore enforcible. Year-round reserves may not serve much of a purpose in Bangladesh since there is a need to allow the fishery to be exploited as much as possible in the interest of fishing-dependent livelihoods, and also because most floodplain species are adapted to survive very high levels of mortality.

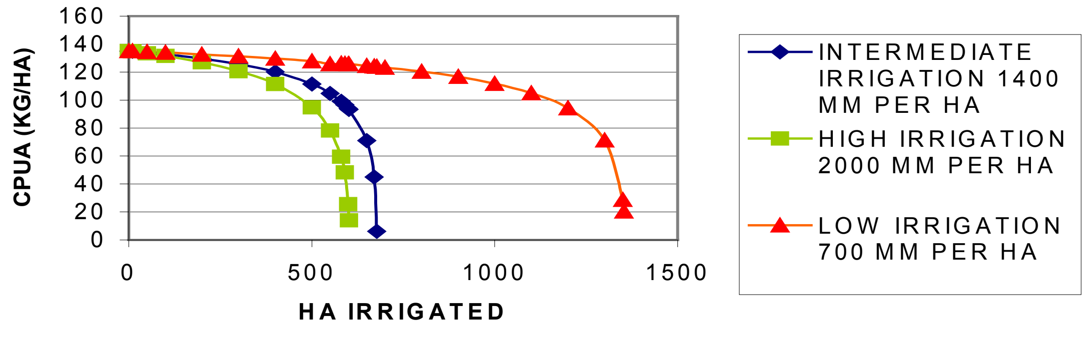
- Dry-season reserves have been suggested by previous study, but optimal closure size is a key unknown, and the simulations for the PIRDP in this study (see diagram below) suggest that most benefits peter out after about 25% reservation of area, attaining a maximum with a closure between 30 and 40%. Even an area closure amounting 10 to 15% of deeper beel and river section areas would provide significant benefits within two to three years of reserve establishment. Apart from the professional fishers who would lease such areas, reserves would also imply restrictions on the drainage of plots by farmers to free up more land for *Boro*.



Limiting dry-season water abstraction for irrigation (chapter 4)

- A typical dry-season rice crop will need in excess of 1000 mm per ha of water. A single low lift pump abstracting irrigation water can remove upwards of 140,000 cubic metres of water from a single *beel* or pond in a single season.
- With dry-season water maintenance being key to the health of the fishery, continued abstraction poses a major threat to fishing-dependent floodplain livelihoods. This has never been quantified, however.
- Our simulation of the effects of abstraction on fish yields in the PIRDP can be seen in the diagram below, based on three different, typical irrigation schedules in Bangladesh, ‘low’, ‘intermediate’ and ‘high’.
- Focusing on the ‘intermediate schedule’, it is apparent that abstraction effects on the fishery can be dramatic. There is a threshold beyond which further abstraction results in rapid yield loss for given levels of effort.
- For the 6776 ha floodplain area that we model, abstraction to irrigate more than 500 ha of winter rice results in rapid fish yield loss, with a complete failure of recruitment and collapse of the fishery occurring after about 600 ha (see below).

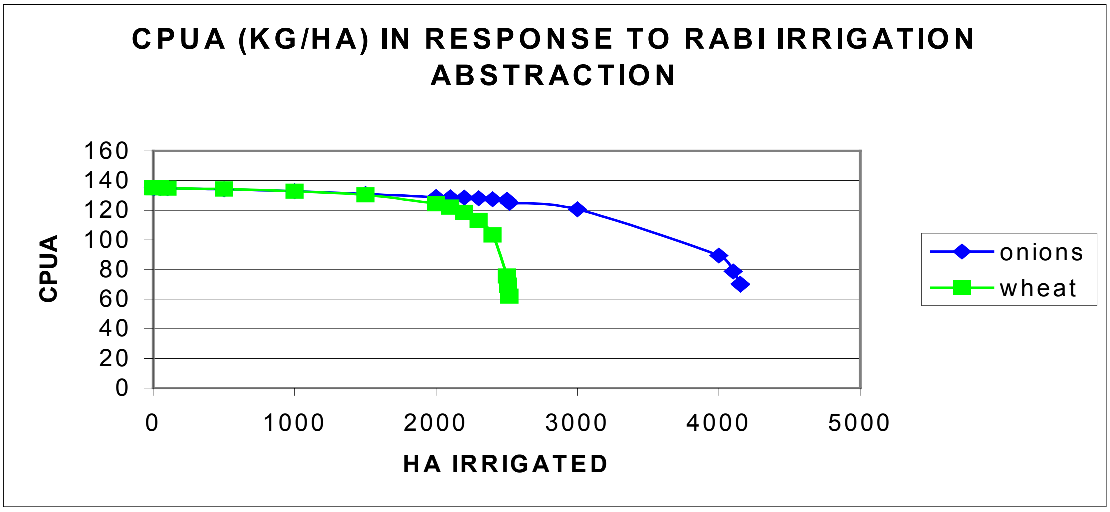
FIGURE XXX: CPUA (KG/HA) IN RESPONSE TO BORO IRRIGATION ABSTRACTION



- Regression estimation of the catch – abstraction relationship shows a loss of 0.03 kg of fish per hectare for every hectare irrigated. For the 6776 ha area modelled, this amounts to a loss of 203 kg of fish for every hectare irrigated by abstraction.

- Although water-saving management practices are certainly possible in some situations, the general problem is characterised by the extent of boro rice itself, rather than the amount of water applied to the crop. Thus diversification out of the winter rice is probably the most viable long-term strategy. Significant proportions of even higher elevation plots are often given over to boro. This is an undesirable trend since irrigation requirement and the comparative disadvantage of rice compared to alternate rabi crops increases with elevation.

- Similar simulations of the catch-abstraction relationships were generated for two alternative crops found in PIRDP, wheat and onion, results seen below.



- Due to the lower water requirement, alternative rabi crops are seen to have a far gentler effect on the fishery. Regression analysis shows that irrigation of wheat and onion in the PIRDP has only a sixth and a tenth, respectively, of the effect of boro on the fishery.

- Static analysis of the profitability and labour requirements of alternative crop cycles enabled by building crop budgets shows that diversified patterns can compete well with boro-based systems, even in medium and medium-low elevation land. Returns as well as labour use are higher. Win-win situations for the agricultural and fisheries sectors are thus possible, but will likely require a concerted effort towards rolling back the ‘borocentrification’ of the floodplain economy to whatever extent possible. Inclusion of a programme of rabi diversification adapted to local circumstances within action research strategies is recommended. Such diversification is feasible and desirable not only for high elevation plots, but also for medium and medium-low plots.

Dry season water retention (chapter 5)

- Results show that significant gains can be reaped from maintaining higher dry season water levels on the floodplain, with the resultant tradeoff with the agricultural sector being quite marginal. Results are summarised in the table below.

Changes in key variables in response to increased water retention

	Baseline +0.25 m	Baseline +0.5 m
Extra fish yield (tonnes)	85.6	175.7
Lost rice land (ha)	8	16
Value of extra fish	3680800	7555100
Value of lost land	109936	219872
Net extra returns	3570864	7335228
Increase in fish value / Loss in agricultural value	33.4	34.3

- A 0.25 metre increase in water height at the sluice gate, seen to result in 85 tonnes of additional fish catch in the region, results in a sacrifice of only 8 hectares of land devoted to winter rice out of approximately 6674 at the baseline. If the dry season sluice gate water levels are increased by an average of 0.5 metres, the additional 175 tonnes of fish catch will come at the cost of only about 16 hectares of rice production.

- The additional value of fish production created by water retention arising from a 0.25 m water height increase is equal to approximately 3.6 million taka, while the cost (foregone revenue from rice production) is only about 109,000 taka. Thus there is a net value increase in excess of 3.5 million taka for the 6773 hectares area modelled. Increased returns to the fishery outstrip decreased agricultural revenue by a factor of 30. This proportion roughly holds for even higher water retention.

- The results confirm speculations of previous research that dry season water retention could be a low-cost means to achieving improved fish yields for the landless and professional fishers as well as the opportunistic fishers on the floodplain. The tradeoff with agriculture being marginal, this can be accomplished without requiring large-scale sacrifices from particular sections of the population.

Early-onset flooding and the role of short duration varieties (chapter 6)

- Analysis of data from Charan beel area shows low and very low elevation plots are almost exclusively given over to two cropping patterns – fallow/fallow/boro and fallow/fallow/mustard in the kharif1/kharif2/rabi seasons. The risk with these patterns on the lower-lying land classes, which are the first to be flooded, is that if an early onset of flooding occurs prior to the boro harvest, crop damage results.

- GIS modelling shows that 45% of ‘very low’ (VL) plots suffer some form of damage if the flood arrives even one week early. A two-week early flood also damages a significant number of ‘low’ (L) plots. When early flood damage does occur, it tends to be substantial, almost wiping out the crop (table below).

Crop damage estimates by land elevation

Very Low Land Crop Damage: % of Plots in Damage Categories					
	No damage	**20% to 40%**	**40% to 60%**	**60% to 80%**	**80% or higher**
Baseline Flooding	100%	0%	0%	0%	0%
1 Week Early	55%	0%	5%	0%	40%
2 Weeks Early	50%	0%	0%	0%	50%

Low Land Crop Damage: % of Plots in Damage Categories					
	No damage	**20% to 40%**	**40% to 60%**	**60% to 80%**	**80% or higher**
Baseline Flooding	100%	0%	0%	0%	0%
1 Week Early	92%	3%	0%	0%	5%
2 Weeks Early	61%	3%	11%	0%	26%

- Damage to VL occurs almost exclusively to plots following the fallow /mustard /boro pattern. Farmers squeeze in this extra mustard crop after flood drawdown in order to pay for expensive inputs going into the boro crop. This delays the planting, and eventually, harvest of boro, exposing the crop to early-onset flood risk.

- Analysis of the elevation-wise operation of land by household socio-economic category reveals that poorer households are more likely to have higher proportions of VL and L lands in their portfolios. The poorer households at Charan are also therefore more exposed to early flood risk – *i.e.,* there appears to be evidence of a ‘double burden’. With floodplain livelihoods for landed and landless alike centred around the Boro crop, early-onset risk constitutes a very significant impediment to livelihood security.

- Structural solutions to early-onset flooding, such as submersible embankments are unlikely to work for this region. This is because most of the early flooding in this area is from impounded rainfall rather than river flooding.

- A potential solution exists in ‘squeezing’ the crop calendar at some point during the year so that the boro crop can be harvested a week or two earlier. Analysis of varietal information from the area reveals that there is little scope for accomplishing this with the mustard crop, since alternative varieties to the *tori-7* varieties currently popular in Northcentral Bangladesh are all of longer duration. However, analysis of varietal composition by land-type in Charan shows that there is indeed scope for mitigating early flood risk by promoting short-duration boro varieties. Three varieties are currently predominant in the area: IR8, BR16 and BR11. These are older generation, longer-duration varieties. A new generation of short-duration varieties such as BR26, BR28 and BR29 are available that could enable harvests early enough to minimise early flood risk.

<u>Early flood season sluice management (chapter 7)</u>

- A suite of 11 different models was studied. One was a base model, representing a natural floodplain with no flood control structure. The next set (models 1a to 1e in table below) assumed a FCD structure with the sluice manager first opening sluice gates on <u>May 15</u>, and keeping them open until a target water level of a) 10.50m b)10.75m c) 11.00 m d) 11.25m e) 11.50m was reached, upon which gates were closed again. The final set (models 2a to 2e) specified first opening of gates on <u>May 31</u>, with the same set of target water levels as described before. These specifications very roughly capture a range of options that may be implemented by sluice managers in the early flood season. Earlier initiation of opening (May 15 instead of May 31) and longer openings after initiation (*i.e.*, higher target water levels) are expected to benefit the fisheries sector at the cost of the agricultural sector. Summary results are shown in the table below.

Model	Mean		
Scenario	Agriculture Returns	Fisheries Returns	Total Returns
	(Taka)		
Base Model (natural)	367,112,490	340,028,728	707,141,219
Model 1a (May 15, 10.50)	421,306,953	198,711,364	620,018,317
Model 1b (May 15, 10.75)	405,654,305	208,038,291	613,692,596
Model 1c (May 15, 11.00)	387,778,293	217,109,967	604,888,260
Model 1d (May 15, 11.25)	379,112,070	220,907,544	600,019,614
Model 1e (May 15, 11.50)	370,588,258	224,166,352	594,754,610
Model 2a (May 31, 10.50)	421,832,751	198,711,364	620,544,115
Model 2b (May 31, 10.75)	406,180,103	208,038,291	614,218,394
Model 2c (May 31, 11.00)	388,304,092	217,109,967	605,414,058
Model 2d (May 31, 11.25)	379,637,868	220,907,544	600,545,412
Model 2e (May 31, 11.50)	371,114,056	224,166,352	595,280,408

- Firstly, the natural floodplain is seen to provide larger returns than any result achieved by manipulation of sluice gates.

- As expected, agricultural returns decrease with longer openings (higher target water levels) while fisheries returns decrease, given a certain date of initiation of opening.

- Our results show that in all cases, improved agricultural returns from longer closures do make up for lost fisheries returns.

- The data of initial opening (May 15 or May 31) does not appear to make a significant difference to either sector.

- However, the previous two points have to be qualified in light of two weaknesses in our model: (a) we have not been able to include a measure of the extent of fish migration through sluice openings. Thus all our ‘fish production’ modelling is on the basis of creation of habitat (flooded depth and area). This is likely to result in an underestimation of benefits to the fisheries sector due to longer sluice openings. (b) Fishing costs are notoriously difficult to capture in quantitative estimates. Our approach of using fixed wage rates may overstate the opportunity cost of fishing, and therefore understate the benefits.

- Most importantly, although increased agricultural benefits from more stringent closures are estimated to more than make up for lost fisheries benefits, the increased net returns estimated for longer closures are not large. It is possible that correction of the above weaknesses will result in the two effects balancing out, or even in fisheries losses from more closure exceeding agricultural gains.

- At the very least, there seems to be a clear case for keeping gates open for as long as possible in May. The agricultural sector (which is modelled more precisely) is not seen to be affected significantly by keeping the gates open longer in May. This is consistent with qualitative observations from previous research that sluice closures in this period are done at the behest of a small number of influential landowners operating *Boro* plots in very low lying areas and beels. Longer openings at this time would assist the in-migration of fish fry and fingerlings, providing improved catches for a large number of households dependent on fishing during the flood season.

1.6 Contribution of outputs

The insights generated on each specific management strategy investigated are of value in themselves. However, the whole is greater than the sum of the parts. Interestingly, when the results are considered from a broad perspective, it emerges that there is a specific, narrowly-defined key to the amelioration of most of the problems discussed in this research. *The management of dry season rice production in low and very low lands* provides a basis around which a programme of integrated floodplain action research could be built. As is well known, the organisation of floodplain production in Bangladesh is very complex, with the natural resource base as well as the condition of dependent livelihoods varying seasonally and spatially, with a series of linkages implying that changes to one part of the system have knock-on effects elsewhere. In this complex chain of causality, however, our results indicate that a management strategy built around the specific aspect above has the ability to help solve a variety of problems, precisely because of these causal linkages. We elaborate below.

Our results show that the problem of *Boro* crop damage from early flood risk is severe only in low and very low lands. This is because late drainage from these plots during drawdown, and the economic pressure to squeeze in an extra cash crop prior to *Boro* cultivation results in late planting, and consequently late harvesting in mid to late May instead of early to mid-May. If the *Boro* crop could come off these plots two weeks earlier (in our study site, this could be accomplished by using the newer generation of varieties), this problem would be solved. However, the widespread practice of keeping sluice gates closed throughout May benefits precisely these unharvested low and very low *Boro* plots. This is seen in our results on flood season sluice management, and has also been reported in earlier studies on the basis of qualitative observations. If these plots were harvested earlier in May, the pressure on sluice managers to keep gates would be correspondingly lower. Sluice openings in May would allow in-migration of fry and fingerlings, providing benefits to much of the fishing-dependent population.

Actually ‘retiring’ lowest lying plots from winter *Boro* production altogether would help solve another set of problems, in addition to the above. The very lowest land thus freed up could be used for higher dry season water retention. Our results indicate that even small amounts of land used in this way could result in a significant enhancement to fishing productivity. The pressure on water abstraction would also be reduced, shown to be a significant impediment to productivity of the fishery in this study. If even 20 to 30% of this additionally created and pre-existing areas under water in the dry season could also be designated as harvest reserves, further productivity increases can be reaped.

The major contribution of this project has been to provide an increased awareness of this key aspect to the future management of floodplains, in addition to the specifics of each individual management strategy as detailed elsewhere. When considered in tandem with results from the recent NRSP project on consensus building among floodplain stakeholders, it provides a link between understanding and implementation in future action research. A quantified understanding has been provided of some aspects of the planning problem previously appreciated only qualitatively. Action research can therefore proceed on the basis of some notion of anticipated benefits and tradeoffs, instead of trial-and-error in the field.

The fishery is accorded a particularly important role in this project. This is natural, since in the land-water and the agriculture-fisheries interfaces, it is water and fisheries, respectively, that have been left out under traditional development planning. Thus the most obvious groups to eventually benefit most from this research are the professional and semi-professional fishers. However, a range of other poor floodplain dwellers also have a significant stake in this fishery, ranging from the landless agricultural labourers to the small and medium farmers. Even if their primary sources of annual income derive from other sources, they are dependent on the fishery during the lean flood season when few agricultural opportunities are available. It is thus anticipated that the results reported here can eventually benefit this entire spectrum of the floodplain poor. Thus the outputs are completely consistent with NRSP-LWI's overall goal of 'Improving livelihoods of poor people through sustainably enhanced production and productivity of RNR systems'.

Obviously, 'retirement' of land is easier said than done, especially in a land-scarce, poverty-stricken area where large imbalances in social power have resulted in a trend proceeding the opposite way, *i.e.,* drying-up and occupation of low land. However, Bangladesh has a strong track record in NGO activity, and local action researchers have been successful in mediating solutions between polarised groups in the past. Hearteningly, those influential in policy circles also appear to be increasingly receptive to messages emanating from multisectoral studies such as ours. While wrapping up our final dissemination seminar in Dhaka, the discussant Dr. Nishat, country representative for IUCN, opined that our results provided further evidence for, and resonated with, his view that reservation of lowest-lying land for fisheries should become a cornerstone of floodplain policy in Bangladesh. He is planning to take this up in forthcoming policy meetings. The project's research has also received an enthusiastic reception from some others in policy positions. For example, Dr. Mokammel Hussain, Deputy Director of Planning at the Department of Fisheries, is now in charge of a significant floodplain fisheries portfolio. He has welcomed the quantitative counterfactual simulations provided by the project, since most available information is either empirical observation or qualitative evidence, and has requested that a copy of complete final results be sent to him directly. Towards the end of this project, we also started receiving requests for copies of detailed research results. These have come so far from the Fourth Fisheries Project, NEFISCO/Dutch Embassy, and Winrock-Bangladesh. The other main actors that the outputs of this project are targeted at, the various NGOs working on floodplain development in Bangladesh, have been provided overviews of the project activities via three dissemination seminars.

Dissemination was undertaken in the following ways:

(i) A feedback session at Dhaka in December 2001 brought together a small (8) group of key GO and NGO officials. The objective of this session was to provide an initial set of results and obtain feedback that could be used to further improve the modelling in its final stages.
(ii) A large final dissemination seminar was held in Dhaka in May 2002. This was attended by 22 participants from a wide cross-section of GOs, NGOs and international donor organisations.
(iii) Some project results were also presented recently (July 2002) at the IUCN wetlands conference in Dhaka. More than 50 members of our target audience were reached this way.
(iv) Early on in the project, the project leader visited a number of GOs, NGOs and international organisations to appraise them of the activities and objectives of the project. At that time, these organisations were requested to indicate whether they wished to receive briefing papers after project completion. All those who expressed interest will be sent briefing papers within a week or two of submission of this report.
(v) A website has been set up for the project.

1.7 Publications and other communication materials.

- Journal articles (in preparation for submission):

a) B. Shankar, A. Halls and J. Barr, '*Quantifying the tradeoff between irrigated rice and inland fisheries production in the floodplains of Bangladesh'* (submitted to *International Journal of Water*)
b) B. Shankar and J. Barr, '*Non-structural management of early flood risk in floodplain rice production in Bangladesh*' (submitted to *Quarterly Journal of International Agriculture*).

- Symposium, conference and workshop papers and posters:

a) B. Shankar, A. Halls, J. Barr and M. Rahman, '*Management strategies to improve Floodplain livelihoods in Bangladesh: Some modelling results*' presented at Wetlands conference, IUCN, Bangladesh, July 2002 (to appear in edited conference volume).
b) A. Halls, B. Shankar and J. Barr, '*Fish out of water: Modelling tradeoffs between Agriculture and fisheries in the floodplains of Bangladesh',* abstract submitted to LARS –2 (The Second Large River Symposium, Phnom Penh, February 2003).

- Media presentations

a) Project website: www.personal.rdg.ac.uk/~aes98bs/bangladesh.html

- Reports and data records:

a) Literature reviews: Various reviews, incorporated into detailed research results, in appendix A.

1.8 Project Logframe

Logical Framework

Narrative Summary	Measurable Indicators	Means of Verification	Important Assumptions
Goal: Improved resource-use strategies in floodplain production systems developed and promoted.	By 2002, new approaches to integrated natural resource management which explicitly benefit the poor validated in two targeted areas. By 2004, these new approaches incorporated into the strategies for the management of floodplain resources, including common pool resources, in two targeted countries.	*Reviews by Programme Manager.* Reports of research team and collaborating/target institutions. Appropriate dissemination products. Local, national and international statistical data. Data collected and collated by Programme Manager.	*Target beneficiaries adopt and use strategies.* Enabling environment exists. Budgets and programmes of target institutions are sufficient and well managed.
Purpose: Improved technical understanding and integrated management of floodplain habitats developed and promoted.	Optimal seasonal management strategies detailed for multiple-use floodplain habitats in Bangladesh	*As for NRSP LWI Logical Framework, Activity 2.3.* CNC 99/01	GOs and NGOs committed to technical solutions, & participate effectively in projects
Outputs: A set of recommendations and guidelines for future action research in Bangladeshi floodplains. The guidelines will be based upon an evaluation of alternate technical (management) strategies in terms of economic (returns/wealth) criteria, livelihood effects, and institutional constraints to implementation.	Comprehensive set of guidelines, by Nov 2001.	Summary Report, delivered by end-Dec 01, and disseminated to target institutions by same date.	*Availability of appropriate data to evaluate all strategies in requisite detail.* Target institutions are able and prepared to consider the results of research in future floodplain involvement

1.9 Keywords

Bangladesh, floodplains, agriculture, fisheries, livelihoods, multidisciplinary analysis.

1.10 Annex

Annex A, immediately following (chapters 2 to 8), contains detailed research results. Final project inventory has been submitted separately (nil entry).

References

- Barr, J. J. F. 1996. Preliminary investigtion of agricultural diversification and farmers' practices in Bangladesh floodplain production systems involving rice-fish production - a whole system approach, Project R6383 final technical report to ODA.

- Barr, J. J. F. 2000. Investigation of livelihood strategies and resource use patterns in floodplain production systems in Bangladesh. Project final technical report to DFID-NRSP.

- de Graaf, G. J., Born, B., Uddin, K.A., Marttin, F. 2001. *Floods, fish and fishermen.* Dhaka: The University Press

- de Graaf, G. J., Dhar, G.C., and Mahera, N.S,. 2000. The CPP fisheries data base, CD-ROM. FMS, Dhaka, Bangladesh

- FAP17. Final Report Executive Summary of main Volume.:

- Halls, A. S., Kirkwood, G. and Payne, A.I. 2001 *A dynamic pool model for floodplain-River fisheries*, unpublished manuscript.

- Halls, A. S. 1998. Impact of flood control schemes on river fish migrations and assemblages in Bangladesh. *Journal of Fish Biology* 53:358-380

- Heady, C. J., McGregor, J.A., and Winnett, A.B. 1995. Poverty and sustainability in the management of inland capture fisheries in south and southeast Asia, project final technical report to ODA.

- Hoggarth, D. D., Halls, A.S. 1997. Fisheries dynamics of modified floodplains in southern Asia: Project final technical report to ODA.

- Islam, M. 2001. Floodplain resource management: An economic analysis of policy issues in Bangladesh. *Ph.D. thesis,* pp. 152., Urbana-Champaign: University of Illinois

- IUCN. 1993. *Freshwater wetlands in Bangladesh: Issues and approaches for management.* Dhaka: IUCN.

- Ministry of Water Resources (2000). National Water Plan. Dhaka: Water Resources Planning Organization.

- Muetzelfeldt, R., and Taylor, J. 1997. The suitability of AME for agroforestry modelling. *Agroforestry Forum* 8:7-9

- Roy, I. 1996. Integrating FSR into the national extension system: A case of Bangladesh. Journal for Farming Systems Research-Extension, 6(2), 45-53.

- Sen, B. 1995. Rural poverty trends, 1963-64 to 1989-90. In *Rethinking rural poverty: Bangladesh as a case study*, ed. H. Z. Rahman, and Hossain, M. Dhaka: University Press Limited

- Siddiqui, M. R., Islam, M.R., Ahmed, N.U., Magor, N.P., Khan, A.H. 1994. Impact of FSR on farm families in Bangladesh. Dhaka: BRRI

- Soussan, J. 2000. Sustainable Local Water Resource Management in Bangladesh - Meeting Needs and Resolving Conflicts - Project Final Technical Report to DFID-NRSP.

- Soussan, J., and Datta, A. 1998. *Community partnership for sustainable water management. Experiences of the BWDB Systems Rehabilitation Project. Volume 1, Summary Report.* Dhaka: University Press Ltd

- Tsai, C.-F., and Youssouf Ali, M. 1997. *Openwater fisheries of Bangladesh* Dhaka: University Press Ltd

Chapter 2: Study Site and Model

2.1 The Pabna Irrigation and Rural Development Project (PIRDP) study site

Material in chapters 3 to 5 are based on a model calibrated to data for the PIRDP region. This chapter provides some background information on both the study site as well as the model.

Located to the south of the lower Atrai basin in the North West region of Bangladesh, the PIRDP is a large flood control, drainage and irrigation (FCDI) project. Almost 160 km of embankments protect an area of about 184,000 hectares from the flooding of the Atrai river to the north, the Jamuna to the east and the Padma to the south (FAP 17, 1994a). The FCDI project has proceeded in two phases, with phase 1 completed in 1992, and phase 2 commencing in 1995. Apart from providing flood control for about 440,000 floodplain dwellers, the project also provides controlled irrigation for a command area of 18,680 ha (ADB, 2001). However, with the Jamuna moving progressively westward, the PIRDP embankment has been prone to breaching in recent years, despite continued efforts to move it away from the river.

The area is in Agro-Ecological zone 12, the Low Ganges River Floodplain, and has been historically prone to deep flooding from the Jamuna and the Padma (Brammer, 1997). The soils are olive brown loams and silty clays in the higher elevations, and silty clays to clays in the lower regions. The subsurface structure of the soils is silty loam to silty clay in the higher parts and clay in the lower parts (Alam, *et. al,* 1996). The percentage distribution of different land-types in the area is as follows:

Land type	Description	Flood depth	Flooding	% of total land
F0	Highland	0 to 30 cm	Intermittent	19.4
F1	Medium high	30-90 cm	Seasonal	35.4
F2	Medium low	90-180 cm	Seasonal	16.6
F3	Low	180-360 cm	Seasonal	21.8
F4	Very low	Greater than 360 cm	Perennial	6.8

Source: UNDP/FAO

Although medium-high lands occupy the largest area, the table indicates that the extent of medium-low, low and very low lands is substantial. In accordance with its flooding status and elevation make-up, it has historically been one of the major deepwater rice areas of Bangladesh. The construction of the FCDI structure has encouraged the expansion of winter rice cultivation in the area. Providing impetus for the replacement of Broadcast *aman* by higher yielding, HYV transplanted *aman* is an important objective of most flood control projects. However, in the case of the PIRDP, flood control has also been used to control the rate of water increase to protect the deep water *aman* crop (FAP17b, 1994).

In the first stage of embankment construction, the effect of the FCDI structure on the once thriving fishery inside was not given adequate attention. A feasibility study carried out in 1991 prior to the second phase, however, indicated that about 75% of the potential catches from secondary rivers, floodplains and *beels* inside the PIRDP had been lost between 1984 and 1990 (FAP17b, 1994).

In 1995, DfID-FMSP commenced a project, ‘Fisheries dynamics of modified floodplains in southern Asia’, in a section of the PIRDP, with two primary objectives: (a) To understand the implications of migration, reproduction and dry-season survival strategies of river fish on the management of inland capture fisheries, and (b) To understand the impacts of flood control measures on fish production potential of hydrologically modified floodplain sites (Hoggarth and Halls, 1997). The project was based in the south-west corner of the PIRDP scheme, at the confluence of the Jamuna and the Padma (figure 2.1). The site was divided into 3 sections, ‘outside’ (the embankment), ‘inside’ and ‘adjacent’, with data collected from all sections, but analysis built around the ‘inside’ and ‘outside’ sections in order to capture the effects of hydrological modification. Detailed biological data were collected using catch/effort, length frequency and mark-recapture surveys, as well as data on morphological details of local dry-season water bodies and hydrological parameters such as sluice gate management practices.

Based upon data collected in the project, a dynamic-pool fisheries model was developed as described by Halls (2001). The **F**lood**p**lain **f**isheries **model** (FPFMODEL) is built around the detailed population dynamics of a single species, *Puntius Sophore* (Puti), which accounted for approximately 17% of the annual catch recorded at PIRDP project study site in the1995-96 split year. A hydrological module within the model connects the weekly water heights observed at sluice gates with the area and volume of water on the floodplain, which in turn has an iterative interaction with the fish population. This allows the model user to observe the simulated outcomes of (a) hydrological manipulations that alter weekly water heights, *e.g,* sluice-gate management, (b) manipulations that alter the area and volume of water upon the floodplain, and (c) direct manipulation of factors affecting fishing mortality rates, for example closed seasons and areas. The simulation modelling in chapters 3-5 is based upon various such manipulations of the FPFMODEL. A brief outline of the assumptions and technical details of the model is presented in pages 5 and 6. For further details, the reader is referred to Halls *et. al.* (2001).

No socioeconomic data were collected within the ‘Fisheries dynamics…’ study. Thus no means are available to us to directly connect the outputs from the FPFMODEL simulations with household level livelihood profiles. However, FAP17 did conduct a socio-economic study in an ‘agricultural village’ (Boalia), and a ‘satellite fishing village’ (Ahmedpur). These villages are located around the Gandahasti beel complex, fed by the Badai, a distributary of the Ganges. The beel and the villages are adjacent to, but technically not in the ‘inside’ region of the ‘Fisheries Dynamics…’ study and the area modelled in the FPFMODEL, as can be seen in figure 2.1.

These FAP 17 socio-economic data from Boalia and Ahmedpur are used in chapters 3 to 5 to complement the biophysical simulations. The following points need to be noted in this regard:

(i) The biophysical parameters used in the modelling here are strongly site-specific, as is inevitably the case in the floodplains of Bangladesh. Floodplain fish populations are strongly influenced by the areas and volumes of water available on the floodplain. Even in neighbouring areas, water availability can differ significantly due to differences in local geographical features. Thus although Boalia and Ahmedpur, the FAP 17 villages with available socio-economic data, are close to the ‘Fisheries dynamics…’ site, the presence of the extensive Gandahasti beel complex in the vicinity of the former is one of several factors limiting the transferability of the biophysical results.

(ii) Just as biophysical elements differ by sites, the human elements of the fishery, which are adapted to the specific biophysical elements, also differ.

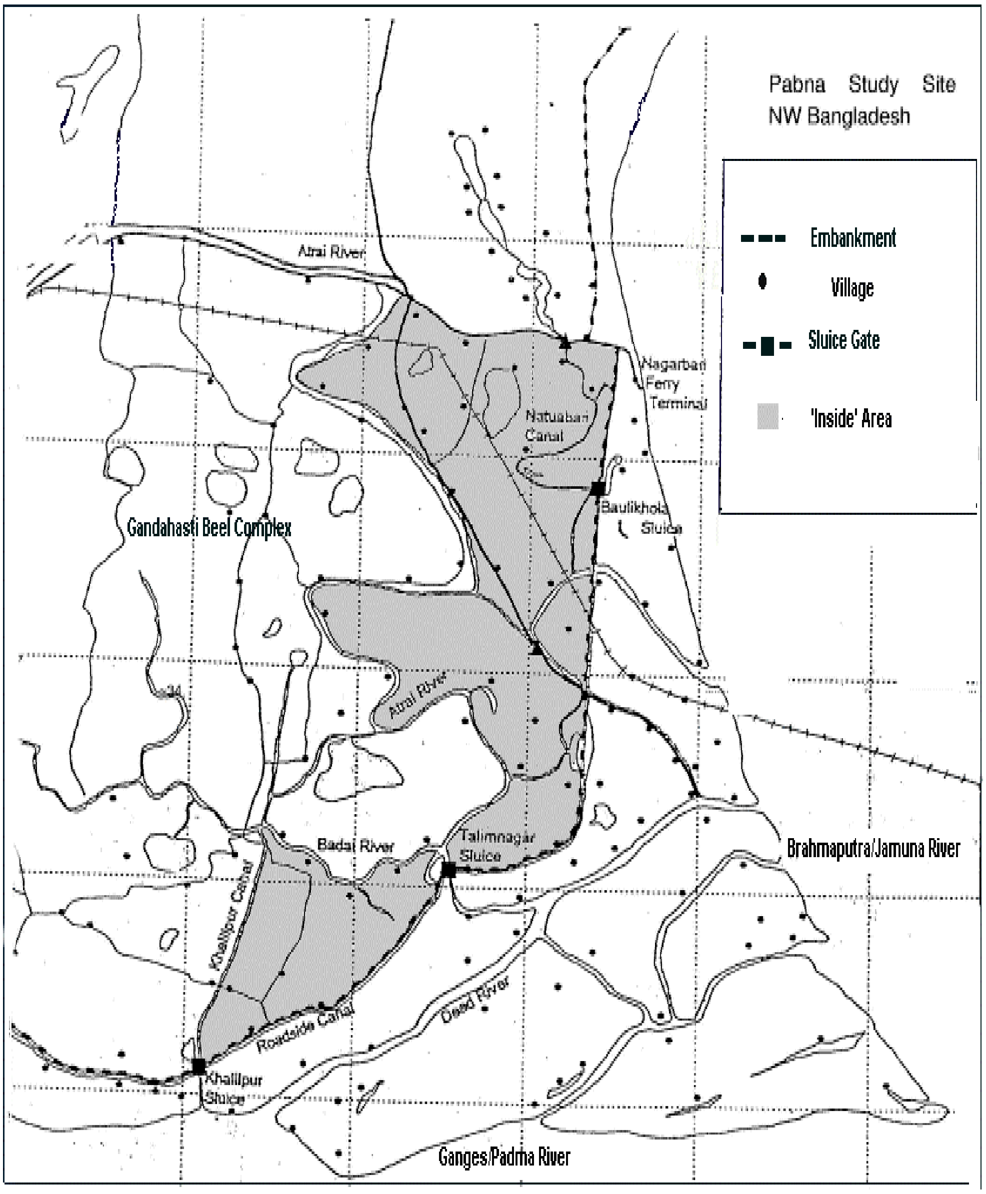
Fishing effort and gear usage in an area with an extensive beel network would be different from an area with a different waterbody makeup.

(iii) The data used to calibrate the FPFMODEL are for the hydrological year 1995-96, while FAP 17's socioeconomic data were collected in 1993. Temporal variations are as significant as spatial variations in floodplain fisheries. Riverine flooding and local precipitation are greatly variable across years in Bangladesh, resulting in significant differences in areas and volumes of water across years.

(iv) The sampling strategies were also very different. The 'Fisheries dynamics…' study adopted respondent-based sampling, with social-stratification not being an important element. FAP 17's socioeconomic stratification was on the basis of land-holding (poverty) classes.

Due to these data limitations, this study does not attempt to *directly* connect biophysical simulations with socioeconomic information in the sense of also producing simulations of socioeconomic outcomes at the household level. Instead, the socioeconomic data are used to provide context to and evaluate the biophysical simulations.

Figure 2.1: Map of PIRDP study site



2.2 The Floodplain Fisheries Model (FPFMODEL)

The floodplain Fisheries Model (FPFMODEL) was developed from the work of Welcomme & Hagborg (1977), and, as described above, was formulated to explore the simultaneous effects of hydrology and management interventions on yield-related fisheries outcomes.

As in Welcomme and Hagborg's model, the FPFMODEL describes the dynamics of a single species or a group of species sharing common characteristics. Growth rates, natural mortality rates and recruitment are modelled as density-dependent, driven by dynamic hydrological conditions, but the model takes no account of potential species interactions.

The model is based upon the same weekly iterative interaction of water height (and therefore the area and volume of water upon the floodplain) and exploitation, with a fish population (Figure 2.2). The main differences between the two models concerns the specification of the sub-models describing growth, recruitment and mortality. These are based upon more conventional models than those used by Welcomme & Hagborg and exploit new insights into the dynamics of floodplain fish populations gained during the last two decades. The effects of these differences on the model predictions are described in Halls (2001).

Figure 2.2: Schematic representation of the FPFMODEL

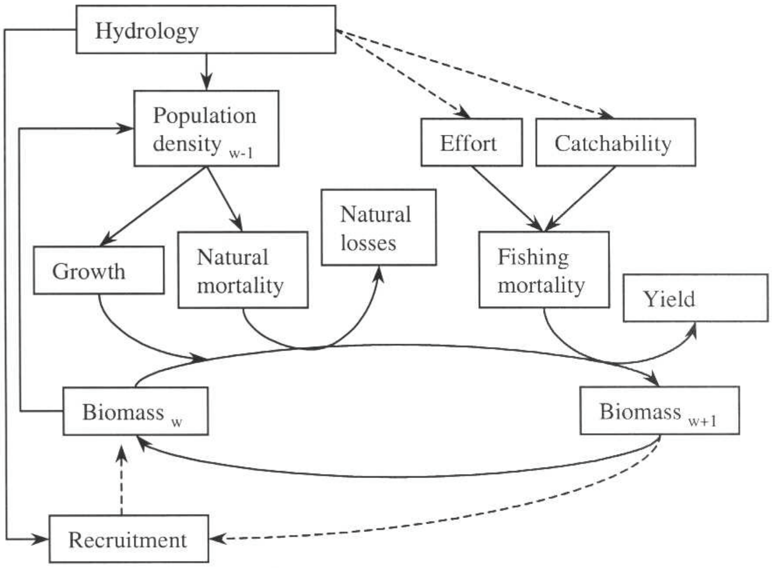


Figure 2.2 (adapted from Welcomme and Hagborg, 1977) shows the process by which the biomass in week w becomes the biomass in the following week w+1 in the model. The weekly process is repeated for the 52 weeks of the year, after which recruitment is added in week 52. The process is then repeated iteratively over several years until equilibrium is reached. Solid lines indicate direct influences or operations and broken lines indicate indirect or occasional operations.

The strength of the model lies in its simplicity, generality and flexibility. It may, for example, be easily modified to include other species (without interaction), analogous the BEAM4 model (see below). The population and hydrological model algorithms, and parameter estimation details are fully described in Halls (2001).

Other extensions to the basic dynamic pool model include the BEAM4 model of Sparre & Willman (1992), used by the 'Poverty…' study. The predictions generated from this study are not, however, easily comparable with those generated for the PIRDP using the FPFMODEL for a number of reasons. This is further discussed in chapter 3.

2.3 References

- ADB, 2001. Technical assistance to Bangladesh for preparing the Jamuna-Meghna river erosion mitigation program. Manila: Asian Development Bank.

- FAP17. 1994. Supporting volume 13. Village study: Pabna Irrigation and rural development project.

- FAP17. 1995. Final Report, Main Volume.

- Halls, A. S., Kirkwood, G. and Payne, A.I. *A dynamic pool model for floodplain-River fisheries*, unpublished manuscript.

- Hoggarth, D. D., Halls, A.S. 1997. Fisheries dynamics of modified floodplains in southern Asia: Project final technical report submitted to ODA.

- Sparre, P. and Willmann, R. 1991. Software for bio-economic analysis of fisheries: BEAM 4: Analytical bioeconomic simulation of space structured multispecies and multifleet fisheries. *FAO fisheries technical paper* 310.3, Rome: FAO, 229 pp.

- Welcomme, R. L., and Hagborg, D. 1977. Towards a model of a floodplain fish population and its fishery. *Env.Biol.Fish.* 2:7-24

Chapter 3: Closed seasons and closed areas

3.1 Introduction

In this section, we investigate the implementation of closed seasons and closed areas (harvest reserves), using the FPFMODEL. We start with a popular diagram that illustrates various fisheries management objectives. Although the diagram is oversimplistic, particularly given the complex multi-species, multi-gear, seasonal fishery under consideration, it serves the purpose of illustrating the basic objectives and tradeoffs. Subsequently, we review the limited literature on effort control in Bangladeshi floodplain fisheries, including results from prior modelling exercises as well as field-level implementations. Since some simulations of effort control have already been produced by a previous study, we discuss in some detail the contrasting features of the models underlying that study and this one. Results from our application of the FPFMODEL are then presented. This biological information is then combined with socio-economic information available from the region to speculate on how these management options might be positioned in order to socio-economically 'optimise' their effectiveness.

3.2 The simple bio(socio)economics of fishery effort control

Schaefer's (1954) 'surplus production' model is commonly used to capture the relationships between catch, stock size and effort, and to determine effort levels to achieve specific management objectives such as Maximum Sustainable Yield (MSY). Based on the premise that (i) fish biomass growth is related to stock levels in the form of an inverted U-shaped curve and (ii) stock levels are in turn negatively related with effort, Schaefer posits an inverted U-shaped relationship between biomass growth and effort. If the amount of catch in a time period is the same as the biomass growth, the catch is sustainable period after period. Schaefer's curve thus presents an inverted U-shaped relationship between (sustainable) catch and effort, and MSY is where the curve peaks.

Since fishing is an economic activity, Gordon's (1954) argument was that a rent-maximising fishery should aim to operate at a point where profit, or the difference between total revenues and total costs (labour and gear costs), is maximised. This is the point of Maximum Economic Yield (MEY), with the requisite effort being lower than in the case of MSY. This is illustrated in diagram x below, where catches are designated in value terms (the total revenue (TR) curve). MEY occurs where the total cost (TC) curve is parallel to the TR curve (or the point at which the gap between the TR and TC curves is maximised). However, where access is open, as in parts of the floodplains of Bangladesh[10], there is no incentive for rent maximisation, and effort expands until all economic surplus is exhausted (TR=TC).

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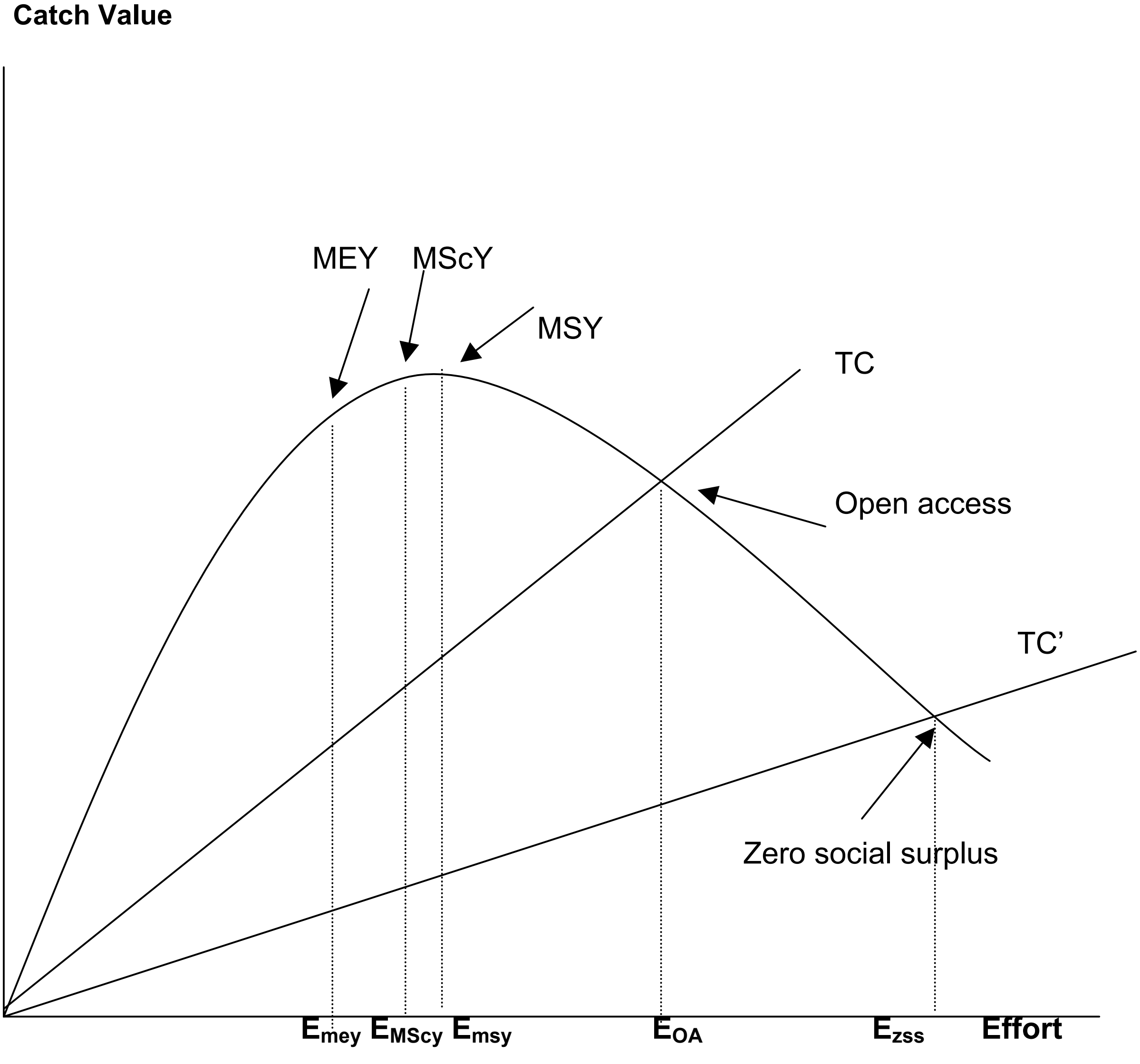
[10] This is speaking loosely, of course. Complex, locally-varying rules and customs are usually in place, even if clearly defined property rights are not. 'Open' access is usually a seasonal feature, and even that is being eroded gradually in many areas. Nevertheless, due to mobility of the fish, use of strongly interceptory gears and large fishermen densities, the incentive to catch a fish before someone else does is similar to what might prevail under a strict definition of 'open' access.

Panayotou (1982) argues that in many parts of the developing world, TC might inflate the true costs of fishing. Where few alternative sources of employment are available, fishing wages may not accurately reflect the true cost of labour. If that is the case, fishing wages should not be included in the total cost configuration, and the TC curve should be correspondingly lower, as in TC' in the diagram. In the peak flood season, before the aman harvest, opportunity costs are indeed close to zero in Bangladesh. This dichotomy between fishing wages and the opportunity costs would imply an outcome TR=TC' (zero social surplus) involving even more effort (E_{zss}) than at TR=TC (E_{OA}), when there is no effort control. Even in this situation, the point where social surplus is maximised is at the 'Maximum Socio-economic Yield' (MscY), involving effort level E_{MscY}, where the gap between TR and TC' is maximised. Even where the total cost of fishing is practically zero (gears have no alternative uses as well), this framework does not justify expansion of effort beyond $E_{MSY.}$

Figure 3.1: Relationship between effort and catch (Based on Panayotou (1982))



3.3 The arguments against effort control

(i) A counter-argument could be posed as follows: where employment creation is a critical objective, as in Bangladesh with its labour-surplus economy, ‘excess’ levels of effort then might appear to be socially justifiable. The same catches as those at E_{OA} could be taken with much less effort, indeed higher catches could be taken with less effort. However the open-access and zero-surplus solutions essentially give up a larger pie in exchange for a smaller one with more slices. The sacrifice in catches can be viewed as the cost of increased access to the fishery and better distribution of incomes[11]. Implicit in this argument is the (realistic) supposition that the state does not have the capacity to redistribute the surplus generated by effort control in an equitable way.

(ii) Even where attention is restricted to a fishery with mostly well-defined property rights, such as the leased *jalmohols*, effort restrictions could prove inequitable. Kremer (1994) discusses the *jalmohols* of the *Hail Haor* fishery, where the leases to the fishery are held by the influential rich, who sub-lease the resource to professional fishers through a system of tolls that essentially creams off all surplus beyond the reservation wage of the fishers. The broader fishery also includes labour-intensive subsistence/seasonal fishing by the poor. Effort reduction in this case, argues Kremer, would decrease labour and increase rent, with the extra rent being captured mostly by the lessees. This is because the poorer fishers cannot afford the capital outlays to upgrade to the more expensive gears necessary to take advantage of the greater productivity.

(iii) The fisheries literature also recognises that effort control via closed seasons or areas, by improving returns to fishing in *open* seasons and areas, will lead to an expansion of effort in those open seasons/areas (Beddington and Rettig, 1983). The net effect then might then be that catches are not improved significantly.

(iv) Apart from these socio-economic arguments against effort control, there is also the critical biological question of whether floodplain fisheries can even be characterised by surplus-production model such as the one above. In a multi-species, multi-gear fishery with strong seasonality, simple catch-effort depictions may be misleading. With each species having its own catch-effort relationship, the overall catch-effort relationship, which is an aggregate constructed from species-specific relationships, could be relatively flat, with declines in one fish species being counterbalanced by expansions in others that take its place in a competitive environment. Floodplain fish production is thus extraordinarily resilient to heavy exploitation (Welcomme 1977; Hoggarth, *et. al.* 1999). When this is the case, reduced effort levels may not produce significant catch increases, but will result in alterations in the species composition and value of the catch, which given the selectivity of gears, may have serious distributional implications.

With these simple arguments for and against effort control in the form of closed seasons and closed areas laid out, we now turn to the literature on these management controls in Bangladesh. Since the literature is limited but each

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[11] As Panayotou points out however, this is ignoring the fact that there are multiplier effects associated with catches. The welfare of those involved with storing and marketing fish is sacrificed as effort expands beyond MSY and total catches decline, and could well offset employment gains in the catching of fish. In Bangladesh, it is estimated that about 2 million people are thus employed in this post-harvest sector, including traders, transporters, packers, etc (IUCN, 1990).

component of the literature comprises a significant piece of research, we briefly review these in turn[12].

3.4 A review of previous literature on effort control in Bangladesh floodplain fisheries.

Poverty and sustainability in the management of inland capture fisheries in south and south-east asia (1995)

This DfID-funded research project (henceforth referred to as the 'Poverty…' study) combined multi-species biological modelling of the fishery in *Hail Haor* in Northeast Bangladesh, with extensive primary socio-economic data, to predict the impacts of a range of effort-control strategies, including several closed seasons. Importantly, data collected for biological modelling and socio-economic analysis were consistent. Within a specific area of *Hail Haor*, data on biological and socio-economic aspects were collected from the *same* sample of households. When the biological data were inputted into a simulation model and alternate management strategies simulated, the translation into effects on the incomes of individual households could be done directly and consistently[13].

The simulation model used, FAO's BEAM 4, is a multi-species, multi-gear dynamic-pool model. It is important to note for our discussion that the model operates on a yield-per-recruit basis, assuming that recruitment is constant through time irrespective of the level of fishing mortality and other factors that could otherwise effect recruitment. Any potential benefits from effort control would thus be determined only by the age at which the fish are caught. Since rapid growth occurs primarily over the flood season immediately after recruitment, the closed season combinations explored in this project were restricted to the flood and drawdown seasons.

The closed seasons explored in the study were found to have negligible effects on catches in the *Hail Haor* fishery, commensurate with the notion of a relatively flat catch-effort curve. The conclusion then was that although the fishery is inefficient (effort could be considerably reduced without affecting yields), there is no evidence of overfishing (*i.e.*, of being on the declining portion of figure 3.1 above). Closures would simply redistribute catch between gears, and in the longer run, lessees would readjust the tolls on gears to continue to extract all possible surplus. Thus the essence was that closed seasons were unlikely to have productivity effects, but could well have significant (possibly negative) distributional effects.

However, the study did note that reserves might be desirable, but '…*they are justified as an insurance against recruitment failure, rather than as a policy that will actually increase yields.*' (Heady, 1995 page 60). In sum, the conclusions of this study were that neither closed season nor areas were likely routes to increased catches and enhanced incomes for the poorer fishers using labour-intensive fishing methods in Bangladesh.

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[12] It is not our intention to provide a detailed review of the multifarious activities and outputs of these projects. Our focus in this section is only on the findings regarding closed seasons and/or areas, and key arguments central to our overview.

[13] As noted before, it is the unavailability of such completely consistent data that prevents us from extending our own simulations fully to socio-economic outcomes.

Fisheries dynamics of modified floodplains in southern Asia (1997)

The DfID-funded fisheries dynamics project described by Hoggarth & Halls (1997) was designed with the objective of collecting primary biological information relating to hydrologically modified floodplains in Bangladesh[14]. Extensive information was collected both inside and outside the Pabna Irrigation and Rural Development Project (PIRDP) flood control project (Figure 2.1). A key objective was to subject the widespread, but inadequately verified notion that flood control schemes have led to substantial declines in the floodplain fisheries of the country, to detailed scientific scrutiny.

In contrast to the 'Poverty…' study, with its focus on a single large waterbody with leased sections, the PIRDP sites consisted of a network of waterbodies, including secondary rivers, *beels*, canals and seasonally flooded floodplain areas. Only certain sections of the secondary rivers,15% of the beel area, and 10% of the canal area in this region was under leased fishing (Hoggarth and Halls, 1997).

Analysis of the data demonstrated that observed total mortality rates were very high, and that reproduction rates could be significantly enhanced by preserving stocks, especially in the deeper *beel* and river section areas, where the probability of fish survival over the dry season was highest. In other words, not only could effort control over the dry season conserve stock as a precaution against recruitment failure, but could lead to *enhanced* recruitment and thereby better catches over the rest of the year. On the basis of these findings, the study recommended dry-season effort control, either in the form of closed seasons, bans on exploitative dry-season gears such as dewatering, or closed areas in the deeper *beel* and river sections. With the various disconnected dry-season waterbodies becoming one large expanse of water in the flood season, sanctuary benefits would extend to all, including the poorer strata of society that fish seasonally on the inundated floodplains and along the margins of *beels* and rivers. Due to the seasonal interconnectedness of the waterbodies and the mobility of the fish, the project came to the conclusion that a series of small reserves, at least every 5 km or so, would provide the greatest benefits. Since the benefits are dispersed but sacrifices are localised to the reserve area, such schemes would have the best chance of success if several adjoining communities participated.

As described in chapter 2, the FPFMODEL developed during the course of this study, is a dynamic-pool model that accounts for the effects of spawning stock size on subsequent recruitment described by a compensatory stock-recruitment relationship (SRR) for the model species. The FPFMODEL is, therefore capable of estimating recruitment as well as yield-per-recruit benefits of effort control[15].

Using this model, Halls, *et.al.* (2001) simulated the annual yields resulting from a variety of closed seasons. The results indicated that exploited populations were both growth and recruitment over-fished and that even single-month closures could provide significant increases in yield, with closures in October, January and April (when observed fishing mortality was highest) resulting in the largest annual benefits. Much of the increased benefits were predicted to arise from improved recruitment rather than improved yield-per-recruit.

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[14] The project did not collect socio-economic data.

[15] In contrast to the BEAM 4 method, however, the FPFMODEL is a single-species model, originally calibrated to data for Puti (*Puntius Sopphore*), which comprises about 17% of the catch observed in the PIRDP area.

Recommendations surrounding the best time to enforce a closed season are, however, subject to the existing seasonal pattern of fishing effort. The results also suggest that a closed season towards the end of the dry season could alternatively take the form of dry season reserves.

In contrast to the conclusions of the 'Poverty…' study, this project thus found strong evidence of overfishing and great potential benefits from effort control and other interventions designed to reduce fishing mortality.

Community Based Fisheries Management (CBFM)

This initiative has proceeded in two parallel phases. The first was undertaken by the Centre for Natural Resource Studies (CNRS), Bangladesh, which carried out a series of community-management initiatives in beel and floodplain areas within Bangladesh. The focus was on habitat restoration: (i)de-siltation of canals connecting beels with rivers to improve access for migratory fish, and maintain supplies of water for irrigation and (ii) community fisheries management, including an element of effort control. Inclusion of various elements of the community in the design of management was central to the process. The premise was that, if communities could jointly and voluntarily plan and undertake management strategies, and if the management strategies were seen to produce sufficient benefits to all, the initiatives would sustain themselves and continue to produce benefits for the community even after the project was completed (CNRS, 1998).

A principal study site was the Shingaragi beel area in Tangail district, with a variety of mechanisms controlling access to a collection of waterbodies comprising *beels* and *chawks* (which have open access in flood season) and *pagars* (privately owned ditches). The *pagars* were routinely dewatered in the dry season, restricting recruitment possibilities for the subsequent year. The project leased out a tiny *pagar* area (25 decimals) and used it to demonstrate the benefits of reserves. The fish catch monitoring in the next year immediately reported higher catches of key species. The success of this demonstration led the community to decide on additional *pagar* conservation.

The other strand of CBFM, undertaken by ICLARM in collaboration with the DoF and 5 development NGOs, was based on similar principles of community management implemented by Beel Management Committees (BMCs), and was implemented in 19 different waterbodies around Bangladesh. These ranged from 16 ha to 1620 ha in size, with wide differences in the extent of closure of waterbodies. The waterbodies were among those under the control of DoF, with fishers gaining access through individual licensing[16]. Given the large differences in the waterbodies, access arrangements and the social structures of fishing, arrangements were left flexible according to conditions prevailing at individual sites (Thompson, *et.al.*, 1999) The management strategies were focused on effort control in the form of reserves, closed seasons, and bans on exploitative gears, supplemented by education, training and subsidised credit to meet fishing costs and to help tide over closed seasons.

Reviewing project experiences in four such waterbodies, one mostly closed and three others mostly open, Sultana and Thompson (2000) note that effort control thus instituted under community management has gained wide acceptance with high compliance levels. For example, in one site, Ashurar Beel, a small permanent sanctuary coupled with a late dry/early flood (March-July) closed season resulted in

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[16] Except the flowing rivers, which are now open access fisheries.

near doubling of catch over two years from 1997 to 1999[17]. Benefits here accrued not only to the professional fishers who were the members of the scheme, but to the wider community as well. More generally, sanctuaries and closed seasons resulted in increased catches in all 3 open waterbodies, with benefits not limited only to members.

Management of Aquatic Resources through Community Husbandry (MACH)

The MACH project commenced its field operations in 1999, with a similar community-management ethos and strategies based on the establishment of sanctuaries and habitat restoration. A government project with donor assistance, it is being implemented by five NGOs in three different locations in Bangladesh, the *Hail Haor* Basin in the Northeast, the Turag-Bangshi basin in Gazipur and Tangail districts, and in the Kongsha-Malijhi basin in Sherpur (MACH-CNRS, 2000).

Reviewing project progress at the end of the first year of operations at the Hail *Haor* site, the first year impact report (MACH-CNRS, 2001) notes that the establishment of sanctuaries and time closures in the site has resulted in a 10% reduction in effort (2158 to 1934 days). This sacrifice has come principally from professional fishers, while subsistence and seasonal fishers have been allowed access even in intervened areas. Fish catch per unit area (CPUA) was found to have increased in all habitats in the project area at the end of the first year, with annual weighted overall CPUA increasing from 163 kg per ha at the baseline to 191 kg per ha in the first project year.

It is, however, recognised that a one-year change is often inadequate to draw sufficient conclusions about floodplain fisheries, due to natural yearly variability and hydrological conditions, and final judgement has to be reserved until longer time-series data from the site are available as the project progresses.

At the Turag-Bangshi site, nine sanctuaries were set up in the deeper *beel* areas, combined with a closure in the late summer breeding season. The project's impact monitoring reported catch more than doubling in the first year. Despite the imposition of sanctuaries and closures, annual effort actually increased in this first year. The report opines that this increase in effort was probably in response to greater fish abundance arising from the intervention. Anecdotal evidence from local fishers supported this assertion.

3.5 Discussion

The above review suggests a dichotomy in the thinking about effort restrictions (and other interventions designed to improve overall yield or yield-per-recruit) in the literature. There are two dimensions to this, biological (will effort restrictions lead to increased catches?) and socio-economic (if increased catches were possible, would the beneficiaries include the poorer fishers using labour intensive methods?). We discuss these in turn.

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[17] Although this is partly attributable to increased flooding in 1998 (Sultana and Thompson, 2000)

The ‘Poverty…’ study expresses scepticism about the potentially yield-enhancing ability of such strategies, while the PIRDP biological study as well as the field implementation experiences suggest that considerable gains can be achieved even from moderate restrictions aimed at reducing fishing effort (mortality).

In attempting to resolve the conflicting conclusions from the two biological studies, the following <u>initial</u> points of difference may be noted:

(i) The FPFMODEL, which predicts substantial gains from effort restrictions, is a single-species model. As noted above, the aggregate catch-effort relationship in a multi-species setting may be much flatter than for a single species.

(ii) The ‘Fisheries dynamics…’ study is based on a hydrologically modified floodplain area, in contrast to the relatively pristine ‘Poverty..’ study site. Hydrological modification, by limiting fish migration into the floodplain and lowering water levels (thereby limiting fish habitat as well as increasing the catchability of the fish) leaves the fishery much more vulnerable to overexploitation than in unmodified sites.

(iii) The area of *Hail Haor* on which the ‘Poverty…’ study is based has a better definition of property rights than the PIRDP site on which the ‘Fisheries Dynamics…’ is based. The *Hail Haor* site was composed of a series of sub-leased *jalmohols*, while much of the PIRDP site is open-access, as discussed above. It could be argued that there is a better incentive for conservation in sites with better-defined property rights, even considering the disincentive provided by fish migration between units.

Perhaps most importantly however, these discrepancies in the predictions from the two models reflect significant differences (Table 3.1) in the assumptions and therefore the algorithms underlying each model.

Table 3.1 The assumptions and modelled processes underlying the FPFMODEL and BEAM 4

Assumption / Modelled Processes	**FPFMODEL**	**BEAM 4**
Number of gears included	Multiple (implicit)	10
Number of species/guilds included	1	5
Recruitment	Density-dependent upon SSB	Constant
Natural Mortality	Density-dependent	Constant
Growth	Seasonal and density-dependent VBGF	Non-seasonal VBGF
Fishing mortality	Seasonal	Seasonal
Hydrology	Included	Not included

SSB- Spawning Stock Biomass; VBGF- von Bertalanffy Growth Function.

Thus, whilst the BEAM-4 modelling exercise in the ‘Poverty…’ included several species grouped into ecological guilds, and seasonal patterns of exploitation by several different gear types, the results are conditional upon the assumption that recruitment is constant irrespective of the size of the spawning stock biomass or hydrological conditions. The model also assumes that natural mortality rates remain constant throughout the flood cycle and that growth rates conform to the standard von Bertalanffy growth function. Empirical evidence described by, among others, Welcomme (1985; 2001) and Halls et al (1998) suggests that these assumptions are unlikely to be met in the floodplain environment. With 'recruitment-overfishing' assumed not to exist, yield from the fishery is dependent only upon the age at which fish are caught which determines individual fish weight and numbers of fish surviving.

The insensitivity of the above model yield predictions to the closed seasons reflects the wide range of growth and mortality parameter values estimated for the species included in the modelling exercise and the assumption of constant recruitment. For some species, growth rates were estimated to be very high, with corresponding high mortality rates, whilst for other, growth rates and mortality rates were estimated to be low[18].

Early season closures protect the slower-growing, longer-lived species, but at the expense of losing yield from the faster-growing, shorter lived species. Conversely, late season closures give rise to high yields from the faster-growing, shorter-lived species, but counter-balanced by diminished yields from the slower-growing, longer-lived species. Thus the model prediction that the net effect of within-year closures is negligible.

However, more recent studies, based upon larger and more comprehensive datasets, suggest, that for those floodplain species sampled, patterns of growth and mortality are similar – populations are virtually annual with the majority of growth occurring during the first 3 months of life corresponding to floodplain inundation.

With these patterns of growth and mortality coupled with empirical evidence of density-dependent natural mortality and recruitment, effort control may indeed be expected to affect yields as found in the following sections.

Results from the implementation projects also provide support to the hypothesis that the source of the discrepancies does not lie in site characteristics or considerations relating to numbers of species modelled. Firstly, many of the sites in the implementation projects described above report significantly increased *overall* catches, indicating that the FPFMODEL's predictions are not artefacts of consideration of a single species. Secondly, there is no indication that increased catches are observed mostly only in hydrologically modified sites. For instance, Ashurar beel, in CBFM's portfolio, recorded higher catch increases after intervention than Goakhala Hatiara beel, which is protected by flood control embankments (Sultana and Thompson, 2000). Similarly, the Ashurar site, formerly leased and licensed under the NFMP after 1995, could be said to have had *more* access control than the Goakhala site, which has historically been mostly comprised of private land, with largely open-access fishing. The reviewed action research projects have only been in operation for limited periods of time, and more definitive conclusions can only be made after longer time-series of data are available. However, the evidence thus far seems to indicate that effort control in the form of closed seasons and/or areas does contribute to greater *overall* catches in the multi-species fishery, and that these effects are not limited to sites that are hydrologically modified or characterised by access that is largely open.

The weight of the available evidence then points towards the allowance for yield increases via enhanced recruitment as the explanation for conflicting conclusions reached by the two studies. Certainly, the successful implementation projects have

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[18] Moreover, he growth and mortality parameters for the selected species guilds in the 'Poverty…' study were estimated (with considerable uncertainty) from 'patchy' length frequency data and empirical relationships.

targeted their effort control activities towards increased recruitment. MACH project's closed seasons have come late in the dry-season and early flood season (March/April) onwards for three to five months, so that adult fish preserved in the sanctuaries are given the chance to move out and reproduce with the arrival of the first floods, and fry are allowed to grow. A similar strategy has been followed by CBFM, where in the open beels, closed seasons for two to three months are instituted around May[19].

As discussed above, the 'Poverty…' study also expresses scepticism at the socio-economic desirability of effort control. With the lessee maintaining a stranglehold over gains from the fishery via tolls, increased catches might simply translate into increased rents for the lessee, with few benefits flowing to the poor sub-lessees. While this is a valid observation, two points can be advanced in support of a counter-argument that this is not a sufficient impediment to the success of effort control regimes.

(i) Since 1986, there have been significant changes made to the property rights regime in floodplain waterbodies in Bangladesh, as noted in literature review. Under the NFMP, leasing of a number of *jalmohols* has been terminated and replaced by a licensing regime administered by the DoF. Although this move has not been entirely successful in practice, and former lessees and influential middlemen continue to exert their influence, the policy does provide a foothold for 'genuine fishers' to begin to appropriate more of the returns from the fishery.

(ii) The 'rent-seeking absentee lessee' argument presumes the lack of institutional help in managing effort control. The community-based management action research projects described above have worked around the middleman problem by providing financial and institutional help in the direct acquisition by genuine fishers of licenses or leases. Since the continued monetary dependence of the fishers on former lessees was an important reason for the status quo in the fishery despite the NFMP, the CBFM project, in many of its sites, has provided financial help toward the acquisition of licenses. However, as Toufique (1999) points out, there is more to the inability of genuine fishers to gain *de facto* property rights under NFMP than just a lack of financial capital, there is also a lack of social capital that results in high transaction costs. Acquisition of *de jure* rights to fish the resource is not enough, there is also a need to guard the acquired rights to property from poaching, encroachment, etc. Fishers, belonging to a heterogeneous and unorganised class with generally low social standing, find it much harder to thus guard the resource than traditional lessees do. This asymmetry in power creates an asymmetry in transactions costs, argues Toufique, and fishers are therefore not able to extract rents to the extent that middlemen-lessees can. These lessees are therefore able to maintain their stranglehold over fishing resources despite policy changes unfavourable to them. In this regard, apart from financial help in the acquisition of licenses/leases, the direct involvement of the DoF in the CBFM project has helped loose the grip of powerful former lessees on fishers. Organisation of fisher groups by NGOs has also helped fisher group empowerment.

The MACH project's strategy provides another example. The *Hail Haor* fishery continues to be dominated by a system of leases today, just as noted in the 'Poverty…' study. But the project has managed to get the leases for the

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[19] Paul Thompson, personal communication.

project waterbodies transferred to the local project communities, thus ensuring that any increased returns from the fishery will accrue directly to the fishers. [20]

3.5 *Closed Seasons simulation results*

The baseline catch in the area modelled is shown below in Table 3.2.

Table 3.2: Monthly estimates of catch (kg) of Puntius Sophore and all species inside the PIRDP for the split year July 1995-June 1996. Source: MRAG (1997)

Month	***P. Sophore***	**All species**
July	2972	5411
August	590	6916
September	662	31857
October	4706	56408
November	1892	29510
December	1016	9317
January	4261	26882
February	1348	6832
March	1082	4296
April	2850	9025
May	0	0
June	0	0
Total catch (kg)	**21397**	**186454**
CPUA (kg/ha)	**5.2**	**45.4**

As can be seen, negligible catches were recorded in the area in May and June in the study 1995-96. Therefore, closed season runs were generated involving all months other than those two. Single-month, two-month and seasonal (three-month) closed seasons were simulated by setting fishing mortality in the calibrated FPFMODEL to zero in those months. As indicated by previous research on floodplain livelihoods in Bangladesh, while improvement of yearly fish catches is an important objective, the strong seasonality of livelihood profiles and fishing access implies that it is equally important *when* in the year most of the benefits accrue. Hence all simulations are generated on a monthly basis, as % changes from the baseline, in table 3.3.

Three important points emerge:

(i) Firstly, the annual yield changes provide clear evidence of overexploitation in the PIRDP, with even single-month closures having the capacity to provide significantly improved catches. The catch increases range from a minimum of 25.4% for a single-month closure in August, to a 138% increase for a three-month closure in the dry-season, January-March. Closures in October, January and April are predicted to be particularly productive, resulting in yield increases of 67.9, 100.2 and 94.7% respectively. As seen in table 3.3, these

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[20] Indeed, it appears now that the real management problem now lies in the flowing rivers, which were declared open access in 1995. A complete lack of property rights makes organisation of producer communities difficult. CBFM has experienced such problems in one of their riverine sites, Kali Nodi (Sultana and Thompson, 2000).

are all months in which exploitation (fishing mortality) in the study site is relatively high. Detailed results (not reported here) demonstrate that these yield increases come almost entirely from improved recruitment at the lower fishing mortality rate. Gains relative to sacrifice are particularly high later in the dry-season when the remaining fish are highly fecund spawning individuals experiencing low rates of growth and natural mortality.

(ii) Two and three month closures are seen to provide higher benefits than single month closures. However, although longer closures provide greater benefits, the *marginal* benefits from longer closures are usually not very large. For example, a January closure increases yields by 102%, a two-month January-February closure by 125%, and a three-month January-March closure by 138%. Another way of viewing the same effect is to note that yield gains from the aggregation of three *separately* simulated one-month closures are seen to be significantly less than that from a single *continuous* 3 month closure. For instance, single month closures in October, November and December respectively result in 67%, 59% and 32% yield increases, while a continuous 3 month closure in October-December only provides a 67% increase in yields. This phenomenon reflects the somewhat complex interaction between fishing effort (mortality) [which is not constant from one month to the next], fish density, density-dependent natural mortality, growth, and recruitment, and sacrificed yield/ removed biomass. Intuitively, however, this is primarily because the remaining fish density will be higher for the longer, continuous closure (fewer fish are removed during the simulation year). Density-dependent *natural* mortality, will therefore be higher, leading to a smaller spawning stock at the end of the year and thus less recruitment at the start of next year and ultimately less yield for the same sacrifice of catches. Growth (individual mean weight) will also be affected in a similar way, but the results suggest this to be insignificant.

Needless to say, longer time closures impose greater inconvenience on the participating community, especially with income and nutrition from fisheries constituting such an important part of the livelihood profiles of poor households. Longer closures are also more difficult to enforce and administer, and less likely to gain the approval of all categories of fishing-dependent households. With the marginal productivity gains from longer closures seen to be relatively small, a case could therefore be made for short closed seasons. However, this has to be balanced against the substantial variability in hydrological conditions from year to year. While the 1995-96 hydrological year to which the FPFMODEL is calibrated can be considered a ‘normal’ hydrological year, the timing and magnitude of flood rise, peak and drawdown, and the extent of water retained on the floodplain during the dry-season can have very different profiles from year to year. Thus, basing a closed season strategy on a small, fixed window in time can be risky.

(iii) The relative attractiveness of late dry-season closures in terms of yield gains relative to sacrifice, as seen in (i), and the need for closures to be long enough to minimise the effects of year-to-year variability, as discussed in (ii), suggest that a two or three month closure late in the dry-season could form the basis for an effort-control regime, at least in the area modelled. The monthly breakdown of annual yield simulations in table 3.3 provides a further rationale for such a strategy. The bulk of the yield gains from late dry-season closures are seen to accrue in the early and peak flood seasons (July-October) of the following hydrological year. For example, a two-month closure in March-April is predicted to increase catches by 120% in the simulation. The monthly breakdown shows that catch enhancement in the months immediately following this closure (July-October) is particularly high. For July, the yield increase under the new strategy is 205%, and in August, September and October, 161%, 148% and 143% respectively. These early and peak flood months are periods of relatively high dependence on the fishery by the landless poor, since agricultural opportunities are limited while the *aman* crop is growing, while access to the fishery is relatively unfettered. This is discussed further in the section below on livelihood profiles in the PIRDP.

Table 3.3: Closed season simulation results

			Single Month Closures							
	July close	**Aug close**	**Sept close**	**Oct close**	**Nov close**	**Dec close**	**Jan close**	**Feb close**	**Mar close**	**Apr close**
MONTH	**New Catch as % of Baseline Catch**									
July	0.0	124.1	169.7	219.7	192.2	0.3	271.8	172.5	156.3	245.2
Aug	159.7	0.0	161.3	201.1	179.6	138.0	238.9	163.6	150.0	220.0
Sept	159.2	132.0	0.0	195.7	176.0	136.8	229.3	161.1	148.3	212.7
Oct	158.5	132.2	202.6	0.0	174.6	136.3	225.7	160.1	147.5	209.9
Nov	155.4	130.8	198.3	281.6	0.0	134.6	215.9	156.8	145.1	202.0
Dec	152.1	129.2	190.8	270.0	221.5	0.0	206.3	153.3	142.5	194.0
Jan	148.6	127.5	183.4	251.2	213.0	148.2	0.0	149.7	139.9	186.3
Feb	147.9	127.2	182.0	247.5	210.7	148.4	314.0	0.0	139.4	184.8
March	147.6	127.0	181.3	245.7	209.6	148.1	318.1	182.6	0.0	184.0
April	146.6	126.5	179.1	240.4	206.2	147.1	307.9	182.4	90.5	0.0
May	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
June	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
YEAR	**150.6**	**125.4**	**159.1**	**167.9**	**159.4**	**132.5**	**202.4**	**154.1**	**143.3**	**194.7**
		Two Month Closures					**Three Month Closures**			
	July-Aug	**Sept-Oct**	**Nov-Dec**	**Jan-Feb**	**March -Apr**		**July-Sept**	**Oct-Dec**	**Jan-March**	
	New catch as % of baseline catch									
July	0.0	275.1	230.0	343.0	305.5		0.0	327.6	402.3	
Aug	0.0	241.2	208.8	285.2	261.5		0.0	275.7	319.6	
Sept	196.0	0.0	202.7	268.1	248.6		0.0	260.4	294.8	
Oct	195.5	0.0	200.3	261.7	243.8		322.0	0.0	285.7	
Nov	189.4	409.6	0.0	247.1	231.7		303.3	0.0	267.3	
Dec	182.8	374.7	0.0	233.4	220.1		280.8	0.0	250.5	
Jan	176.4	334.5	264.5	0.0	209.1		260.1	420.9	0.0	
Feb	175.1	326.8	261.6	0.0	207.0		256.1	408.8	0.0	
March	174.5	322.9	259.5	422.1	0.0		254.1	401.8	0.0	
April	172.5	312.3	253.4	405.7	0.0		248.3	384.1	488.2	
May	100.0	100.0	100.0	100.0	100.0		0.0	0.0	0.0	
June	100.0	100.0	100.0	100.0	100.0		0.0	0.0	0.0	
YEAR	**176.0**	**183.2**	**175.6**	**225.7**	**220.2**		**224.2**	**167.7**	**238.8**	

3.6 Closed areas (harvest reserves) simulation results

Based on intuition generated by the examination of the biological data, particularly rates of reproduction and mortality, the ‘Fisheries Dynamics…’ study had recommended dry-season reserves as an effective management tool. Reserves also have the advantage of being a relatively easily enforcable means of controlling effort, since they are highly visible and easily understandable. Although year-round reserves have been successfully applied in coastal areas around the world, the ‘Fisheries dynamics…’ study opined that year-round reserves would serve little purpose in Bangladeshi floodplains, particularly given that most species were adapted to survive very high levels of mortality, and the need to allow the fishery to be exploited as much as possible in the interests of fishery-dependent livelihoods (Hoggarth and Halls, 1997). That study therefore recommended *dry-season* reserves. Since the mobility of most fish species in the area extended to only a few kilometres and the fisheries are strongly interceptory, multiple small reserves every five kilometres or so were proposed.

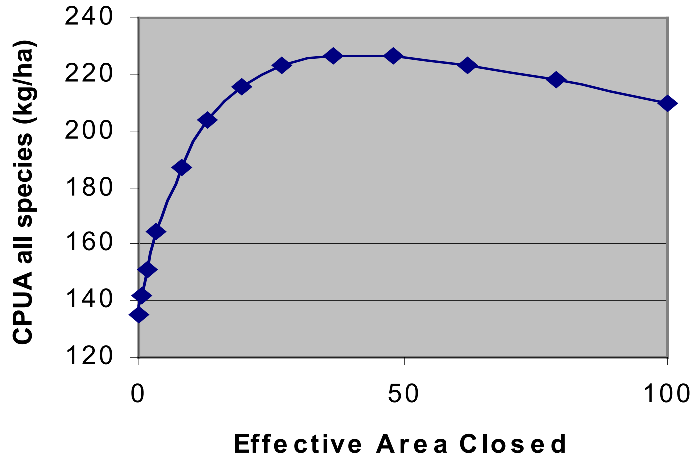
The optimal size of these multiple reserves, however, remains a key unknown from a management perspective. The FPFMODEL was therefore used in this study to explore how productivity (CPUA) might vary with reserve area for the pattern of catches observed inside the PIRDP for the split year 1995/96 and corresponding hydrological regimes. This was achieved by assuming that the estimated proportion of the population caught during the dry season will vary linearly and inversely with reserve area. Thus if the reserve area = 100% of dry season water body area (DSWB), the proportion of fish removed during the year will be equivalent to those removals taken upto the beginning of the dry season (approximately 60%). If the reserve area = 0% of DSWB area, then the proportion of fish removed will be equivalent to the existing removals (approximately 95%). The removal proportions and the effects of closure on CPUA are shown in figures 3.2 and 3.3 respectively.

The optimal reserve area is predicted to be between 30-40% of DSWB area, giving rise to a total annual removal rate of between 80-85% per year. That said, most of the gains are realised within a closure of 25% or so of the total DSWB area, with marginal returns to increased area closures tapering off rapidly after that. Productivity inside the PIRDP is predicted to increase by up to 140% reflecting the current heavy exploitation during the dry season period. Model simulations predict that the initial loss of yield following the establishment of reserves is small (1-10% for reserve area of 1-28%) relative to the expected long term gains and short lived corresponding to the first dry season period. Thereafter, immediate gains are predicted with the full benefits being realised close to three years after establishment.

Reserves are thus seen to play a substantially more productive role than merely providing insurance against recruitment failure. In the ‘Fisheries dynamics…’ project, it was noted that the probability of dry-season survival was highest in the deeper *beel* areas and secondary river sections. Setting aside about a quarter of the DSWB area, principally in these sites with greater water retention through the season, would thus seem to afford significant gains to the fishery. Professional fishers are predominant on these sites, and therefore the onus of the sacrifice would fall upon this group. The institutional model applied by CBFM and MACH, where leases/licenses are acquired on behalf of the actors involved in the effort control programme, monetary help is provided to help participants cope with sacrifices, and small amounts of subsistence fishing continue to be tolerated during the effort control initiative, would appear to provide an attractive basis for an implementation strategy

Figure 3.2: Linear relationship assumed between closed area and removal of fish in the dry-season (November-June) inside the PIRDP.

Figure 3.3: FPFMODEL simulation of CPUA in response to area closed during dry-season in the PIRDP.



3.7 The socioeconomic dimension

The above exploration of effort control has concentrated on the biological element, taking human effort inputs as given. Paramount to the success of managing this fishery for the poor, however, is an understanding of livelihood profiles, and in particular, dependence on the fishery, as they change through seasons. Since sacrifices (effort control) are necessary in order to provide benefits (improved catches), with the relationship proving acutely time-sensitive, it is vital to know when the opportunity costs of sacrifice will be high or low, and when the provision of benefits will be most welcome for the floodplain poor. As noted before, socio-economic data pertaining directly to the modelled site are not available to us to enable direct simulation of livelihood outcomes. Hence we rely on socio-economic data collected by FAP17 in an adjacent area. It is worth reiterating that the socio-economic data are for a different area, a different year and from a different sampling framework compared to the biological data used in the modelling. Hence they can only be used to derive broad patterns to complement the simulation modelling results. In particular, we wish to know: (i) the seasonal profile of fishing activity through the year, and (ii) the importance of fishing in the livelihood activity portfolio of various categories of households, by season. Knowledge of these issues will enable us to comment on who will have to bear the sacrifices associated with particular effort control regimes and who will benefit the most, and to what extent.

FAP 17 data source

We rely on two different sources of data in this section, the FAP17 fisheries dataset, which provides information on catches and catch distribution according to gear, and the FAP 17 socio-economic dataset, which provides a picture of livelihood profiles of communities living by Gandahasti beel. The fisheries study conducted area-based catch assessment surveys, with data collected from the beel, surrounding floodplain area as well as sections of the Badai river running through the beel (figure 2.1). The socio-economic study collected community-based information for two communities for which fishing activity is mostly concentrated around the Gandahasti beel and floodplain area. One community is an ‘agricultural village’, Boalia, where livelihood activities are predominantly centred on agriculture, and the other is a ‘fishing’ village, Ahmedpur, a fishing *para* that is part of a larger village.

However, as is typical in floodplain systems, fishing forms part of livelihood portfolios in the agricultural village, just as some of the income of residents in the fishing village derives from agricultural activities. The socio-economic study categorised households in agricultural villages into ‘medium farmers’, ‘small farmers’ and ‘landless’[21], and households in fishing villages into ‘F1’ (fishing is only source of income), ‘F2 (fishing is a primary, but not only source of income), ‘F3’ (fishing is a secondary source of income) and ‘F4’ (fishing is a negligible source of income). Although Ahmedpur did not contain any ‘professional fishers’ (F1 households), various FAP17 publications indicate there are indeed a small number of professional Hindu fishermen operating in the area, fishing a wide variety of waterbodies in the flood season, and leased sections of the Badai river in the dry season. Since the construction of the PIRDP and consequent reduction in water levels, various perennial waterbodies in the area have gradually dried out, leaving only the Badai

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[21] Information on large farmers is not reported in the dataset and associated publications, since they are small in number and do not form part of the interest group of the study.

river, a central portion of Gandahasti beel, and various small depressions in the beel and floodplain retaining water all year round (FAP17, 1995a). With this development, and due to a general exodus of traditional Hindu fishers from the area over the years, the number of professional fishers has dwindled. However, since the socio-economic study in the area was designed on a community rather than a waterbody or area basis, and the chosen fishing village did not happen to contain professional fishers, information on this community is not available. This has to be borne in mind when we interpret the data.

The following discussion relies on four tables derived from the two datasets: (i) Table 3.4, containing information on monthly catch in the Gandahasti beel and floodplain area, with breakdown by Bengali gear types, (ii) Table 3.5, showing gear-ownership by household groups in the northwest, (iii) Table 3.6, showing average monthly incomes by source and household category for Boalia agricultural village in 1992-93, and (iv) Table 3.7, showing average monthly incomes by source and household category for Ahmedpur village in 1992-93. The discussion proceeds by taking the four major fishing seasons in turn, rising & peak flood, drawdown, early dry-season and late dry-season/early monsoon. In piecing together the narrative, we also draw on material FAP17 publications and data documentation.

Rising & Peak Flood (mid June-mid Oct)

With heavy precipitation falling on the floodplain and overbank flooding from the rivers commencing, the water level in the beel starts to rise rapidly in mid-June. Various waterbodies that became disconnected in the dry-season are reconnected, and the beel-resident fish move out on to the floodplain. By mid-June, the Boro harvest and the aman planting have been completed, and few agricultural opportunities are available. Once the water covers the rice fields, the land becomes common fishing property. The low opportunity cost of time coupled with this change in property rights implies that most households are involved in fishing, including women and children.

As seen from Table 3.4, from July to September, the peak flood months, relatively expensive gears such as *moi* and *ber jal* account for high proportions of the catch. Table 3.5 shows that these gears tend to owned by professional fishers. 84.5% of *ber jal* owners are F1 professional fishers, and it accounts for 20% and 22% of catch, respectively, in August and September. Similarly, *moi* jal, which takes 64% of catch in July, is also predominantly owned by professional fishers. These data on catch and ownership indicate that although the numbers of professional fishers may be low, the peak flood season affords them the chance to attain high returns to their larger, more expensive gears which are more efficient in high waters. At the same time, relatively cheap gears owned by all floodplain residents, such as *daun* hooks and *doiar* traps also land significant catches, although catch per unit effort (CPUE) is likely to be low for these gears with the fish widely dispersed in the water. However, despite CPUE being low, the total effort at this time is so high that overall catches are significant.

The importance of income from fisheries for almost all categories of households during this season is clearly seen in Tables 3.6 and 3.7. For the F2 fishermen in Ahmedpur village, fishing is the only source of income in June-July and August-September, and about 80% of income in September-October. This is in stark contrast to the late dry-season period, when they have practically no income from fishing. For this group, average annual income is 19,423 taka per annum, which is higher than for the landless in the agricultural village, but nevertheless low compared even to the small farmers. For the F3 fishers in Ahmedpur, fishing is not quite that important, with incomes well-diversified for this group via livestock holding and self-employment. But fishing income is nevertheless an important seasonal supplement at a time when agricultural incomes are dipping. In September-October, for instance, fishing provides about 50% of their average income. With an annual average income of 37,874 taka, this group is clearly doing very well. But even for this well-to-do group, fishing becomes important in the peak flood season.

The medium farmers in Boalia agricultural village are the least dependent upon fishing, with only 2.6% of their annual average income coming from fishing (Table 3.6). For this group, and for the small farmers, for whom 6.7% of the annual income comes from fishing, agricultural incomes continue to flow throughout this season by virtue of operation of high elevation plots that remain flood-free. By careful alignment of crop cycles on multiple higher elevation plots, a continuous stream of income can be provided even through the flood season.

The landless are by far the poorest among the categories in the agricultural as well as fishing village, with an annual income of only 10,057 taka. Once the boro harvest is completed in the April-June period, agricultural labouring income for this group sharply drops off, going down from 236 taka (27% of monthly income) in May-June to 102 taka (12% of monthly income) to 57 taka (5% of monthly income) in July-August. With only high-elevation plots under crops in this season, demand for their labour is low. With cultivable land in short supply, their opportunity to share-crop also declines sharply, evidenced by the decline in their income from agriculture during this period. Fishing-related activity becomes very important for livelihood sustenance during the peak flood season for this poorest of groups. Fishing and fish-trading together account for 22% of income in June-July and 24% in July-August, rising to 42% and 37% in August-September and September-October, respectively.

Drawdown (mid-October to December)

Around mid-October, the water begins to slowly drain off the higher floodplain elevations into the lower lying areas such as beels. With the water, the fish also move into deeper portions of beels, khals and other residual waterbodies. Waterbodies begin to get disconnected, and the fish thus become concentrated and easy to catch. *Aman* harvest occurs in October-November, and preparation for *Boro* planting begins with seedbed preparation in November. Thus agricultural activity picks up considerably in this period; however fishing activity continues unabated and even intensifies since fishing is often complementary to agriculture in this period. Labourers hired for boro seedbed operations drain plots and remove the fish, keeping a share for themselves (FAP 17a, 1994). Access starts to become restricted as the borders of individual plots start to become visible.

Fishing is very efficient in terms of catch per unit effort during this period, and a variety of gear are in use. As fish move with the draining water, it becomes easy to catch them with traps. However, all kinds of gear are in use and take significant catches during this period, ranging from the relatively expensive *Ber jal* to the cheap and ubiquitous *Daun* hooks.

For the F2 fishing households in Ahmedpur, fishing continues to be absolutely critical. Income from fishing and fish trading constitutes 100% of their average income all through from October to December. For the well-off F3 households, income from fishing tails off somewhat, with self-employment income and agricultural labour income picking up due to the *Aman* harvest and *Boro* planting. The small farmers in Boalia benefit substantially from fishing during this period, with about a quarter of their income coming from fishing. For the landless, labouring incomes picks up with the renewed agricultural activity; but fishing and fish trading is still extremely important, providing about 40% of income in this period.

Early Dry-Season (January-March)

By the time the *Boro* crop is planted, the *natural* drainage of water off the floodplain and shallower *beel* areas has occurred. Agricultural activity in January and February is intense, with the *Boro* germinated seedbeds now being transplanted on to the plots. Private rights to floodplain lands begin to be asserted. As FAP 17 (1994a) notes, landowners are not only increasingly claiming rights to begin cultivation on their lands earlier and earlier, but are also claiming the right to fish out 'their' plots. Thus throughout the drawdown season, some landlords may not allow fishers to operate on 'their' plots, claiming that ownership of the plot also implies sole right to catch the fish that congregate there. Officially, such fishing rights do not exist, but the skewed balance of social power enables landowners to enforce this.

There is a very distinct change in the profile of catch breakdown by gear in this period compared to previous months. Table 3.4 shows that fish aggregation devices in the form of *katha* (brushpiles) and *kua* (fish pits) take the bulk of the catch, 58% and 62% respectively in January and February. By aggregating the fish in the *kuas* and draining out the pits, every last fish can be captured in a relatively inexpensive way. Table 3.5 shows that *katha/kua* ownership is practically exclusive to landowners for whom fishing is at best a secondary or tertiary activity. F1 and F2 fishers have no ownership of kathas/kuas in Gandahasti beel at all. *Kuas* are often dug to store water to irrigate the boro crop. As the crop grows, the *kua* will be dewatered by the landowner to provide irrigation, with the trapped fish extracted as a bonus.

For the most fishing-dependent of household categories in the socio-economic study, the F2 households in Ahmedpur, there is a dramatic change in livelihood portfolios during this period. With access to inundated land rapidly shrinking, their dependence on fishing drops off during these months. In its place, they take to post-harvest activities like fish trading to sustain themselves, apart from taking advantage of the *Boro* season to find labouring work. A similar trend of declining dependence on fishing is observed for F3 households in Ahmedpur, and landless labourers in Boalia. Small and medium farmers in Boalia village, on the other hand, continue to derive income from fishing by virtue of their ability to build *kua* on their plots. What is more, the fishing returns come at little cost, since *kua* are usually dewatered for irrigation purposes in any case. Over the years, even landowners who normally would not count fishing as a significant livelihood-sustaining activity have realised the value of the fish on 'their' land, and have actively taken steps to exploit this resource. *Kuas* and *Kathas* have thus proliferated, inevitably hastening the decline of the fishery since dewatering by mechanical means leaves little chance for fish survival.

Late Dry-Season/Pre-Monsoon Season (April-May)

By April, the only remaining water is in the deeper parts of the beels and river sections, apart from assorted small depressions that have not been dewatered. The earliest boro harvests take place in mid-April, and the weeks following are characterised by concentrated activity in harvesting the Boro crop. The opportunity cost of time is high for most household groups because of the labour demand generated by the Boro crop. The fish that survive the dry-season are concentrated in deeper beel and river areas. Professional fishers are the only group spending significant amounts of time fishing in this period. In the PIRDP area, they mainly operate on leased sections of the Badai river and in deeper *beel* areas(FAP 17, 1994a). Later in this season, the first rainstorms arrive, and there can be temporary surges in the level of water in the *beels* and rivers. The migratory species of fish also begin their spawning runs up the rivers at this time.

Table 3.4 shows the trap fishery to be most active during this period characterised by low catches. These traps are used by professional fishers to intercept beel resident fish as they move on to the floodplain with the arrival of the first rains. Although most household categories are busy with the *Boro* harvest at this time, and only professional fishers generally have access to the leased areas, FAP 17 (1994a) reports that casual fishing by non-leasing households is also becoming increasingly prevalent. Apparently, opportunistic fishers can often be found fishing on leased areas that they have no legal rights to. However, the professional fishers are a small group with low social standing, and are hence unable to stop this activity. In Table 3.4, this shows up in the form of catches taken by cheap (and destructive) gear such as *current jal* (monofilament gill net).

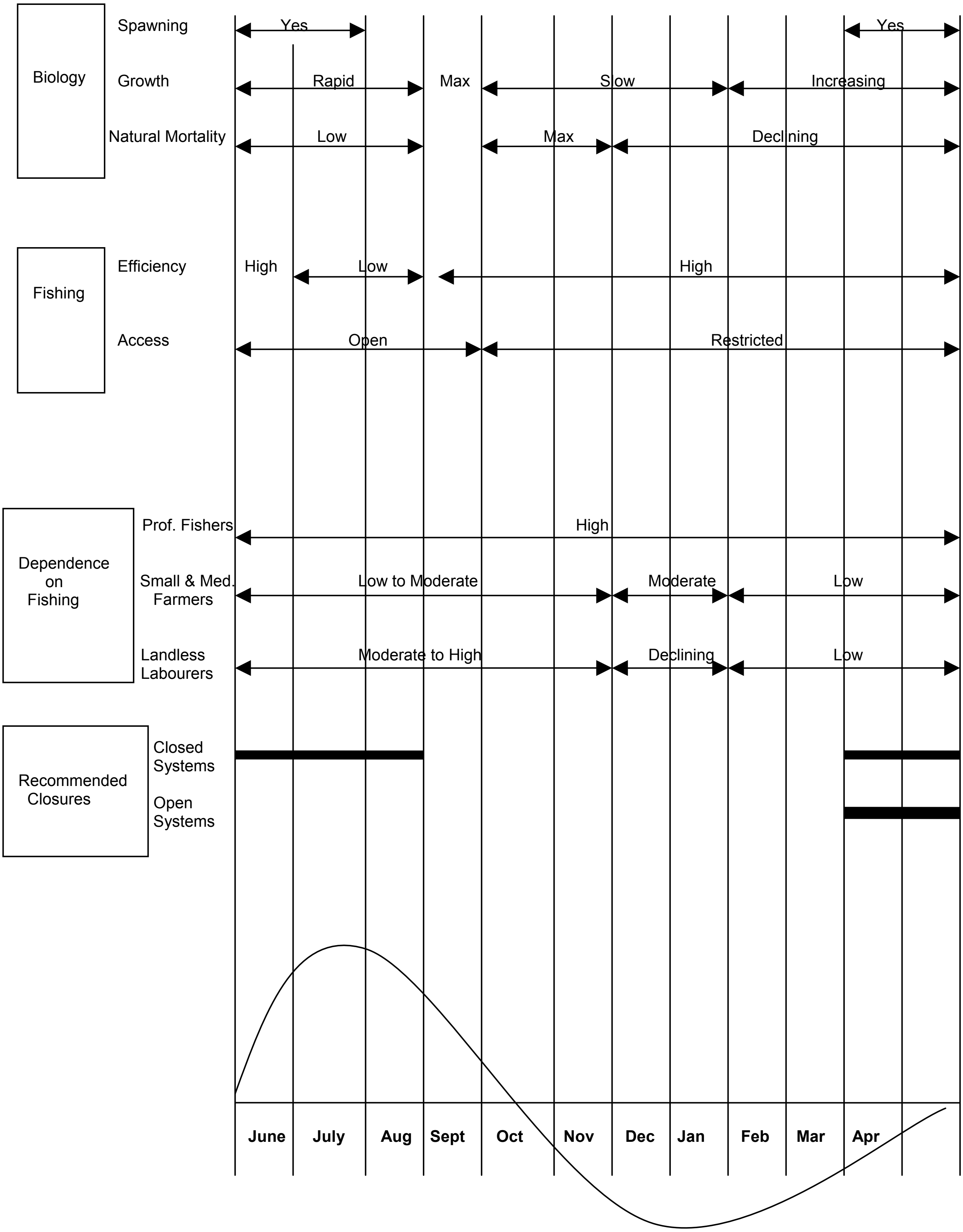
Tables 3.6 and 3.7 show that for most household categories in the two communities, income from fishing has dwindled to negligible levels, with income from labouring and agriculture peaking as the *Boro* crop comes off the land. Small farmers continue to derive some income from fishing, presumably by having household members fish illegally on leased sections. As noted before, F1 professional fishers leasing or sub-leasing the river and *beel* sections were not covered by the socioeconomic survey, but are probably the only group making significant incomes from fishing during this period.

3.8 Discussion and Conclusion

In contrast to an earlier study, our simulations have indicated substantial gains to be reaped from effort control regimes in the floodplains of Bangladesh. In the case of closed seasons, estimated gains range from 25% to 138% annual yield increases, depending on the timing and length of closures. Longer closures provide increased benefits, but the simulation results indicate that the marginal benefits to increased closure length tapers off rapidly. In light of this, and given the fact that management difficulties are likely to increase rapidly while participant enthusiasm drops off as closure length increases, closures longer than two to three months do not appear to be attractive.

The optimal timing for instituting closed seasons has to carefully balance biological parameters with socio-economic constraints. A pictorial encapsulation of the key temporal factors, both biological as well as socio-economic, to be borne in mind when implementing a closed season strategy is presented in figure 3.4 below.

Figure 3.4: Temporal schematic of biological and socioeconomic parameters relevant to a closed season regime



Recommendations about the best time to implement a closed season will always be subject to the existing pattern of monthly fishing effort (mortality), and it is worth reiterating here that our simulations are very much site-specific. However, it is likely that gains in yield-per-recruit can always be achieved from a closing the fishery during floodplain inundation, corresponding to the period when fish growth is at a maximum and natural mortality rates are likely to be at their lowest (figure 3.4). Fish density and catchability (at least during the flood season) are also low during this period making fishing operations less efficient.

However, closures during this period are likely to have serious equity implications in open waterbodies and floodplain areas. Open access rights to the landless poor exist only during the flood season, a time when agricultural labour demand drops off sharply while the *aman* crop grows. As observed in our discussion on livelihood profiles in the PIRDP area, the F2 fishers have practically no other source of income in this period, while the landless derive over a quarter of their meagre incomes during this period from fishing.

Nor are closed seasons recommended during the drawdown period when fish catchability, and therefore fishing efficiency is at its highest and where losses due to natural mortality arising from predation are also very high. Although the *aman* harvest and *boro* transplanting begin to provide significant incomes from agricultural activities during this period, fishing is also often complementary to agriculture, with plots being drained as part of land preparation. Again, F2 fishers in the PIRDP are seen to be absolutely dependent on the fishery in this period, and the landless and small farmers also benefit significantly.

In the early dry season, access to fishing areas becomes largely restricted, and there is declining dependence on the fishery for landless labourers. Professional fishers continue to operate leased sections of deeper beel and rivers, but the major change is in the increased proportion of catch going to landowners draining *kuas*. There is some merit to controlling effort in this period. However, *kua* draining is also for irrigation purposes, and there continues to be some dependence on the fishery for the range of household types, even if it is declining for many categories. If the *kua* catch in this period could be restricted instead of a complete closure, it would bolster the spawning stock, which could be protected with a late dry-season closed season involving relatively low sacrifices.

Closed seasons towards the end of the dry season/beginning of the flood season would protect spawning fish (figure 3.4) and provide significant benefits with relatively low sacrifices. It is the professional fishers that predominantly operate in this period, and this would be the group that would have to make the sacrifices. Some amount of (unauthorised) fishing by non-lessees takes place at this time, but this does not take a significant proportion of this period’s catch. For all categories apart from professional fishers, dependence on the fishery is minimal. This also helps in terms of the management of the effort control regime, since organisation of a very heterogeneous group is not necessitated. Additionally, the monthly breakdown of our closed season simulations for the PIRDP show that the bulk of the benefits from a closure in this period would flow in the peak flood period, when it would also be most welcome for the poorest.

In light of the above points, figure 3.4 indicates a closed season recommendation in April-May. For closed water-bodies with access restricted throughout the year, additional closure in the June-August period would provide additional yield-per-recruit benefits.

Closed areas are an alternative way of instituting an effort control regime, with the advantage of being more easily visible and understandable, and therefore enforcible. Year-round reserves may not serve much of a purpose in Bangladesh since there is a need to allow the fishery to be exploited as much as possible in the interest of fishing-dependent livelihoods, and also because most floodplain species are adapted to survive very high levels of mortality. The 'fisheries dynamics' study had suggested small dry-season reserves every 5 km or so based on the limited mobility of the fish, and the interceptory nature of the fishery. Optimal closure size is a key unknown, and the simulations for the PIRDP in this study suggest that most benefits peter out after about 25% reservation of area, attaining a maximum with a closure between 30 and 40%. Even an area closure amounting 10 to 15% of deeper beel and river section areas would provide significant benefits within two to three years of reserve establishment. Apart from the professional fishers who would lease such areas, reserves would also imply restrictions on the drainage of plots by farmers to free up more land for *Boro*.

Any effort control programme would inevitably have to include a programme of fisher group empowerment in addition to provision of financial help to tide over periods of sacrifice. Models of institutions to enable this have been developed on the field in Bangladesh by MACH and CBFM. In addition, a recent research project on consensus building funded by NRSP (Barr, 2001) has also explored the building of appropriate institutions.

Table 3.4: Monthly catches by gear in Gandahasti Beel area, 1992-93

MONTH	GEAR	CATCH	%	MONTH	GEAR	CATCH	%
JUN	DOIAR TRAP	2500	93	JULY	MOI JAL	1653	63.9
	NOL BARSI	139	5.2		DOIAR TRAP	508	19.6
	CURRENT JAL	17	0.6		BER JAL	203	7.8
	THELLA PUSH	6.6	0.2		CURRENT JAL	175	6.7
					THELLA PUSH	43	1.69
		2662.6				**2582**	

MONTH	GEAR	CATCH	%	MONTH	GEAR	CATCH	%
AUG	DAUN HOOK	3621	44	SEP	DAUN HOOK	1920	65
	BER JAL	1632	20		BER JAL	662	22
	MOI JAL	1488	18		DOIAR TRAP	205	7
	DOIAR TRAP	1007	12		CURRENT JAL	82	2.8
	THELLA PUSH	164	2		NOL BARSI	41	1.4
	NOL BARSI	110	1.3		KOI JAL	0	0
	CURRENT JAL	65	0.8				
	TUKRI SCOOP	36	0.4				
		8123				**2910**	

MONTH	GEAR	CATCH	%	MONTH	GEAR	CATCH	%
OCT	DAUN HOOK	2982	66	NOV	DAUN HOOK	3098	38
	BER JAL	751	16		BER JAL	2628	32
	THELLA PUSH	511	11		THELLA PUSH	882	11
	CURRENT JAL	226	5		CURRENT JAL	821	10
	DOIAR TRAP	25	0.5		DOIAR TRAP	647	8
	UCHA SCOOP	0	0				
		4495				**8076**	

MONTH	GEAR	CATCH	%	MONTH	GEAR	CATCH	%
DEC	DOIAR TRAP	3187	53	JAN	KATHA/KUA	4121	58
	BER JAL	842	14		DOIAR TRAP	2611	37
	DAUN HOOK	719	12		THELLA PUSH	141	2
	CURRENT JAL	619	10		CURRENT JAL	89	1.2
	KOI JAL	482	8		JHAKI JAL	58	0.8
	NOL BARSI	99	1.6				
		5948				**7020**	

MONTH	GEAR	CATCH	%	MONTH	GEAR	CATCH	%
FEB	KATHA/KUA	1453	62	MAR	CURRENT JAL	38	37
	DOIAR TRAP	640	27		DOIAR TRAP	28	27
	AKRA HOOK	119	5		DAUN HOOK	11	11
	NOL BARSI	63	2.7		UCHA SCOOP	11	11
	JHAKI JAL	24	1		JHAKI JAL	6.8	6.7
	CURRENT JAL	22	0.9		THELLA PUSH	5	5
		2321				**99.8**	

MONTH	GEAR	CATCH	%	MONTH	GEAR	CATCH	%
APR	DOIAR TRAP	251	77	MAY	DOIAR TRAP	177	72
	CURRENT JAL	51	15		NOL BARSI	68	27
	THELLA PUSH	21	6.5				
		323				**245**	

Table 3.5: Characteristics of Gear Owners, North West Region

Gear Category	Gear Code	Bengali Gear Name	Observations	Fisherman Category				First Ranked Source of Income (%)				
				1	2	3	4	Fishing	Farming	Labour	Trade	Other
Gill Nets	65	Chandi jal	34	91.2	-	8.8	-	91.2	-	5.9	2.9	-
	88	Current jal	1083	29.3	21.8	38.2	10.6	51.2	15.4	30.6	1.7	1.1
	123	Koi/Fashi jal	172	42.5	22.4	26.5	8.7	64.9	10.6	18.8	4.5	1.2
	282	Monofilament Net	312	47.9	23.4	26.7	2.0	71.2	6.5	16.4	3.8	2.0
	316	Kajuli jal	70	74.3	25.7	-	-	100.0	-	-	-	-
Seine Nets	45	Ber jal	561	84.5	11.2	4.4	-	95.6	1.0	1.6	1.7	-
	89	Deol	201	3.5	2.7	34.2	59.5	6.3	62.2	24.5	1.7	5.3
	202	Moi jal	555	44.2	21.7	26.4	7.7	65.9	6.4	20.4	2.0	5.3
	276	Hat panch	31	40.9	29.6	29.6	-	70.4	7.5	22.0	-	-
	297	Horhori	57	54.2	34.4	9.6	1.8	88.6	3.5	7.9	-	-
	306	Baoli	149	44.1	23.5	25.4	6.9	67.6	11.1	19.9	0.7	0.7
Bag Nets	271	Suti jal	87	55.5	11.5	26.4	6.6	67.1	10.9	7.3	13.0	1.8
Lift Nets	105	Dharma jal	73	6.4	1.4	67.8	24.5	7.7	43.0	26.8	12.1	10.4
	266	Veshal jal	522	84.6	8.4	6.7	0.4	92.9	2.7	3.3	0.8	0.4
Scoop Nets	263	Ucha	69	20.0	2.9	54.6	22.5	22.9	18.1	57.5	1.4	-
	287	Hat Tana jal	70	-	1.4	85.0	13.6	1.4	6.0	55.5	28.6	8.6
	296	Tukri	68	1.5	1.8	31.5	65.3	3.2	27.6	34.5	9.2	25.5
Clap Nets	234	Shangla jal	59	39.2	21.6	35.9	3.4	60.7	12.2	15.3	6.7	5.1
Katha/kua	149	Horga	31	-	-	38.6	61.4	-	88.3	4.8	6.9	-
Traps	95	Doiar	938	24.0	18.5	42.5	14.9	42.6	22.7	26.6	5.4	2.7
	286	Deal	86	4.7	1.3	52.9	41.1	6.1	32.3	43.5	10.7	7.4
Hooks and Lines	30	Sip	867	3.2	4.5	33.3	59.1	7.6	34.8	32.6	11.7	13.4
	152	Tana Barshi	110	17.7	6.9	22.6	52.7	24.6	15.4	13.6	25.4	20.9
	272	Daun	652	34.9	22.0	37.7	5.5	56.9	6.0	33.6	3.0	0.6
	278	Nol barsi	106	19.8	18.1	48.6	13.4	38.0	11.0	46.5	-	4.5
Spear	170	Koch	73	7.5	2.7	35.8	53.9	10.3	34.4	30.0	16.1	9.2
Cast Nets	164	Jhaki jal	1221	36.0	12.5	29.7	21.8	48.5	17.7	21.9	5.5	6.4
Push Nets	255	Thella jal	655	4.1	6.9	44.0	44.9	11.1	36.5	38.2	6.0	8.2
Hand and Dewater.	97	By hand/Dewatering	43	-	-	56.7	43.3	-	53.4	43.2	-	3.5
	307	Hand fishing	304	3.3	1.1	27.7	67.9	4.4	48.0	32.5	5.3	9.7
Other	291	Urani	38	9.1	12.2	30.4	48.3	21.3	39.7	23.5	7.6	7.9
	298	Akra	335	27.2	17.0	38.8	17.0	44.2	10.3	40.3	1.2	4.0
	317	Thushi	34	2.9	13.4	59.5	24.2	16.3	10.0	52.3	21.4	-

Source: Computed from FAP 17 socioeconomic database.

Table 3.6: Income from various sources at Boalia agricultural village, 1992-93

Category	**Activity**	**Apr-May**	**May-Jun**	**Jun-Jul**	**Jul-Aug**	**Aug-Sep**	**Sep-Oct**	**Oct-Nov**	**Nov-Dec**	**Dec-Jan**	**Jan-Feb**	**Feb-Mar**	**Mar-Apr**	**TOTAL**	**%**
Medium	Agriculture	2077	3936	2585	2705	1489	2371	982	394	1191	208	442	2155	20534	58.2
	Fish Culture	0	0	0	0	0	0	0	0	0	377	19	346	726	2.1
	Fishing	0	0	28	102	104	152	164	97	41	107	63	60	919	2.6
	Large Livestock	183	184	161	114	1156	69	60	32	32	75	95	208	2368	6.7
	Non-Ag. Labour	484	484	484	484	484	484	484	484	511	484	484	592	5947	16.9
	Self Employment	369	257	353	41	26	951	46	43	44	226	9	2246	4611	13.1
	Small Stock	6	9	5	9	22	14	4	7	5	1	14	7	104	0.3
	Ag. Labour	40	0	0	0	0	0	0	0	0	22	22	0	84	0.2
	TOTAL	**3157**	**4870**	**3616**	**3450**	**3275**	**4041**	**1737**	**1057**	**1824**	**1500**	**1148**	**5614**	**35293**	**100.0**
Small	Agriculture	1232	1656	1671	1295	1246	1398	979	517	166	274	373	1884	12691	43.4
	Fish Culture	0	0	0	0	0	0	0	38	76	0	0	0	98	0.3
	Fishing	125	58	10	169	98	367	434	388	88	146	66	0	1948	6.7
	Large Livestock	353	22	32	10	10	864	23	82	72	54	54	43	1620	5.5
	Non-Ag. Labour	410	410	410	3270	410	410	410	410	410	1818	410	417	9191	31.4
	Self Employment	502	239	175	246	233	188	157	129	135	834	54	140	3032	10.4
	Small Stock	28	7	11	13	120	105	40	33	38	56	17	64	531	1.8
	Fish Trading	0	0	27	27	29	16	13	0	0	22	18	0	151	0.5
	TOTAL	**2650**	**2392**	**2336**	**5030**	**2146**	**3348**	**2040**	**1597**	**985**	**3204**	**992**	**2548**	**29262**	**100.0**
Landless	Ag. Labour	241	236	102	57	57	68	226	172	251	238	190	374	2212	22.0
	Agriculture	228	265	248	162	127	108	60	67	0	15	189	47	1516	15.1
	Fishing	24	0	118	183	211	244	269	230	96	64	19	15	1473	14.6
	Large Livestock	0	0	0	0	0	0	0	35	24	0	741	0	801	8.0
	Non-Ag. Labour	142	97	81	81	81	67	67	67	77	82	102	187	1130	11.2
	Self Employment	329	194	159	422	140	267	171	158	162	154	162	303	2621	26.1
	Small Stock	16	17	21	84	39	85	59	56	59	30	42	26	534	5.3
	Fish Trading	28	54	56	74	116	119	123	164	125	0	0	0	859	8.1
	TOTAL	**1008**	**863**	**785**	**1063**	**771**	**958**	**975**	**949**	**794**	**583**	**1445**	**952**	**10057**	**100.0**
Village	Agricultural Labour	146	134	58	33	33	38	129	98	143	140	113	213	1277	6.5
	Agriculture	839	1346	1054	948	661	869	457	235	288	113	283	896	7989	40.7
	Fish Culture	0	0	0	0	0	0	4	8	17	80	4	73	175	0.9
	Fishing	41	13	75	163	164	252	283	237	82	91	39	21	1460	7.4
	Large Livestock	116	44	41	26	246	205	18	45	37	28	454	53	1312	6.7
	Non-Agric. Labour	273	248	238	867	238	231	231	231	242	549	251	323	3920	20.0
	Self Employment	376	217	204	303	136	394	142	127	131	319	106	677	3131	16.0
	Small Stock	17	13	15	52	53	74	43	40	43	30	30	31	443	2.3
	Fish Trading	16	31	37	48	72	71	73	93	71	0	0	86	598	3.0
	TOTAL	**1823**	**2046**	**1722**	**2439**	**1602**	**2134**	**1372**	**1114**	**1054**	**1350**	**1280**	**2101**	**19707**	**100.0**

Source: Computed from FAP17 Socioeconomic database

Table 3.7: Income from various sources at Ahmedpur fishing village, 1992-93

Category	Activity	Apr-May	May-June	June-July	July-Aug	Aug-Sept	Sept-Oct	Oct-Nov	Nov-Dec	Dec-Jan	Jan-Feb	Feb-Mar	Mar-Apr	TOTAL	(%)
F2	Ag. Labour	0	0	0	0	0	0	0	0	0	0	140	175	**315**	1.6
	Agriculture	100	0	0	865	0	0	0	0	0	0	0	2700	**3665**	18.9
	Fish Trading	0	0	0	0	0	120	300	290	175	590	475	415	**2365**	12.2
	Fishing	0	0	893	1025	1230	460	2110	5205	2105	0	0	0	**13028**	67.1
	Small Stock	50	0	0	0	0	0	0	0	0	0	0	0	**50**	0.3
	TOTAL	**150**	**0**	**893**	**1890**	**1230**	**580**	**2410**	**5495**	**2280**	**590**	**615**	**3290**	**19423**	100.0
F3	Ag. labour	237	255	265	185	110	85	216	153	284	148	182	314	**2434**	6.4
	Agriculture	7513	1198	1707	1403	744	530	531	360	307	211	216	1569	**16289**	43.0
	Fish trading	0	19	25	31	35	39	56	55	60	68	55	59	**502**	1.3
	Fishing	0	183	502	728	742	1085	995	577	102	84	38	14	**5050**	13.3
	Large Livestock	114	81	93	506	46	113	107	91	79	0	0	54	**1284**	3.4
	Non-Ag. Labour	0	0	0	0	0	0	0	0	0	129	121	0	**250**	0.7
	Non-Ag. labour	0	0	0	0	0	0	0	0	0	129	121	0	**250**	0.7
	Self Employment	1421	241	234	114	107	136	918	493	950	1086	36	86	**5822**	15.4
	Self employment	1421	241	234	114	107	136	918	493	950	1086	36	86	**5822**	15.4
	Small Stock	10	3	3	0	40	59	2	7	28	0	9	10	**171**	0.5
	TOTAL	**10716**	**2221**	**3063**	**3081**	**1931**	**2183**	**3743**	**2229**	**2760**	**2941**	**814**	**2192**	**37874**	100.0
Village	Ag. Labour	162	175	182	127	75	58	148	105	194	101	169	271	**1767**	6.6
	Agriculture	5094	763	1105	887	451	245	289	180	137	144	142	1882	**11319**	42.1
	Fish Trading	0	13	17	21	24	64	133	129	96	232	187	171	**1087**	4.0
	Fishing	0	125	625	822	895	888	1346	2034	733	58	26	9	**7561**	28.1
	Large Livestock	78	56	63	347	32	78	73	62	54	0	0	37	**880**	3.3
	Non-Ag. Labour	0	0	0	0	0	0	0	0	0	88	83	0	**171**	0.6
	Self Employment	974	165	160	78	73	93	629	338	651	744	24	59	**3988**	14.8
	Small Stock	22	2	2	0	28	41	1	5	19	0	6	7	**133**	0.5
	TOTAL	**6330**	**1299**	**2154**	**2282**	**1578**	**1467**	**2619**	**2853**	**1884**	**1367**	**637**	**2436**	**26906**	100

Source: computed from FAP17 socio-economic database.

References

- Barr, J.J.F. 2001. Methods for consensus building for management of common property resources, project final technical report submitted to DfID-NRSP.

- Beddington, J. and. Retting, B. 1983. Approaches to the regulation of fishing effort. *FAO fisheries technical paper, no 243*

- CNRS. 1999. Community-based fisheries management and habitat restoration project - completion report, Phase 1.

- FAP17. 1994. Supporting volume 13, Village study: Pabna Irrigation and rural development project.

- Gordon, H. S. 1954. The economic theory of a common property resource: the fishery. *Journal of Political Economy* 62:124-142

- Halls, A. S. 1998. An assessment of the impact of hydraulic engineering on floodplain fisheries and species assemblages in Bangladesh. Unpublished Ph.D. thesis, Imperial college, University of London, 526 pp

- Halls, A.S. 2001. A dynamic pool model for floodplain-river fisheries. Manuscript, Renewable Resources Assessment Group.

- Halls, A.S., Hoggarth, D.D. and Debnath, D. 1998. Impact of flood control schemes on river fish migrations and species assemblages in Bangladesh. Journal of Fish Biology. 53: 358-380.

- Heady, C. J., McGregor, J.A., and Winnett, A.B. 1995. Poverty and sustainability in the management of inland capture fisheries in south and southeast Asia, project final report to ODA.

- Hoggarth, D. D., et al. 1999. Management guidelines for Asian floodplain river fisheries. Part 2: Summary of DfID research. FAO *fisheries technical paper, no 384/2.*

- Hoggarth, D. D., Halls, A. 1997. Fisheries dynamics of modified floodplains in southern asia: project final technical report to ODA.

- IUCN. 1990. Fisheries resources - Phase 1. Dhaka: National Conservation Strategy Secretariat, Bangladesh Agricultural Research Council

- Kremer, A. 1994. *Equity in the Fishery: A floodplain in N.E. Bangladesh.* Centre for Development Studies, University of Bath

- MACH-CNRS. 2000. Baseline report on fisheries, vegetation, wildlife and household protein consumption. Dhaka: MACH

- Panayotou, T. 1982. Management concepts for small-scale fisheries: economic and social aspects. *FAO fisheries technical paper no. 228*

- Schaefer, M. B. 1954. Some aspects of the dynamics of populations important to the management of commercial marine fisheries. *Bulletin of the Inter-American tropical tuna commission* 1:25-26

- Sultana, P., and Thompson, P. 2000. Community fishery management implications for food security and livelihoods. In *IIFET 2000 Proceedings*

- Thompson, P., Sultana, P., Islam, N., and Kabir, M. 1999. An assessment of Co-management arrangements developed by the Community Based Fisheries Management Project in Bangladesh, paper presented at the *International workshop on fisheries co-management*, Penang, Malaysia.

- Toufique, K. A. 1999. Property rights and power structure in inland fisheries in Bangladesh. In *Sustainable inland fisheries management in Bangladesh*, ed. H. Middendorp, Thompson, P., and Pomeroy, R. Makati City: ICLARM

- Welcomme, R. L., and Hagborg, D. 1977. Towards a model of a floodplain fish population and its fishery. *Env.Biol.Fish.* 2:7-24

- Welcomme, R.L. 1985. River fisheries. FAO fisheries technical paper 262. Rome: FAO.

Chapter 4: Surface water abstraction for Boro irrigation

4.1 Introduction

With the introduction and promotion of small-scale irrigation, the cropping pattern on the floodplains has shifted away from rainfed deepwater rice in the monsoon season and dryland crops in the rabi season, to a pattern heavily centred on an irrigated dry season boro rice crop. Much of the irrigation boom has made use of tubewell technology, and thus exploited ground water, leading to its own set of problems. Nonetheless, there has been a consistent use of abstraction of surface water for irrigation – its currently supplies about a third of demand.

During the dry season the water that remains in floodplain waterbodies has many demands placed upon it. It is a common good in which rights to bathe, wash animals, navigate boats, and draw irrigation water are held communally (Toufique, 1997; Chadwick, *et. al.* 1999). As the water recedes into closed water bodies, the fishing rights fall under *jalmahal* leasing regulations. Nonetheless, as the water further recedes due to evaporation or abstraction, fish are concentrated and become easier to catch, stimulating increased involvement in fishing by seasonal and opportunistic fishers (FAP 17, 1994). If this fishing becomes too intense, then the over-wintering fish population is critically reduced, reducing its ability to recover in the next flood season. For this reason, there are a number of development initiatives to establish fish refugia and seasonal catch bans in dry season water bodies.

While it is more straightforward to identify over-fishing in shallow dry season water bodies as impacting on the fish population and thus fisheries productivity, little previous work has been done to quantify the impact of water abstraction on the productivity. Nonetheless, when interviewed in R6756, fishermen frequently identified surface water abstraction as cause in the long term decline in productivity they had observed. Surface water abstraction is thus an on-going source of conflict between fishing interest and those farming with surface water irrigation. This chapter examines and quantifies the problem for the PIRDP area, and explores possible mitigating measures using crops with lower irrigation demand.

4.2 The extent of surface water irrigation in Bangladesh

The history of irrigation development in Bangladesh is well documented (*e.g.* Wood and Palmer-Jones (1991); Hossain (1986)). While the rice economy was geared towards flood season *aman* production initially, the introduction of irrigation-intensive HYV rice in the late sixties and seventies resulted in rapid expansion of irrigated *Boro* cultivation. This period was initially marked by government-subsidised installation of DTW's and LLP's. The large capacities of these initial 2 cusec installations, and the co-ordination of sufficient farmers required to make these schemes more viable posed some initial problems. The introduction of 0.5 to 1.5 cusec STW's, however, created a burgeoning of small-scale irrigation and concomitant HYV rice boom that has continued unabated. Where irrigation is assured in the dry-season, the high-yielding nature of the *boro* crop makes the previous lower-yielding deep-water rice based cropping systems relatively less attractive.

Table 4.1 below presents the trends with irrigation broken down by methods.

Table 4.1: Areas irrigated by various methods in Bangladesh (thousands of hectares)

Year	Ground	Surface	Modern	Traditional	Total
1970	48	1121	659	599	1169
1975	106	1325	784	648	1432
1980	358	1280	1174	464	1639
1985	893	1204	1664	432	2097
1990	1746	1280	2594	432	3026
1995	2592	1158	3048	348	3396

* Sources: BBS (1997), FAO (2001) and Alauddin and Tisdell (1998)

The table clearly illustrates that the expansion of groundwater via STWs has resulted in surface-water irrigation methods becoming relatively less important over time. In absolute terms, however, surface-water irrigated area has not declined. Indeed, in the more flood-prone, lower-lying areas adjoining water-bodies that we are primarily interested in, irrigation via surface water is likely to be a more significant part of total irrigation than is reflected in regional or national statistics. Indeed, given the recent problems with arsenic in ground water (Rashid and Mridha, 1998), and the suspicion that arsenic-contaminated groundwater might be resulting in high arsenic levels in rice (Orr, 2001), it is probable that there has been a renewed interest in surface water irrigation that is not reflected in Table 4.1.

Large-scale surface water irrigation projects drawing water from main rivers, such as the Ganges-Kobadak and the Chandpur irrigation project are limited in scope, supplying only about 10% of total surface-water irrigation in Bangladesh (Ahmed, *et. al.*, 1990)[22].

There are three primary ‘minor’ surface water irrigation technologies, drawing water from secondary rivers, *khals* and beels. *Dhoans* are tipping channels (canoes) that raise water using a lever and a counterbalance, by dipping one end of the canoe into the inlet and tipping it so that water flows out into the irrigation channel at the other end. Swing baskets are operated by two people at a time swinging the two ends of a rope to which a bucket is attached in the middle, raising small amounts of surface water. LLPs, being diesel-fuelled power pumps, have a water-extraction rate that is

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[22] Although there is increasingly a view that further irrigation expansion in Bangladesh will have to come from these sources (Orr, 2001).

an order of a magnitude higher than the traditional methods like *dhoans* and swing baskets. Information in table 4.2 below highlights the extractive capacity of LLPs compared to other modes of irrigation.

Table 4.2: Irrigation and extraction capacity of minor irrigation systems in Bangladesh*

System	**Volumes raised (litres/sec)**	**Typical command area (hectares)**
Dhoan	1.1	0.40
Swing basket	1.7	0.14
LLP	56.6	14
STW	16-30	4.8
DTW	56.6	20

*Source: Herbon (1990)

Given the temporal decline of traditional methods, as seen in table 4.1, and the naturally limited capacity of *Dhoans* and swing baskets observed in table 4.2, continued threats to the fishery via surface water extraction can be attributed principally to the operation of LLPs. Typical (2 cusec) LLPs have the capacity to irrigate upto 30 hectares, but as seen in table 4.2, average command areas are about 14 or 15 hectares. Given their high discharges, they are more economically viable when their command areas are larger, and hence there is always pressure for an LLP owner to extend operations beyond the immediate vicinity of the *beel*, pond, or river from which extraction takes place. There are strong natural limits to such expansion, dictated by elevation, soil permeability, etc. However, it is still frequently found that long main channels are able to carry LLP-pumped irrigation water to command areas some distance away (Wood and Palmer-Jones, 1991). Of more recent advent are 1 cusec LLPs, and mobile LLPs (5 horsepower or less) that are reportedly being used as 'taxi pumps'[23] in some floodplain areas. The introduction of such cheaper and more transferable extraction equipment can be expected to exacerbate the situation by widening access and providing opportunistic owners the means to exploit even the smaller and shallower dry season waterbodies.

4.3 Water requirements for Boro irrigation

Compared to other rice systems, irrigated rice is generally recognised as highest yielding, but also the most input (particularly, water) intensive. A rice crop will typically require between 1000 and 3000 mm per hectare per season, depending on efficiency of irrigation management, including field losses. Water is required for land preparation at the start of the season, with two to three weeks of soaking at the outset. Ploughing, harrowing, puddling, land-levelling and transplanting in subsequent weeks have to be done in soft soil, requiring further applications of water. The standing crop itself will require submergence of about 5 to 7 cm in the field

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[23] Richard Palmer-Jones, personal communication.

(Mikkelsen and De Datta, 1991). In many developing countries, with insufficient standards in operation and maintenance, field losses due to evaporation, transpiration, land soaking and preparation, percolation, seepage and surface runoff can be huge, and even when operated at 100% efficiency, field losses may be as high as crop requirement (Greenland, 1997).

Across Bangladesh, there is considerable disparity in the quantities of water applied to the Boro crop. Boro water demand will generally depend on: (i) soil structure: heavy textured soils with tendencies to puddle are easier and cheaper to irrigate (Morris, *et. al.*, 1997), with lower water requirements due to natural moisture retention qualities. (ii) land elevation: lower lying land, by virtue of retaining more water after flood drawdown, will have lower irrigation need. Not only do these physical factors determine the water requirement for the Boro crop, but they also play a broader role in the very choice of Boro over competing *rabi* crops. By requiring more water, and being physiologically more tolerant to waterlogging, the natural comparative advantage of the rice crop is increased as land elevation is lowered and soils become more impermeable.

Apart from these physical factors, however, the incentive structure of the local irrigation scheme also plays a part in determining how much water the crop receives. As will be discussed later, there are great inter-regional differences in irrigation water payment structures. In some irrigation markets, payment is on the basis of fuel costs, which provides an incentive to conserve water. In others, payment may be on the basis of crop shares. In these cases, both the irrigation supplier as well as the farmer share the risk of crop production and thus have an incentive to ensure plentiful supplies of water to the crop. With ground as well as surface water being essentially open access resources to anyone who has the capital to invest in a pump (Palmer-Jones, 199???), crop share arrangements may well result in applications in excess of crop requirements as there are no incentives to manage the resource will greater efficiency.

These disparities are reflected in Table 4.3 below, where Boro water applications recorded in three different studies are reported. The application levels look innocuous at first glance, but a hint of the extent of abstraction and the resultant lowered availability of water to the fishery is provided by conversion to volume figures. A 1000 mm per ha application, at the bottom end of the range given in the table, translates to 10,000 cubic metres of water extraction for every hectare irrigated. With a typical command area of 14 hectares (35 acres), a single LLP could remove 140,000 cubic metres of water from a *beel* or pond in a single season. When losses from conveyance are taken into account, this number could be substantially larger.

Table 4.3: Irrigation water applications to Boro crop recorded in 3 studies

	Application range*
Biswas and Mandal (1993)	600 to 850 mm per ha
BRRI (1996)	1278 to 1318 mm per ha
Sufian (2001)	1300 to 2650 mm per ha

*Water for land soaking and land preparation has been added to plant growth stage water applications in this computation.

4.4 Modelling the effect of boro irrigation abstraction on the fishery

Methodology:

In order to assess the effects of surface water abstraction on the fishery, three alternate boro irrigation schedules were put together. Multiple schedules were necessitated by the wide variation in boro water applications in Bangladesh. The application rates and their temporal distribution through the *rabi* season were established on the basis of previous literature (Biswas and Mandal (1993); Mandal and Dutta (1995); Sufian (2001)). Additionally, experts on rice production and irrigation from the Bangladesh Agricultural Research Council (BARC) were consulted in preparing the schedules[24]. The developed schedules are presented in tables 4.4-4.6. In all cases, land preparation is assumed to begin in the second week of December, continuing on to the first week of January. Transplanting is assumed to occur in the second week of January, and harvest in the second week of April. It is assumed that there is no rainfall during the *boro* growing season. Obviously, factors such as the number of applications and the amount of water in each application is subject to wide variation. The developed schedules attempt to present an ‘average’ or ‘typical’ picture, with consideration given to widely observed farmer practices, such as reductions in water applications in weeks seven and eight after transplanting, to promote tillering.

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[24] Our thanks to Dr. S.B.Naseem and his colleagues in BARC for their inputs.

Table 4.4: Amount of irrigation applied to Boro crop at different schedules

(**high** case: 400 mm for LS & LP and 1600 for crop growth – 2000 mm per ha total)

Period	Water applied	Comments	Crop Growth (weeks after Transplanting)
Dec 2nd week – Jan 1st week (100 mm per week evenly)	400 mm	Soaking & initial and final Land Preparation including transplanting	0
Jan 2nd week	140 mm	**Vegetative phase**	1
Jan 3rd week	160 mm		2
Jan 4th week	170 mm		3
Feb 1st week	180 mm		4
Feb 2nd week	180 mm	**Reproductive Phase** * during 7 and 8 weeks after transplanting farmers apply less water to encourage tillering (branching) of rice plants, standing water of more than 7 cm at this growth stage depresses tillering ability of the crop.	5
Feb 3rd week	170 mm		6
Feb 4th week	120 mm*		7
Mar 1st week	130 mm*		8
Mar 2nd week	180 mm	**Ripening phase** **No irrigation applied** Harvest	9
Mar 3rd week	170 mm		10
Mar 4th week	0 mm		11
Apr 1st week	0 mm		12
Apr 2nd week	0 mm		13

Table 4.5: Amount of irrigation applied to Boro crop at different schedules

(**low** case: 100 mm for LS & LP and 600 for crop growth – 700 mm per ha total)

Period	Water applied	Comments	Crop Growth (weeks after Transplanting)
Dec 2nd week – Jan 1 week (25 mm per wk evenly)	100 mm	Soaking & initial and final Land Preparation including transplanting	0
Jan 2nd week	40 mm	**Vegetative phase**	1
Jan 3rd week	60 mm		2
Jan 4th week	70 mm		3
Feb 1st week	80 mm		4
Feb 2nd week	80 mm	**Reproductive Phase** * during 7 and 8 weeks after transplanting farmers apply less water to encourage tillering (branching) of rice plants, standing water of more than 7 cm at this growth stage depresses tillering ability of the crop.	5
Feb 3rd week	70 mm		6
Feb 4th week	20 mm*		7
Mar 1st week	30 mm*		8
Mar 2nd week	80 mm	**Ripening phase** **No irrigation applied** Harvest	9
Mar 3rd week	70 mm		10
Mar 4th week	0 mm		11
Apr 1st week	0 mm		12
Apr 2nd week	0 mm		13

Table 4.6: Amount of irrigation applied to Boro crop at different schedules

(**Intermediate** case: 200 mm for LS & LP and 1200 for crop growth – 1400 mm per ha total)

Period	Water applied	Comments	Crop Growth (weeks after Transplanting)
Dec 2nd week – Jan 1 week (50 mm per wk evenly)	200 mm	Soaking & initial and final Land Preparation including transplanting	0
Jan 2nd week	80 mm	**Vegetative phase**	1
Jan 3rd week	120 mm		2
Jan 4th week	140 mm		3
Feb 1st week	160 mm		4
Feb 2nd week	160 mm	**Reproductive Phase** * during 7 and 8 weeks after transplanting farmers apply less water to encourage tillering (branching) of rice plants, standing water of more than 7 cm at this growth stage depresses tillering ability of the crop.	5
Feb 3rd week	140 mm		6
Feb 4th week	40 mm*		7
Mar 1st week	60 mm*		8
Mar 2nd week	160 mm	**Ripening phase**	9
Mar 3rd week	140 mm		10
Mar 4th week	0 mm	**No irrigation applied**	11
Apr 1st week	0 mm		12
Apr 2nd week	0 mm	Harvest	13

With the schedules established, the FPFMODEL was used to simulate the effect on PIRDP 'inside' fish catches of these extractions. The 1995-96 dry-season water levels were chosen as the baseline, and it was assumed that no abstraction occurs at the baseline[25]. Then the water volumes in the PIRDP dry-season waterbodies were reduced by the abstracted amounts, and the FPFMODEL was used to generate predictions of numbers of recruits, yield per recruit and other biological parameters, and of course, yield itself. The simulations (for each irrigation schedule) proceeded by assuming one hectare of *boro* irrigated by abstraction, and then two, three, and so on until the abstraction levels caused recruitment failure.

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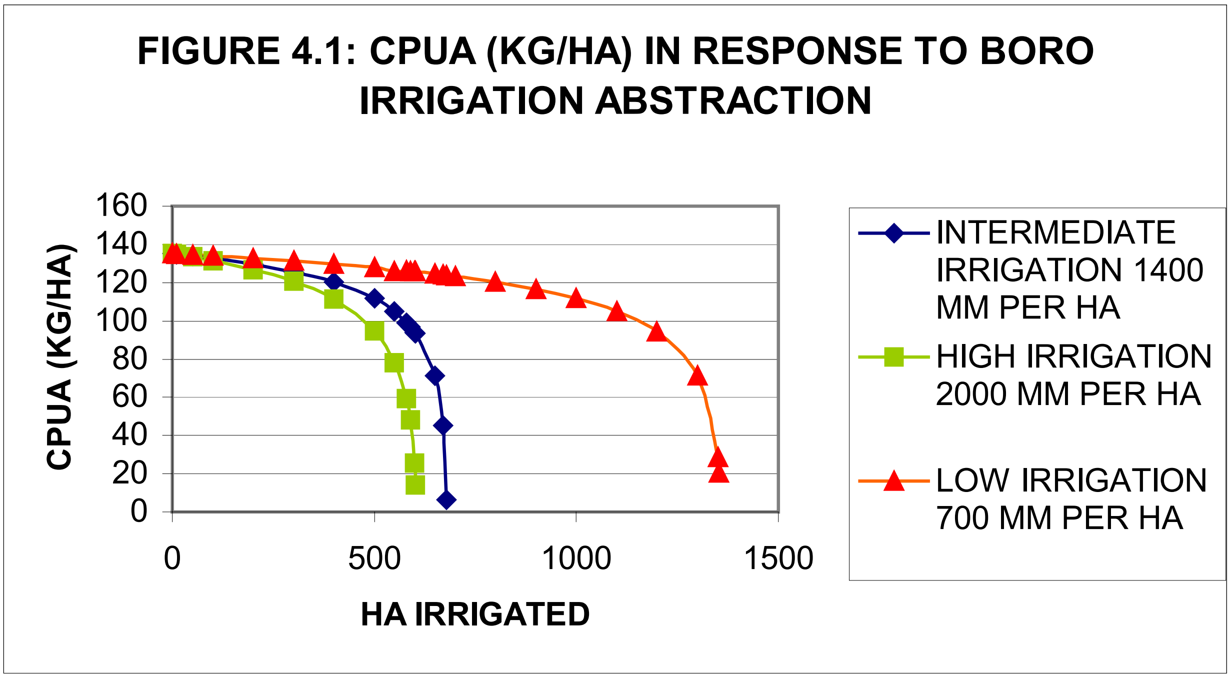
[25] In reality, abstraction does occur in the PIRDP at the baseline, from reports of FAP(17). However, we find that this does not pose a problem for the accuracy of the simulation, due to linearity in the CPUA-abstraction relationship. This will be explained shortly.

4.5 Results

The results are summarised in figure 4.1 below:

Figure 4.1: CPUA – hectares irrigated relationship



The diagram shows that the effects of abstraction on the fishery can be quite dramatic. After a threshold range is passed, the decline in catches is very rapid, until recruitment failure occurs and the fishery collapses. In the site with an area of 6773 ha inside the PIRDP that we consider, for example, abstracting surface water to irrigate more than 500 hectares or so based on the 'high' or 'intermediate' irrigation schedules results in rapid loss in fish productivity, with a complete collapse occurring after about 600 hectares is irrigated. The losses are predominantly due to reduced recruitment to the fishery.

Yet, our interest is not so much in the levels of abstraction that cause catastrophic failures in the fishery, as in the widespread losses caused by more moderate abstraction levels in most floodplain sites. For abstraction to the extent of causing recruitment failure and complete collapse of the fishery is perhaps not a common occurrence in Bangladesh, though there are well documented examples of *pagar* and *kua* fishing in which fish are aggregated to sump areas, which are pumped out in the dry season so that every last fish is caught. There are natural bounds to the extent of abstraction that can take place, since as the waterbodies progressively dry up, it becomes more difficult and expensive to operate LLPs and other extraction equipment for rice irrigation.

How can the relationship between CPUA and hectares irrigated via surface abstraction shown in the diagrams be quantified? Estimation of regression relationships is one way. However, there are two problems in this regard: (i) the relationships are seen to be substantially non-linear, after thresholds are passed. A non-linear regression could be estimated, however the relationship between CPUA and irrigated hectares would then not reduced to a simple quantity, but would rather depend on the point at which the relationship is estimated, and (ii) as discussed above, if abstraction is already existing at the baseline and a non-linear relationship is estimated, ignoring the baseline abstraction would bias the results. However, the solution to this was found in the fact that the relationships are seen from the figure to be approximately linear until thresholds are reached. As discussed above, it is this portion that is of particular interest to us. By estimating linear regressions pertaining to the linear portions, we can obtain simple scalar quantities for the CPUA-hectares irrigated relationship. Linearity of those initial portions also implies that lack of knowledge about baseline abstraction levels will not bias results.

Regressions were estimated for the linear portions of the CPUA-hectares irrigated relationship shown above. The results are presented in table 4.7 below:

Table 4.7: Regression results for CPUA – Ha irrigated relationship

High schedule: R^2=0.99

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	135.5865	0.422925	320.5927	5.68E-10
HA IRRI	-0.04742	0.002743	-17.2856	6.57E-05

Intermediate schedule: R^2 = 0.97

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	135.6619	0.490101	276.804	1.17E-11
HA IRRI	-0.03573	0.002357	-15.1576	2.27E-05

Low schedule: R^2 =0.98

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	135.4856	0.222788	608.1366	2.33E-32
HA IRRI	-0.01643	0.00047	-34.9377	5.07E-15

The regression results demonstrate a significant impact of abstraction on the fishery, even at lower ranges of abstraction at which fishery collapse is not a threat. For the ‘intermediate’ schedule, which can be expected to be average for the area, every additional hectare of irrigation via surface-water abstraction results in a loss of approximately 0.03 kg of catch per hectare, per year. If this is extrapolated to the entire ‘inside’ PIRDP site of 6773 hectares, the loss amounts to about 242 kg of fish for every hectare irrigated. For the ‘low’ schedule, which is characteristic of water applications on low elevation plots, the reduction is 0.01 kg per hectare, or 67 kg of catch loss for the site as whole, per year.

4.6 Potential solutions and interventions

Substitution of groundwater for surface water irrigation

Does the solution to the abstraction problem lie in encouraging and enabling a switch to alternative (groundwater) modes of irrigation? Three factors point to an answer in the negative.

(i) The hydrological interconnectivity between ground water aquifers, surface water bodies and rivers implies that additional pressure on ground water sources would continue to deplete surface sources of water. Bhoumik (1986), cited in Khan (1988), reports that almost 50,000 dry season waterbodies in the Barind area have almost dried up, with groundwater pumping from shallow aquifers nearby being a major contributory factor. The connectivity between groundwater aquifers and rivers is also liable to cause reduced streamflows in rivers, in turn negatively affecting fish populations. Stream channels of rivers often have a direct connection with unconfined aquifers, with the relative water level gradient determining whether the stream is recharged by the aquifer or the aquifer receives base flow discharge from the river (Khan, 1988). Dry season water groundwater abstraction via shallow tubewells thus contributes to reduced lowered dry season flows in rivers.

(ii) Concerns are being expressed in several quarters that groundwater extraction in Bangladesh is reaching the limits of its potential. The relentless expansion of STWs has resulted in several aquifers drying out in the dry-season. In some parts of the country, this has resulted in deeper wells being dug, and switches made from shallow to deep tubewells, with the latter yet to prove financially viable (Zohir, 2001).

(iii) Arsenic contamination of groundwater from naturally occurring sources is now recognised as a widespread problem in Bangladesh. Occurring as geological deposits at depths of 40 to 150 feet, arsenopyrites contaminate groundwater with arsenic concentrations ranging from 0.1 to 3.0 mg/l (Rashid and Mridha, 1998). Forty-one out of sixty-four districts in Bangladesh have recorded arsenic levels above safe maximum limits, contributing to various skin diseases, ulceration and cancer. This problem quite possibly extends beyond the use of groundwater for drinking purposes. IRRI-Bangladesh's Poverty Eradication Through Rice Research Assistance (PETRRA) project is currently supporting research on arsenic in the food chain. It is suspected that irrigation from arsenic-contaminated groundwater might be resulting in high arsenic levels in rice. If this is the case, then any future growth in irrigation would inevitably have to come from either 'safe aquifers' or surface water sources! (Orr, 2001).

Promoting water-saving management practices

As indicated earlier, water efficiencies (ratio of water used to water applied) can be quite low in developing countries. Firstly, water applied for land preparation is often considerably in excess of technical requirements. While applications of about 150 to 200 mm are generally considered adequate for this purpose, Ghani *et. al* (1989) found that the actual use in the Ganges-Kobadak irrigation project in Bangladesh was often ten times this amount. The more permeable the subsoil, the greater the tendency for water applied for land-preparation to pass through the topsoil, flowing to surrounding areas through lateral drainage (Guera, *et. al* 1998). Since the Boro crop is transplanted, land soaking may continue while the seedbeds are being prepared and germinated. The longer the process of land preparation, the greater the scope for water loss.

Secondly, water applications in the crop growth periods could be considerably in excess of crop requirements. The excess water plays no productive role, either running off the surface or seeping/percolating into the ground. Two factors contribute to excess applications during crop growth. Maintenance of high water levels is sometimes pursued as a weed-control strategy in rice. Also, where irrigation is not reliable, farmers may attempt to store excess water as insurance against irrigation failure. In irrigation schemes in Bangladesh, mid-season pump breakdown is a common feature. Also, LLP schemes in particular are vulnerable to the risk of the water source unexpectedly running dry later in the season.

Some avenues exist for saving water applications in this context. Guera, *et. al.* (1998) suggest the following: (i) Adoption of improved varieties with shorter growth durations could save water during crop growth stages. (ii) Better soil nutrient and weed management practices could produce higher yields for the same water applications, and in this manner perhaps encourage the reduction in water applications. (iii) Reducing the period of land preparation could save water at an early stage in the season. (iv) In drier areas where seeping/percolation is a problem, shallow, dry tillage after harvest of the previous crop would minimise the formation of soil cracks and the occurrence of bypass flow. (v) Application of enough water during growth stages to keep the soil saturated, in contrast to the widespread practice of maintaining ponded water, is adequate. (vi) Adoption of direct-seeding methods of crop establishment instead of transplanting rice can result in considerable water savings. Wet-seeding of rice, where pregerminated seeds are broadcast on saturated and puddled soil, and dry-seeding, where ungerminated seeds are broadcast on dry but moist and unpuddled soils, have proven successful elsewhere in Asia, primarily in areas where labour is at a greater premium than in Bangladesh, where labour-intensive transplanting is common.

In this study, our primary concern is with irrigation for Boro rice production in low-lying, flood prone areas. While there is doubtless scope for water saving in practically any irrigated rice production system, some of the above approaches may be less relevant to the situation that particularly concerns us. With LLP command schemes (particularly in *beel* areas) being dominated by lands classified as low and medium-low in elevation, water use in land preparation is unlikely to be excessive. In fact, LLP command areas often also include very low land reclaimed by draining water from the beels after drawdown, and lack of soil moisture will not be a problem in such plots. Also, evidence from experiments in irrigated lowland rice has not indicated that direct water reductions can be an unqualified success. Bouman and Tuoung (2001) use evidence from a number of experiments in topical Asia to demonstrate that, although there is scope for substantial savings in water, yield reductions due to drought stress are possible. Also, as heavier soils become drier, their percolation rates increase and cracks may develop, hastening bypass flow. Maintaining water applications targeted at soil saturation levels instead of ponded levels requires considerable control over the irrigation process. This strategy is less likely to be successful in irrigation systems that serve several farmers at once, are subject to uncertainty in the precise timing of water applications to individual plots, and where there is no water pricing incentive to use irrigation more efficiently. Other water saving methods such wet and dry-seeding methods have been tested in Bangladesh primarily for *Aus* rice cultivation (BRRI, 1996), but have not found much acceptance as they are also labour-saving strategies, for which there is little demand. They also tend to be more commonly used elsewhere for wet season rice crops.

Significantly, whether ‘overapplication’ of water to plots is a problem that broadly characterises Boro production in Bangladesh is itself a debatable question. In a study on crop diversification possibilities in Bangladesh, Mandal and Dutta (1993) found that the Boro rice plots in their study typically received irrigation amounts equal to or less than their actual needs. In their study, apart from one or two minor horticultural crops, most crops received *less* than their theoretical water requirements in the season. For some crops like Brinjal and Wheat, this underapplication was severe (less than 50% of demand met). For Boro rice, the applications were on average 50 to 75% of requirement for DTW command areas and 75 to 100% of requirement for STW command areas.

4.7 Diversifying out of Boro

If the productivity of open water body fisheries are to be maintained by reducing the impact of abstraction, a solution acceptable to powerful local farming interests who use irrigation would be needed. It is not likely to be feasible to prevent abstraction of surface water altogether, however if other, potentially more profitable, rabi season crops that require lower amounts of irrigation can be promoted, then the tension between dry season cropping and fishing can be reduced. The following section examines a number of potential alternative rabi season crops, their irrigation demand, the impact of this irrigation abstraction on fisheries, and their profitability.

There is by now a significant literature on crop diversification possibilities in Bangladesh. The Department of Agricultural Extension has identified 51 crops to be included as part of national plan for crop diversification. The World Bank views diversification as a significant avenue not only for agrarian growth in Bangladesh, but also as a contributor to nutrition, poverty alleviation, employment generation, and sustainable natural resources management (Ateng, 1998). In 1995, the World Bank completed a sector review on diversification prospects in Bangladesh examining several alternatives to HYV rice production, including speciality rice, wheat, maize, other minor cereals, oilseeds such as mustard and sunflower, pulses such as *khesari*, vegetables such as brinjal, potato and cauliflower, spices such as onions and garlic, and industrial crops such as cotton and jute. In many cases, particularly for several vegetables, fruits and spices, financial as well as economic returns were found to be higher than for HYV rice. Several of these crops are grown in the *rabi* season, and can be viewed as alternatives to Boro production.

There are several reasons why diversification out of rice, particularly Boro, and into alternative crops is deemed desirable: (i) HYV rice monoculture is thought to be unsustainable in the long run, leading to soil stress, accumulating nutrient imbalances, and increased vulnerability to pest and disease threats (Metzel and Ateng (1993), Pagiola (1995)) (ii) Sustained increases in rice acreage and HYV adoption over the years have resulted in a degree of self-sufficiency in rice. There is a worry that, with rice being grown year-round in three seasons, continued rice surpluses could depress rice prices in the future and increase the vulnerability of small farmers locked into rice production, with inadequate experience in cultivating alternate crops. (iii) With dry-season rice being significantly more irrigation-intensive than alternative *rabi* crops, diversification affords the opportunity to conserve water and expensive energy that is required to extract water in lift systems. (iv) With the immediate objective of cereal self-sufficiency having been attained, marked-oriented production generating higher surpluses is seen as the next step in the agrarian growth process (v) Diversified farming-systems, as a subset of diversified livelihood systems, can help risk-averse small farmers hedge against the large production and price risks that are inherent in the production of individual commodities.

Another large project has studied crop diversification possibilities in Bangladesh, focusing particularly on irrigation management in diversified systems. A multidisciplinary team from the Bangladesh Agricultural University (BAU) examined an entire set of research questions regarding diversification out of Boro and into horticultural production, ranging from adoption issues and relative profitability to detailed agronomic matters such as tillage operations, water application methods, irrigation scheduling, soil fertility and pest threats (Biswas and Mandal, 1993; Mandal and Dutta, 1995). Based on field trials in study sites comprised mostly of high and medium land with silty soils in Madhupur, a large number of cropping patterns incorporating horticultural crops were found to be financially attractive as well as environmentally sound. A broad conclusion emerging from the study was that there is little justification for continued *Boro* production in higher elevation plots. With an increase in land elevation, the irrigation requirement and the comparative disadvantage of rice production compared to high-value alternate *rabi* crops grows, as noted earlier. For instance, the intercropped production of potato and brinjal on high land was found to produce four times the net return provided by Boro. Water savings were considerable. Table 4.8 below presents theoretical water demands for Boro and a set of competing *rabi* crops, evaluated at the Jhenidah study site in the BAU study. As is evident, Boro production requires about three to four times as much water application than competing crops. Inclusion of water for land preparation in high lands would further increase this gap, since high lands require considerable soaking for Boro, while most other rabi crops do not[26].

Table 4.8: Expected irrigation demands for rabi crops at Jhendiah (mm per ha for rabi season, not including land soaking and preparation demands)

Rabi crop	Irrigation Demand
HYV Boro	835
Wheat	200
Maize	240
Brinjal	320
Onion	175
Potato	190

Source: Biswas and Mandal (1993)

The potential for, and the importance of, diversification in Bangladesh is by now well-established, and it is not the intention of this study to go into a detailed review. A key point to note, however, is that diversification studies have concentrated on medium-

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[26] In fact, the water application for Boro land preparation alone would be adequate to meet the full irrigation demands of most alternative rabi crops!

high and high lands. This is as it should be, since it is in the higher land elevations that the economic and water-use gaps between Boro and competing *rabi* crops stand out in sharpest relief. However, what about the lower-lying floodplain areas characterised by predominantly medium and low-elevation land, are they fated to suffer the *boro*-fish irrigation trade-off and the consequent effects on livelihoods?

Diversification possibilities in flood-prone areas

Deeply flooded areas with irrigation availability are often characterised by single crops of Boro rice. As seen in Charan Beel[27], 23% of ML plots and 20% of MH plots following a fallow-fallow-boro cropping pattern. However, it was not traditionally so. Prior to the small-scale irrigation revolution, the predominant cropping-system in such areas involved broadcast deepwater *aman* rice in *kharif*, often followed by *rabi* crops such as mustard in the dry-season. As is well-known, deepwater rice is a remarkable crop that will elongate in response to rising floodwaters, thereby minimising the risk of crop-loss due to floods. However, neither DW *aman*, nor typical traditionally following crops like mustard are particularly high yielding.

The expansion of minor irrigation into such areas therefore led to the abandonment of the DW-rice based system in favour of Boro, which can provide upwards of 4 tonnes per ha when irrigation is assured. A key point to note is that the historical expansion of Boro rice in low-lying areas came largely not as a *rabi* crop to follow DW rice, but rather as a single dry-season crop followed by fallow in *kharif.* The reason for this is that the boro harvest is often too late to allow timely establishment of the DW rice crop before the arrival of floods (Catling, 1992). Some innovations have managed ways around this problem. Development of methods of cultivating *Transplanted* DW Aman has enabled DW Aman-Boro rotations in some parts, particularly in Tangail district and parts of the North-west (Catling, 1992). Ratooning provides another opportunity to combine the boro and deepwater rice crops. In parts of Bangladesh, DW rice and Boro may be planted together at the start of the dry-season. Both crops will provide a harvest in May, but after being cut back, the ratoon from the DW crop will grow over the flood period and provide a normal DW Aman harvest in November/December (Miah, *et. al.,* 1990). These innovations remain confined to pockets of flood-prone areas, however, and by and large, the replacement of DW Aman patterns has meant single boro crops, or early rabi crops like mustard followed by boro. As Morton (1989) describes the cropping system changes in deeply flooded areas, '…*The loss of the monsoon crop represents a major opportunity cost attributable to tubewell irrigation. The net benefits of irrigation are therefore significantly less in these areas when compared to those where the introduction of an irrigated boro crop does not preclude a second, monsoon season rice crop.'* (Morton, 1989, page 19).

Since the late 1980's and early 1990's, however, a reversal of trends has been noticed in several deeply flooded areas, with DW aman – based cropping patterns making a comeback. Significantly for our purposes, these seem to have involved DW aman rice in the monsoon, followed by a non-rice *rabi* crop, and have been recorded in low-lying areas. In other words, there is evidence of the existence of some natural momentum for *rabi* diversification even in flood-prone lands, which could be fostered in areas where water abstraction currently poses a significant threat to the fishery. Catling (1992) reports that this trend is possibly because of a temporal decline in Boro yields, faulty irrigation systems, and low rice prices, resulting in better and less risky returns from a DW-aman – rabi pattern compared to a fallow-boro pattern. BRRI-ODA (1986) reported that DW-Aman followed by dry section pulses or

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[27] See the chapter on early-onset flooding and short duration crops.

vegetables was found to be more profitable in the North Central region than a single crop of Boro.

There is strong evidence of this promising trend in the very area that the FPFMODEL is calibrated to. FAP 17's PIRDP socio-economic study notes '*From the 1993-94 season, a considerable number of farmers in Gandahasti Beel are reported to be shifting back to the older cropping pattern of deep-water, broadcast aman followed by rabi crops, particularly onion, as the returns are better* (FAP 17, 1994, page 36). Further indication that alternative rabi crops have a presence even in lower-elevation lands in the PIRDP region is given in table 4.9. The information in this table comes from a survey of cropping patterns within the Talimnagar sluice gate inside PIRDP, conducted as part of DfID-NRSP's project R6383, 'Preliminary investigation of agricultural diversification and Farmer's Practices in Bangladesh floodplain production systems involving rice-fish production'

Table 4.9: Cropping patterns in Pabna FCD/I scheme

Land Type	Single Cropped			Double Cropped			Triple Cropped		
	Kharif 1	Kharif 2	Rabi	Kharif 1	Kharif 2	Rabi	Kharif 1	Kharif 2	Rabi
High	B Aus Jute Bamboo	LT aman Bamboo	Wheat	Jute	LT aman	Wheat Oilseed Pulses Onion	B Aus Jute	LT aman	Pulses Oilseed Wheat Onion
Med. High	Mixed B Aus B aman Jute	Mixed B Aus B aman LT aman		Mixed B aus B aman	Mixed B aman LT aman	Pulses Wheat Oilseed Onions	B aus Jute	LT aman	Pulses Oilseed Wheat Onion
Med. Low	Mixed B aus B aman	Mixed B aus B aman		Mixed B aus B aman	Mixed B aus B aman	Pulses Wheat Oilseed Onions	Jute	LT aman	Pulses Oilseed Wheat Onion
Low & V. Low	Mixed B aus B aman	Mixed B aus B aman Fish	Hyv Boro L Boro	Mixed B aus B aman	Mixed B aus B aman Fish	Onions	Mixed B aus B aman	Mixed B aus B aman Fish	Onion

Source: Alam, *et. al*, in Barr (1996)

The table reveals that, even in the lower lands of this deeply flooded region, viable alternatives to the boro crops have emerged. Pulses, wheat, oilseed and onions, are all successfully grown in the dry season, mostly as part of double-cropped or triple-cropped systems involving broadcast aus and/or aman (DW) in *kharif*. The presence of boro is surprisingly limited in this area – boro only seems to appear as a single crop in low lands. While pulses and oilseeds are traditional lowland *rabi* crops, the presence of lowland wheat and onions is of particular interest since the literature on diversification into these crops is typically centred around high and middle elevation lands in relatively flood-free areas. The presence of onion is seen to extend across the range[28], into the low lands, while wheat has a range from high to medium-low. The extent to which onion was grown in the 1990s to some extent reflects both the poor rice price and the expansion of private storage facilities for agricultural commodities. Cultivation of dry season onions on low land requires very good control of water as excess damages the crop. Studies in R6756 showed that this cropping pattern was possible where farmers at Padma Beel in Rajshaji District co-operated to grow a contiguous block of onion so that surplus boro irrigation would not damage the crop by saturating the soil (Barr, 1998).

There is further evidence of the viability of these patterns, and their competition with single boro patterns in lower elevation lands. BRRI (1997) reports cropping patterns according to land-type for each division in 1997. For Rajshahi division (within which the PIRDP is located), only two patterns had a significant presence in lowlands. These were DW aman-rabi (37,600 ha) and boro-fallow (111, 565 ha). Similar trends were observed in the deeply flooded Sylhet *haor* region.

4.8 Alternative rabi crops and their irrigation effects on the fishery

The preceding discussion indicates the potential viability of non-rice *rabi* crops, even in low elevation flood-prone areas, especially following broadcast aman rice in the monsoon. In the PIRDP area, wheat and onions are observed to be important non-rice *rabi* crops. Table 4.8 above has already indicated that the water requirements of these crops can be considerably lower than for *boro* rice. In this section, we simulate the effects of *rabi* diversification by carrying out FPFMODEL simulations based on irrigation schedules for these crops. The methodology followed is identical to that used for the boro irrigation schedules.

In Bangladesh, the growing calendar for onions occupies about three months from planting to harvest. On average, onions are planted in early/mid January and harvested around early/mid April. Onions are not very water-intensive, but do need water applications to meet evapotranspiration requirements[29]. Excess soil moisture can however result in bulb rotting, and irrigation therefore has to be carefully balanced (Saha, *et. al.*, 1997). The ideal irrigation technique is to use pots/sprinklers during early growth stages, and flush basin flooding with shallow ditches in later stages. The recommendation is to apply 25mm of water at 25mm of soil moisture deficit, with irrigation during bulb formation being particularly critical, and irrigation stopping when plants begin to mature. In practice, this translates to three to four applications of 25 mm per ha each about every fortnight or so (Mandal and Dutta, 1995), with a total of 75 to 100 mm per ha applied in total. Thus, the following average irrigation schedule was developed for onions.

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[28] The cropping pattern survey in NRSP's project R6383 (Barr, 2000) also found onions being produced in low lands in the project site in Rajshahi.

[29] In some areas, both wheat and onions may be grown without any irrigation.

Table 4.10: Onion Irrigation schedule (mm per ha)

Week	Application
January 1st week	25
January 3rd week	25
February 1st week	25
February 3rd week	25
Total	**100**

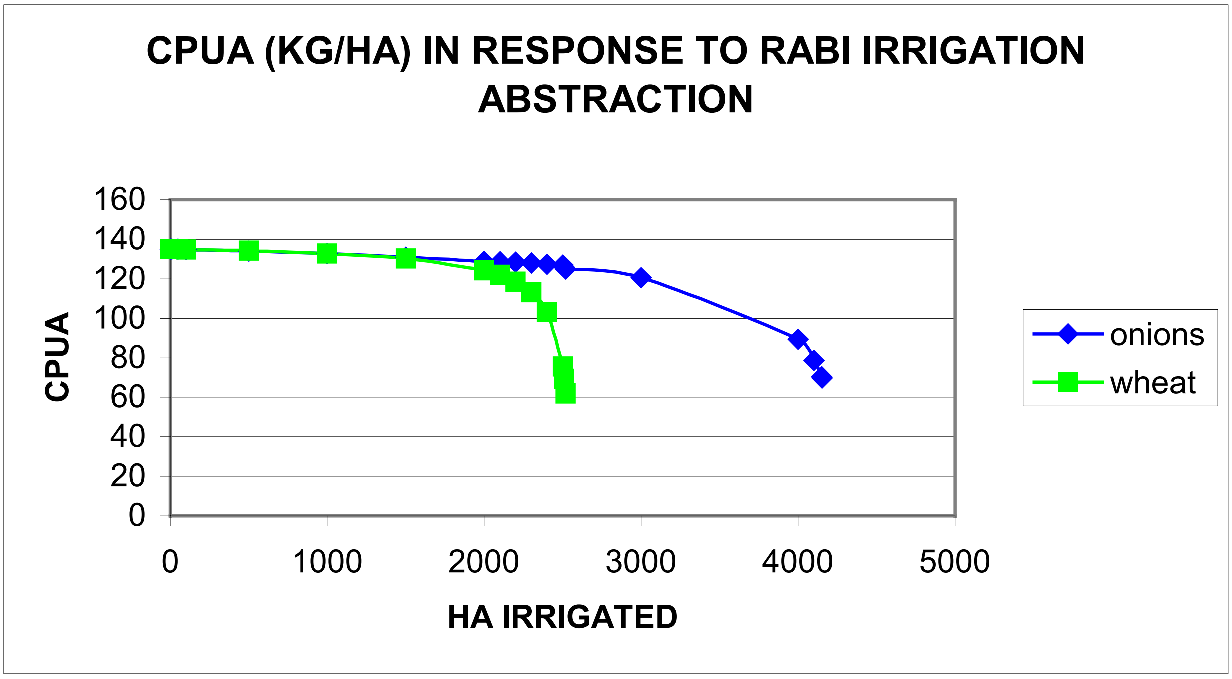
Wheat is a direct competitor for boro rice in several parts of Bangladesh. Medium and higher elevation lands with lighter soils are preferred for wheat cultivation. It becomes an attractive crop compared to *boro* when irrigation supplies are not assured, due to its low water requirement. Mostly it is broadcast sown in late November or early December. Usually, only 2 or 3 water applications are applied, with water delivered via canals directly to the plot, which is flooded to several centimetres depth (Morris, *et. al.,* 1997). The irrigations come earlier on in the crop growth stage in order to ensure good germination and vigorous early vegetative growth. The total application can be anywhere between 80 to 300 mm per ha (Morris, *et. al.*, 1997). On the basis of previous literature, and after consultation with experts at BARC, the following average wheat irrigation schedule was established:

Table 4.11: Wheat irrigation schedule (mm per ha)

Week	**Water applied**
Dec 1st week	80 mm
Dec 3rd week	80 mm
Total	**160 mm**

With these schedules established, a procedure identical to those used for the three boro irrigation schedules was followed to enable a simulation of the fishery effects of water abstraction for these crops. The results are summarised in the figure below:

Figure 4.2: CPUA – Hectares irrigated relationship for alternate rabi crops



This graph, when compared to the one for the boro schedules, illustrates the far gentler effect on the fishery of alternate irrigated *rabi* crops. Dramatic reductions in the productivity of the fishery are observed after only after 2000 hectares in the case of wheat, and after 3000 hectares for onions. Linear regressions similar to those reported for the boro cases were estimated to capture the effect on the fishery of abstraction for wheat and onion irrigation. The results are reported below in table 4.12.

The regression for wheat estimates that every additional hectare irrigated results in a CPUA loss within the catchment of 0.006. This translates to about 40.6 kgs of yield loss for the total area modelled, about one-sixth of the equivalent loss for the 'intermediate' boro schedule. For onions, the estimate is 0.003 kg per hectare loss of fish catch for every additional hectare irrigated via abstraction, or a 20.3 kg yield loss for the entire area, less than a tenth of the effect for boro.

Table 4.12: Regression results for CPUA-Hectares irrigated relationship, alternate rabi crops

Wheat irrigation: $R^2 = 0.93$

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	136.1563	1.062599	128.1351	1.54E-14
Ha irrigated	-0.0063	0.000821	-7.67194	5.9E-05

Onion irrigation: $R^2 = 0.99$

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	135.2181	0.159961	845.32	1.85E-16
Ha irrigated	-0.003	0.000165	-18.1621	1.79E-06

4.2 Economic returns to alternative cropping patterns:

The impact of surface water abstraction on the fishery and its dependent livelihoods has been established in a quantified manner. Even at ‘moderate’ levels of abstraction, the reduction in dry-season water levels, the importance of dry-season water levels for recruitment, and the interconnectivity between floodplain water bodies in the wet-season implies that at the broader *regional/catchment* level, there can be significant reductions to the fishery. Two alternative *rabi* crops we have looked at, wheat and onions, have only a sixth and tenth of the effect of boro on the fishery, respectively, when irrigated by abstraction. But if diversification in the *rabi* season is to be successfully initiated, *one* basic requirement is that these alternative cropping patterns need to be financially/economically attractive *vis-à-vis* boro.

In order to gain an understanding of these relative returns, simple average crop budgets were prepared for four crops, DW aman, boro, wheat and onions. Recent information on costs and returns pertaining directly to the PIRDP site was not directly available. Hence the budgets have been built using several secondary data sources, with an effort made to obtain information as specific to the area as possible (for instance, the price and yield data are specific to Rajshahi division). Where regional data were not available, national estimates were used. The major sources of these data were: The National Water Resources Database of the Water Resources Planning Organisation (WARPO), Bangladesh Bureau of Statistics Statistical Yearbooks and Yearbooks of Agricultural Statistics (1997-99). 3-year averages (96/97 to 98/99) of prices and yields have been taken to provide a picture less sensitive to yearly variations. Some of the costing had to rely on ad-hoc methods. For instance, irrigation costs for the same average level of water application can differ practically from command area to command area, due to differences in pricing systems. In some schemes, quarter crop shares apply, in some others, a fixed charge plus fuel costs, etc. In this case, typical estimated per-hectare costs reported in previous studies (Morris, *et. al.*, 1997; BRRI (1997); BRRI (1998); Siddiqui, *et. al.* (1994)) were used. The full budgets are presented in tables 4.14-4.17. A summary based on returns to the whole cropping cycle is presented in table 4.13 below.

Table 4.13: Returns to some alternative cropping patterns for low-lying areas (Rajshahi Division)

Cropping Pattern* (Kharif1/Kharif2/Rabi)	Net Returns (taka)	Labour use (man-days)	Returns to labour (Tk/manday)
Fallow-fallow-boro	13,742	111	124
Fallow-DW aman - Wheat	14,107	209	67
Fallow-DW aman - Onion	36,178	252	144

The DW aman-wheat combination is thus seen to provide returns comparable to a rotation with a single boro crop, with almost double the labour employment. The DW aman-onion rotation provides very high returns, almost three times that of the single boro rotation, and provides additional employment of about 140 man days during the year. Thus both in terms of profitability and returns to labour, use of onions as an alternative rabi season crop to boro appears a better option at the individual farm scale. Onion requires a higher level of skill and a considerably higher labour input. However at a catchment or other macro scale, there is need for consideration of what other livelihood options are available in the rabi season, and thus whether the extra 140 mandays have a negative opportunity for onions.

4.10 Summary and Conclusions

Abstraction of surface water for irrigation poses a serious threat to the sustainability of floodplain fisheries in Bangladesh. Previous research has accorded a central role to dry-season water maintenance in maintaining the health of the fishery, and rice irrigation water abstraction dessicates waterbodies at a rapid rate due to the high water requirement for rice. Needless to say, this externality imposed on the fishery has important consequences for millions of poor who depend on fishing for their livelihoods.

Several current trends indicate that this problem is going to worsen in the near future. Irrigated winter rice cultivation has spread over time to occupy cultivable land of all elevations. Smaller, cheaper and more mobile low lift pumps are now available. These, in contrast to the earlier generation of 2 cusec LLPs, do not need large command areas to be economically viable, and are also able to exploit smaller, shallower waterbodies. Increased attention is also now being focussed on surface water irrigation since groundwater sources may be reaching the limits of exploitation, and many are additionally feared to be contaminated by arsenic.

Although this issue crops up regularly in problem censuses and participatory research in Bangladeshi floodplains, it appears under-researched. Particularly, little quantified information is available to enable an appreciation of the seriousness of the problem. Using a dynamic pool fisheries model for the PIRDP area, we have estimated that every hectare of *boro* rice irrigated by surface water means results in a reduction of 0.03 kg of fish per hectare. If the 6773 hectare area that we model is visualised as a single ‘catchment’, this translates to 242 kg of fish for every irrigated hectare. Irrigating more than 500 hectares, *i.e.*, only about one-thirteenth of the modelled area via surface water is enough to cause dramatic loss to the fishery. The problem is thus a very serious one.

One route to mitigation is to reduce the amount of water commonly applied to the *boro* crop. Although there are always avenues available to economise on water applied to individual plots, even the broad question of whether *Boro* production in Bangladesh is characterised by ‘excess’ irrigation applications is a debatable one. Indeed, it would appear that the problem lies in the *extent* of *Boro* cultivation itself rather than the amount of water applied to individual plots.

Crop diversification, particularly in the dry season, is being promoted across Bangladesh for a variety of reasons. Almost all alternative *rabi* crops that compete with irrigated rice have lower water requirements and their promotion would provide a means to ameliorate the externality imposed by winter cultivation on the fishery and its dependent livelihoods. In the PIRDP region that we model, wheat and onions represent the most viable alternatives. Simulation of the effects of irrigation for wheat and onions reveals that the consequent impact on the fishery is much less compared to irrigation for *Boro* rice. *Rabi* diversification is thus one of the few mitigation routes that can be applied on a large scale (tailored to local conditions), with several other attendant advantages.

The focus of diversification programmes has mostly concentrated on higher land elevations. This is natural, since the comparative disadvantage of rice compared to alternative crops increases with elevation. However, there is scope for successful diversification even in medium and medium-low elevation plots. This has already happened in some areas, with the DW-*aman* crop, followed by *rabi* crops such as wheat and onions replacing the previous *boro* based systems. Our analysis of static profitability reveals that such *aman* based systems can compete with *boro*-based rotations, especially since the latter is often characterised by a single *boro* crop in lower elevation plots. However, static profitability is but one aspect of the problem, and there is urgent need for research into farm-level decision-making on rotation choice, and how changing livelihood circumstances are affecting decisions about the principal crop or season around which farm systems are constructed.

Table 4.14: Estimated Costs and Returns for Broadcast Deepwater Aman at average yields (Rajshahi Division)

(Monetary variables in Taka per ha at 1998/99 constant prices)

	Units	Quantity	Prices	Costs & Returns
GROSS RETURNS				
- Paddy grain	tonnes	1.5	7,260	10,890
- Paddy straw	tonnes	3	900	2,700
Total				**13,590**
COSTS OF PRODUCTION				
Seed	kg	85	13	1,105
Fertiliser:				
- Urea	kg	50	7.6	380
- TSP	kg	0	13	-
- Muriate of Potash	kg	0	9.45	-
Manure	kg	300	0.45	135
Agro-chemicals	kg	0	540	-
Labour	days	100	42.5	4,250
Farm power	ox-pair days	30	45	1,350
Interest on working capital, at 12% financial costs over 6 months				183
Miscellaneous costs (10 % of financial costs)				305
Total Costs				**7,708**
NET RETURNS PER HA				**5,882**
NET RETURNS PER LABOUR DAY				**101**

Table 4.15: Estimated Costs and Returns for Irrigated HYV Transplanted Boro at average yields (Rajshahi Division)

(Monetary variables in Taka per ha at 1998/99 constant prices)

	Units	Quantity	Prices	Costs and Returns
GROSS RETURNS				
- Paddy grain	tonne	4.5	6,253	28,138
- Paddy straw	tonne	4.5	810	3,645
Total				**31,783**
COSTS OF PRODUCTION				
Seed	kg	30	11	330
Fertiliser:				
- Urea	kg	210	7.6	1,596
- TSP	kg	90	13	1,170
- Muriate of Potash	kg	30	9.45	284
Manure	kg	500	0.45	225
Agro-chemicals	kg	1	540	540
Labour	day	200	42.5	8,500
Irrigation				4,000
Farm power	ox-pair days	32	45	1,440
Interest on working capital, at 12% on financial costs over 6 months				326
Miscellaneous costs (10 % of financial costs)				543
Total Costs				**18,041**
NET RETURNS PER HA				**13,742**
NET RETURNS PER LABOUR DAY				**111**

Table 4.16: Estimated Costs and Returns for Irrigated Wheat at average yields (Rajshahi Division)

(Monetary variables in Taka per ha at 1998/99 constant prices)

	Units	Quantity	Prices	Costs and Returns
GROSS RETURNS				
- Wheat grain	tonnes	2.4	8,195	19,668
- Wheat straw	tonnes	2.4	990	2376
Total				**22,044**
COSTS OF PRODUCTION				
Seed	kg	130	14	1820
Fertiliser:				
- Urea	kg	160	7.6	1216
- TSP	kg	65	13	845
- Muriate of Potash	kg	25	9.45	236
Manure	kg	500	0.45	225
Agro-chemicals	kg	0.25	540	135
Labour	day	125	42.5	5,313
Irrigation				1500
Farm power	ox-pair days	35	45	1,575
Interest on working capital, at 12% of financial costs over 6 months				358
Miscellaneous costs (10 % of financial costs)				596
Total Costs				**13,819**
NET RETURNS PER HA				**8,225**
NET RETURNS PER LABOUR DAY				**108**

Table 4.17: Estimated Costs and Returns for Onions at average yields (Rajshahi Division)

(Monetary variables in Taka per ha at 1998/99 constant prices)

	Units	Quantity	Prices	Costs and Returns
GROSS RETURNS				
- Onions	tonnes	6	8800	
Total				**52,800**
COSTS OF PRODUCTION				
Seed	kg	6	600	3600
Fertiliser:				
- Urea	kg	155	7.6	1178
- TSP	kg	80	13	1040
- Muriate of Potash	kg	65	9.45	614
Manure	kg	500	0.45	225
Agro-chemicals	kg	1	540	540
Labour	days	200	42.5	8500
Irrigation				500
Farm power	ox-pair days	50	45	2250
Interest on working capital, at 12% of financial costs over 6 months				2213
Miscellaneous costs (10 % of financial costs)				1844
Total Costs				**22,504**
NET RETURNS PER HA				**30,296**
NET RETURNS PER LABOUR DAY				**151**

References

- Ahmed, B., Rahman, M., Bottrall, A. 1990. Surface water abstraction for irrigation. In *Environmental aspects of surface water systems of Bangladesh*, ed. A. A. Rahman, Huq, S., Conway, G. Dhaka: University Press, Ltd.

- Alauddin, M., and Tisdell, C.A. 1998. *The Environment and Economic Development in South Asia. An overview concentrating on Bangladesh* London: Macmillian Press

- Ateng, B. 1998. Comparative advantage and crop diversification. In *Bangladesh agriculture in the 21st century*, ed. R. Faruqee. pp. 143-174. Dhaka: University Press Ltd.

- Barr, J. J. F. 1996. Preliminary investigtion of agricultural diversification and farmers' practices in Bangladesh floodplain production systems involving rice-fish production - a whole system approach, Project R6383 final technical report to DfID-NRSP.

- Barr, J. J. F., Zuberi, M.I., Naseem, S.B., Craig, J.F., McGlynn, A.A., Shirley, M.D.F ., Dixon, P.J., and Payton, R.W. 2000. Livelihood strategies and resource use patterns on the floodplains - who does what, where, when? In *People's Livelihoods at the land-water interface. Emerging perspectives on interactions between people and the floodplain environment*, ed. A. Clemett, Chadwick, M.T., and Barr, J. Dhaka: University of Leeds and University of Newcastle, UK

- BBS. 1997. *Statistical yearbook of Bangladesh* Dhaka: Bangladesh Bureau of Statistics

- Bhoumik, M. 1986. A report on the droughts in Rajshahi. In *Daily Sangbad*. Dhaka

- Biswas, M. R., and Mandal, M.A.S. 1993. *Irrigation management for crop diversification in Bangladesh* Dhaka: University Press Limited

- Bouman, B. A. M. a. T., T.P. 2001. Field water management to save water increase its productivity in irrigated rice. *Agricultural water management* 49:11-30

- BRRI. 1996. BRRI annual report for 1996. Dhaka: BRRI

- BRRI. 1997. BRRI annual report for 1997. Dhaka: BRRI

- BRRI-ODA. 1986. Socioeconomic aspects of deep water rice farming systems. *Bangladesh deep water rice project, phase two*. Dhaka.

- Catling, D. 1992. *Rice in Deep Water* London: The Macmillan Press Ltd

- Chadwick, M. T., Soussan, J.G., Alam, S.S., and Mallick, D. 1999. From flood to scarcity: Re-defining the water debate in Bangladesh. *Working Paper, Environment and Development Series No 1.* University of Leeds

- FAP17. 1994. Supporting volume 13 Village study: Pabna Irrigation and rural development project.

- Ghani, M. A., Bhuiyan, S.I, Hill, R.W. 1989. Gravity irrigation management in Bangladesh. *Journal of Irrigation and Drainage Engineering* 115:642-655

- Greenland, D. J. 1997. *The sustainability of rice farming* Wallingford, Oxon: CAB International

- Guera, L. C., Bhuiyan, S.I., Tuong, T.P., Barker, R. 1998. Producing more rice with less water from irrigated systems. *IRRI Discussion paper series*. Los Banos:

- Herbon, D. 1990. Irrigation technologies in Bangladesh: an evaluation of consequences of different technological levels. *Quarterly Journal of International Agriculture* 29:67-78

- Khan, L. R. 1998. Groundwater abstraction. In *Environmental aspects of agricultural development in Bangladesh*, ed. S. Huq, Rahman, A.A., and Conway, G. Dhaka: University Press, Ltd.

- Mandal, M. A. S., Dutta, S.C. 1995. *Crop diversification: findings from a field research programme* Dhaka: University Press, Ltd.

- Metzel, J., Ateng, B. 1993. Constraints to diversification in Bangladesh: A survey of farmers' views. *The Bangladesh Development Studies* 21:39-67

- Miah, M. N. I., Ahmed, N.U., Magor, N.P., Ali, H., Faruque, A.K.M. 1990. An overview of deepwater rice farming systems in Bangladesh. *BRRI Unpublished paper*. Dhaka:

- Mikkelsen, D. S. and De Datta, S.K. 1991. Water control and irrigation. In *Rice*, ed. B. Luh. New York: Van Nostrand Reinhold

- Morris, M. L., Chowdhury, N. and Meisner, C. 1997. Wheat production in Bangladesh: Technological, economic and policy issues. Washington DC: IFPRI

- Morton, J. 1989. Tubewell irrigation in Bangladesh. *ODI-IIMI Irrigation Management Network Paper Series*

- Orr, A. 2001. The transition to market-oriented agriculture: achieving a poverty focus (PETRRA policy studies framework). pp. 29. Dhaka: IRRI

- Palmer-Jones, R. 2001. Irrigation service markets in Bangladesh: Private provision of local public goods or community regulation? In *Workshop on common resources*. Lund University, Sweden:

- Rashid, M. H. and Mridha, A.K. 1998. Arsenic contamination of groundwater in Bangladesh. In *24th WEDC conference: water and sanitation for all*. Islamabad, Pakistan:

- Saha, U. K., Khan, M.S.I., Haider, J., Saha, R.R. 1997. Yield and water use of onion under different irrigation schedules in Bangladesh. *Japanese Journal of Tropical Agriculture* 41:268-274

- Siddiqui, M. R., Islam, M.R., Ahmed, N.U., Magor, N.P., Khan, A.H. 1994. Impact of FSR on farm families in Bangladesh. Dhaka: BRRI

- Sufian, M. A. 2001. Production of wheat in Bangladesh. *Advances in agronomic research in Bangladesh* 5:57-71

- Toufique, K. A. 1997. Some observations on power and property rights in the inland fisheries of Bangladesh. *World Development* 25:457-467

- Wood, G., and Palmer-Jones, R. 1990. *The Water Sellers. A cooperative venture by the rural poor* Intermediate Technology

- Zohir, S. 2001. Impact of reforms in agricultural input markets on crop sector profitability in Bangladesh. *Structural Adjustment Participatory Review Information Network (SAPRIN) document*. pp. 78. Dhaka:

Chapter 5: Dry Season water retention

5.1 Problem Statement

In the previous section, we have highlighted the importance of dry season water maintenance in the health of the fishery and the livelihoods dependent on it, focusing particularly on water abstraction for irrigation. Much attention has been paid to *flood* season water control, particularly in the FAP studies. However, research by Halls (1998) and Halls *et. al.* (2001) has shown that fish yield losses incurred by water level reductions in the flood season, caused for example by flood control embankments, can be counterbalanced by retaining more water on the floodplain in the dry season. In fact, that research demonstrated that the importance of dry season water levels for the fishery increases sharply as flood season water levels increase. Beyond an average flood season water height (FSWH) of about 9 metres at the sluice gates, fish production is determined almost exclusively by the dry season water level. This indicates that even in regions where flood control has diminished fish productivity, concerted efforts to maintain more water in the dry season can scale back losses.

The conflict between the agricultural and fisheries sectors in the dry season is more general than the abstraction problem alone we have already explored, however. The political economy of land and water use in Bangladesh is characterised by agricultural interests determining priorities in the use of land and water and often asserting ‘rights’ where none legally exist. Fisher groups are usually of low social standing, and are often dependent on the richer, landed class for financial help in acquiring leases, purchasing gear, etc, and have little bargaining power (Toufique, 1997). Thus decisions affecting the entire community are often made by a small set of influential landowners, typically medium or large farmers. Opening and closing of sluice gates is an important example of this. Sluice operations are typically determined by local Bangladesh Water Development Board (BWDB) officials in consultation with local farmers (Hoggarth and Halls, 1997). The priority in the flood season is then to control water entry to maintain optimal levels for the predominant local crop[30]. For the dry season, the priority is usually to allow the water to drain quickly off the floodplain land beginning with the drawdown in October and November, so that *boro* may be planted to as large an extent as possible. Setting sluice gates to maximise drainage after drawdown, and actual drainage of large areas of residual water by mechanical means frees up even low-lying *beel* and floodplain land for cultivation.

As described above, previous research by Halls (1998) and Halls, *et. al.* (2001) simulated the effects of higher dry-season water retention on fish productivity in the PIRDP. Increased water level maintenance was seen to have significant productivity effects, and it was concluded that manipulation of water levels by means of sluice gate operations (*i.e.*, blocking drainage at drawdown) could potentially provide a simple and cost-effective means of enhancing fish production (Halls, *et. al.* (2001)). However, it was also noted there that the feasibility of retaining more water should be explored taking into account the effect on the agricultural sector as well. This is accomplished here by exploiting the connection inherent in the FPFMODEL between water levels at sluice gates and the amount of wet/dry land in the modelled region. This aspect of the FPFMODEL has not been described in chapter 2, and hence an intuitive discussion is provided below.

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[30] Flood season sluice gate management is examined in a following chapter.

5.2 Methodology

A sub-project within the ‘Fisheries Dynamics…’ project conducted a census of dry season water bodies (DSWB) at the PIRDP study site, providing details of their hydrology and morphology. The project also took detailed readings of water levels at the Talimnagar sluice gate regulating water flow into and out of the site for 1995 and 1996. Water heights at the sluice gate in the dry-seasons were seen to remain relatively stable at approximately 4.54 (15 ft) in both years (figure 5.1). In Halls (1998), it was suggested that this height is likely to correspond to the elevation of the water table in the region. This was then taken to represent a minimum low water level.

Figure 5.1: Observed water heights at Talimnagar sluice gate, 1995 (Hoggarth & Halls, 1997)

Using this information, and empirical observations on the minimum depths of the various water bodies, the elevations of the water bodies were computed. Assuming that the water height in each water body is directly linked to the water table enables a direct link between water heights at the sluice gate and in each water body. Any change in the water height at the sluice gate correspondingly translates into changes in water depths in each water body. Given estimates of the areas of various water bodies, it is consequently possible to calculate how much extra dry or flooded land results from a change in sluice gate water heights.

In Halls (1998), the empirical observations on water heights at the sluice gate were used to estimate a best-fitting sine curve. This amplitude of this curve could then be changed to simulate higher or lower water levels in the flood and/or dry season. Our interest here is in isolating the effects of higher dry season water levels. Hence the flood season water level is kept fixed at the baseline level of the fitted sine curve, while the water heights for the dry season are increased by 0.25 m. and 0.5 m. in the simulations.

The FPFMODEL simulates changed fish yields in response to changed water heights, as reported in Halls (1998) and Halls *et. al.* (2001). Here, estimates of changes in area flooded are also computed to enable calculation of losses to agriculture. Since the simulation pertains only to increases in dry-season water levels, the additional area flooded is exclusively contained within dry season water bodies. In other words, it is exclusively very low land upon which only a single crop of *Boro* can feasibly be grown. The lost value of agricultural production will therefore pertain to *boro* revenue foregone due to this additional flooding. Boro planting can take place in the period between 15 December and 15 February, after which it becomes too late to plant the crop for a timely harvest. Therefore the 'area lost due to additional flooding' calculation tracks land availability for agriculture specifically for this period.

A budget for the *Boro* crop was estimated in the previous chapter on abstraction, and figures from that budget are used in the financial calculations for the agricultural sector here. Additionally, price and cost estimates were also derived for fish production in the region. Fish prices were obtained from FAP 17's fish price database, with prices weighted by species composition of catch to arrive at an average 'catch price'. Cost calculations for the fishery proved more complex, as opportunity costs can vary widely, and as discussed in chapter 3, can be zero during the flood season. Additionally, reliable data are not available for the PIRDP region. Hence, data on fishermen density, available from the CPP fisheries dataset (De Graaf, *et. al.*, 2000), were used in conjunction with data on estimates of average number of hours spent fishing in the PIRDP, available from FAP 17 (1994). A rate of 50 taka per fishing day, used for example in De Graaf *et. al.* (2001), was used to cost the wage bill. A standardised measure of gear use was not available and hence fishing cost estimates do not include gear costs. In other words, gears are assumed to represent fixed inputs. To the extent that gear costs are variable, our estimates will slightly overestimate fishing returns. All financial estimates were expressed in 1998-99 taka.

5.3 Results and Conclusions

As with all simulations in this research using the FPFMODEL, yield outputs are for *Puntius*, which is assumed to be representative for all species. Table 5.1 below reports monthly changes in yields in response to maintenance of the two increased dry season water height scenarios we consider, by 0.25 and 0.5 metres. Maintaining a quarter metre higher water at the sluice gates during the dry season is seen to result in *Puntius* yield increase by 9.3%. A half metre increase yields a 19.1% increase in catch.

Table 5.1: % change in Puntius yield in response to increased water heights

	% change in Puntius yield in response to increased water heights	
	Baseline +0.25m	**Baseline +0.5m**
July	9.6	19.7
August	9.4	19.3
September	9.3	19.2
October	9.1	18.7
November	8.6	17.6
December	9.1	18.7
January	9.9	20.4
February	10.2	21.1
March	10.3	21.3
April	10.1	20.9
May	0.0	0.0
June	0.0	0.0
Total	**9.3**	**19.1**

Assuming *Puntius* to be representative of all species, total fish catch for the PIRDP modelled area of 6773 hectares is shown in Table 5.2. The 0.25 metre increase in water height increases total catch by about 85 tonnes, while the 0.5 metre increase provides a 175 tonne increase in catch. Clearly, the productivity impacts on the fishery are significant.

Table 5.2: Total catch (tonnes) in response to water heights

	Total catch (tonnes) in response to water heights		
	Baseline	**Baseline + 0.25m**	**Baseline +0.5m**
July	81.1	88.8	88.8
August	84.6	92.6	92.6
September	72.5	79.2	79.2
October	141.3	154.2	154.1
November	69.3	75.3	75.2
December	137.5	150.0	150.0
January	139.0	152.7	152.7
February	46.0	50.7	50.7
March	34.7	38.2	38.2
April	80.2	88.3	88.2
May	12.8	0.0	0
June	20.7	0.0	0
Total	**919.6**	**1005.3**	**1005.2**

Maintenance of higher water heights at the sluice gate will diminish land available for *boro* production. As discussed previously, *boro* is planted between 15 December and 15 February. Hence land that dries up within this period will inevitably be utilised for planting rice. Tables 5.3 and 5.4 provide estimates of flooded and remaining dry area on those dates under the various water height scenarios. Changes from the baseline are summarised in Table 5.5. Interestingly, a 0.25 metre increase in water height at the sluice gate, seen to result in 85 tonnes of additional fish catch in the region, results in a sacrifice of only 8 hectares of land devoted to winter rice out of approximately 6674 at the baseline. If the dry season sluice gate water levels are increased by an average of 0.5 metres, the additional 175 tonnes of fish catch will come at the cost of only about 16 hectares of rice production.

Confirmation that this management strategy is indeed a low-cost means of providing a significant boost to fishing-dependent livelihoods is further reinforced by considering the tradeoff in economic terms. The additional value of fish production created by water retention arising from a 0.25 m water height increase is equal to approximately 3.6 million taka, while the cost (foregone revenue from rice production) is only about 109,000 taka. Thus there is a net value increase in excess of 3.5 million taka for the 6773 hectares area modelled. Increased returns to the fishery outstrip decreased agricultural revenue by a factor of 30.

Table 5.3: Flooded area under various water height scenarios (total area = 6773 ha)

	DRY SEASON FLOODED AREA (HA) ON		
DRY SEASON WATER HEIGHTS	15 DEC	15 JAN	15 FEB
BASELINE +0.5 M	137.9	121.5	114.8
BASELINE +0.25M	131.8	113.8	106.5
BASELINE	125.8	106.1	98.2

Table 5.4: Dry area remaining under various water height scenarios (total area = 6773 ha)

	DRY AREA REMAINING (HA)		
DRY SEASON WATER HEIGHTS	15 DEC	15 JAN	15 FEB
BASELINE +0.5 M	6635.1	6651.5	6658.1
BASELINE +0.25M	6641.1	6659.1	6666.4
BASELINE	6647.1	6666.8	6674.7

Table 5.5: Changes in key variables in response to increased water retention

	Baseline +0.25 m	Baseline +0.5 m
Extra fish (tonnes)	85.6	175.7
Lost rice land (ha)	8	16
Value of extra fish	3680800	7555100
Value of lost land	109936	219872
Net extra returns	3570864	7335228
Increase in fish value / Loss in agricultural value	33.4	34.3

This research has demonstrated that significant gains can be reaped from maintaining higher dry season water levels, with the resultant tradeoff with the agricultural sector being quite marginal. Two shortcomings must be noted with regard to the simulations we have produced. First, maintenance of higher water levels at the sluices will imply some blockage of water at drawdown, and we do not have an estimate of the extent to which rice production will be disrupted close to the sluice when drainage is restricted. Secondly, valuation of fishing costs is subject to considerably uncertainty, and there is a possibility that we may be underestimating this aspect. Even so, the very substantial gap between returns to the two sectors suggests that major potential gains to floodplain productivity and livelihood enhancement are being foregone in the continued trend to dry out maximum possible area for winter rice cultivation.

A contributory factor to this state of affairs is the vague definition and insufficient enforcement of property rights in *beels* and low-lying areas. The larger waterbodies are usually *khas* (government owned) lands that have been designated as *jalmahals* (water estates), and a mix of property rights arrangements from open access to leasehold to access by licence prevails (Sultana and Thompson, 2000). Even in well-defined *jalmahals* such as the *haors* in the Northeast, there are frequent reports of conflicts between farmers operating on the edges of the waterbodies desiring rapid drainage of water, and leaseholder fishermen wishing to maximise water retention (Talukder, 1993). However, there are also many smaller waterbodies as well as waterbodies with limited fishing potential for which property rights are not assigned at all, and are easily encroached upon by influential farmers wishing to expand *boro* cultivation. FAP 17 (1994) reports that ever since the PIRDP was built, water levels inside have declined, and consequently the *jalmahal* designation of several waterbodies has been terminated. This situation encourages the drainage of these waterbodies by surrounding farmers. Thus once a decline in the fishery is initiated, there is a tendency for accelerated deterioration. It has not helped that low-lying areas and *beels* have, until very recently, been considered as ‘not used’ areas by policy-makers, *i.e.,* areas with few prospects and hence of little productive use (De Graaf, *et. al.*, 2001).

Clearly, action research based on consensus building methods of the sort recently investigated in Barr (2002) are required if the foregone productivity is to be captured in floodplain areas. FAP 17 (1994) notes that benefits of sluice management accrue disproportionately to a few influential farmers owning land in low-lying areas. Given that the balance of social power is unlikely to change in the short to medium run, field researchers will have to find a way of ‘co-opting’ this group. However, given that this study has shown that the amounts of land that will have to be ‘retired’ under an increased water retention scheme are marginal, direct monetary compensation may prove a feasible means to approach this aspect.

References

- de Graaf, G. J., Born, B., Kamaluddin, A.M, Marttin, F. 2001. *Floods, fish and fishermen.* Dhaka: The University Press

- de Graaf, G. J., Dhar, G.C., and Mahera, N.S,. 2000. The CPP fisheries data base, CD-ROM. FMS, Dhaka, Bangladesh

- FAP17. 1994. Supporting volume 13: Village study (Pabna Irrigation and rural development project)

- Halls, A. S. 1998. An assessment of the impact of hydraulic engineering on floodplain fisheries and species assemblages in Bangladesh, Unpublished Ph.D. thesis, pp. 526 Imperial college, University of London

- Halls, A. S., Kirkwood, G. and Payne, A.I. 2001 *A dynamic pool model for floodplain-River fisheries*, unpublished manuscript.

- Hoggarth, D. D., Halls, A.S. 1997. Fisheries dynamics of modified floodplains in southern Asia: Project final technical report to DfID-FMSP, UK.

- Sultana, P., and Thompson, P. 2000. Community fishery management implications for food security and livelihoods. In *IIFET 2000 Proceedings*

- Talukder, J. 1993. Socioeconomic issues in the management of freshwater wetlands in Bangladesh. In *Freshwater wetlands in Bangladesh: Issues and approaches for management*, ed. A. Nishat, Hussain, Z., Roy, M.K., Karim, A. pp. 187-210. Dhaka: IUCN, the world conservation union

- Toufique, K. A. 1997. Some observations on power and property rights in the inland fisheries of Bangladesh. *World Development* 25:457-467

Chapter 6: Early Arrival Flood Risk and the Role of Short-Duration Varieties

6.1 Introduction

The management of flood risk in Bangladesh has been largely focussed on control of water levels in the peak flood season. This focus is not surprising, since extreme flood events such as in July-October 1998 due to overspill from the major rivers cause widespread loss of life, habitat and agricultural livelihoods. In some parts of the country, however, even in 'normal' flood years (characterised by hydrographs with typical or average water *heights*), early local rainfall or early discharge of floodwaters from upstream catchments can cause damage to standing *rabi* or *kharif-1* crops prior to their harvest. The timing of typical *kharif-1* and *rabi* (boro) crop schedules and flood timings for the northcentral region are illustrated in table 6.1 below. Overbank river flooding typically commences between mid-June and early July, usually after the harvest of the boro crop. The *aus* and jute crops are still standing at the time, but are not normally affected unless the initial flood is extraordinarily heavy, or the entire calendar of the flood event is shifted forwards in time. *Aus* and jute are also typically planted on high and medium-high lands, in order to protect them from flood damage. With the lower lands given over to Boro, if the flood arrival is more than a week or two early, it has the potential to damage those boro areas that remain unharvested.

Table 6.1: Flood and kharif-1/rabi calendar for the Northcentral region

Crops/Flooding	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Aus			◄	━	━	━	►					
Jute			◄	━	━	━	━	►				
Aman						◄	━	━	━	►		
Boro	━	━	━	━	►							◄━
Normal Flood						◄	━	━	►			
Early Flood					◄	━	━	━	►			

With the rapid replacement of the *kharif-1* season with an extended *rabi* season, the impact of early flood events is thus felt most by the boro crop. While *aman* crop damage due to heavy flooding in the peak flood season can be sometimes mitigated by re-transplanting, early flood arrival often means considerable damage to boro. Early floods are most characteristic of the *haor* regions of Northeast Bangladesh. The *haors* are naturally handicapped with regard to agricultural production, since they are predominantly low-lying, with the peak season flood depths often being too high to allow an *aman* crop. A single boro crop is typical. However, flash (early) floods frequently arrive from the northern hills with little warning, damaging the standing boro crops. The boro crops in the *haor* regions are also often transplanted late using aged seedlings, in order to minimise exposure to cool spells characteristic of the region, which further delays harvesting and exposes the crops to early flooding (Salam, *et. al.* (1994)).

Although flood arrival in the north-east (April-May) is earlier than in the west (June-July), Boro crop damage due to early flooding is not exclusive to the North-east. In project R6756 (Barr, 2000), a problem census conducted at the Charan *beel* site in Northcentral Bangladesh revealed that boro damage in low elevation lands was perceived as a significant problem. Unlike in the northeast where it is widespread and frequent, early flood arrival in other river floodplain areas of the country is often localised and more sporadic, and hence does not attract sufficient attention. However, with an increasingly '*boro*-centric' agricultural economy, the implications of damage to the *boro* crop can be substantial. In this segment, we simulate the arrival of an early flood in the Charan beel area, using GIS methods and data from R6756. By simulating the effect of an early flood arrival, and combining the simulated inundation levels with plot level cropping-pattern, plant growth-stage information and crop damage factors, rough plot-level crop damage estimates are calculated. These estimates are combined with socio-economic information to provide insights into the vulnerability of poorer households to early flood risk. The current choice of crop varieties is then examined in conjunction with information on available alternatives, to determine whether there is scope for managing early flood risk by using shorter-duration alternatives.

6.2 The Charan beel and floodplain Area: Background information & available data

Charan *beel* is a shallow saucer-like floodplain depression, in Tangail district in Northeast Bangladesh. The local administrative unit (*mouza*) is divided between two Agro-Ecological Zones (AEZ): AEZ 8, the Young Brahmaputra and Jamuna Floodplains, and AEZ 9, the Old Brahmaputra Floodplain (FAO & UNDP, 1988). The study site lies just to the east of the boundary between the AEZs, and is in AEZ 9 (Office of Field Services, 1993). The *beel* lies between two distinct river systems – to the west, the Dhaleswari, a major distributary of the Jamuna, which has a peak flow of 3000 - 5400 m^3 sec^{-1} and carries up to 13% of Jamuna flow as overbank spillage, and to the west, the Bangshi, which drains the slightly uplifted Madhupur Tract (EGIS & Delft Hydraulics, 1997). The low-lying floodplain between these rivers is hydrologically complex, subject to seasonal cross-flows between the two systems, and becomes deeply inundated each year in the monsoon, acting as a natural flood water storage area. The *beel* is directly connected to a distributary of the Bangshi via a *khal* (channel), on which there is a regulator gate set in a breached low embankment. The connection is thus open when flood levels permit, and the *beel* hydrology is closely related to peak river flows in the Bangshi distributary (EGIS & Delft Hydraulics, *Op. cit*). The *beel* comprises a small perennial waterbody of 44.5 ha at its centre, surrounded by arable land that is seasonally flooded as the waterbody expands to cover 394 ha during the monsoon. Settlements are located on higher land around the margins of the depression.

The soils are predominantly seasonally flooded, fine textured, non-calcareous grey floodplain soils developed in older Jamuna alluvium, although detailed soil survey has revealed extensive areas of sandy soil around the *beel*, with important implications for irrigated dry-season cropping. In the adjacent *thana* (larger administrative unit), high seepage and percolation losses from paddies of 27 - 29 mm day^{-1} were measured (Khan, 1990). The area falls between the 1750 and 2000 mm yr^{-1} isohyets, with 85 - 90% of precipitation falling between mid-April to September - the *kharif* months. The *rabi* season experiences very litle rainfall and cropping is irrigation dependent. Although annually rainfall exceeds potential evapotranspiration (PET), PET exceeds rainfall by 250 - 400 mm in the *rabi* (Brammer, 1997).

Following a reconnaissance social survey that served as a mini-census to provide a basis for social stratification, a sample of 942 households from three villages around the *beel* was selected by project R6756. Stratification was on the basis of landholding, which is recognised as a reliable proxy for wealth in rural Bangladesh. The stratification is presented in table 6.2 below; this is based on categories used by the Bangladesh Bureau of Statistics in the Agricultural Census and other reports. From this sample, a sub-sample of 210 households was selected for more detailed study, with 30 households belonging to each stratum. Basic socio-economic data were collected for each household in the subsample, including information on landholding, land leased out and in, demographic variables, occupational categories, etc.

Table 6.2. Classification of household on the basis of land-holding

Stratum	Land owned (acres)	Socio-economic category
1.	<0.049	Landless - Categories I & II
2.	0.05 - 0.49	Landless - Category III
3.	0.5 - 0.99	Marginal
4.	1.0 - 2.49	Small
5.	2.5 - 4.99	Medium – I
6.	5.0 - 7.49	Medium – II
7.	>7.5	Large

The project also collected data on a set of biophysical variables over 1997-98. These included flood depth measurements and areal extent of flood spread at approximately monthly intervals during the year, and an inventory of plots belonging to the sample households. A subset of plots was chosen for crop pattern monitoring, recording crops grown during the year, and some basic information on crop growth stages at discrete points in time (a recording taken once a month). This and other information was gathered together in a project GIS, with linkages established between households and plots[31].

6.3 Methodology

(i) Sample selection: In order to analyse the effects of an early flood, it is necessary to have a basic understanding of the cropping system for the entire year. For example, some boro plots may be harvested in April, while others not until May, with the latter plots being more susceptible to damage from early flooding. The reasons for this asymmetry in harvesting times may lie in the use of the particular plots in the previous season or in the flooding status of the plot in previous months. For instance, allowing the plot to lie fallow prior to the boro crop allows for earlier transplanting and

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[31] The intersection between plots and households is not complete. In other words, some plots cannot be linked to household-level socio-economic information, and for some plots owned by the sample households, cropping pattern information is not available. However, there is a significant enough intersection to make our analysis possible.

thereby earlier harvesting. Alternatively, some plots may drain too late for an early *rabi* crop to be squeezed in before the boro, which in turn encourages earlier transplanting of the boro crop. Knowledge of the transplanting date is important for this analysis, and therefore information from the crop growth stages was used to establish transplanting dates for plots, while plots without sufficient information were dropped from the analysis. A small number of plots with alternate *rabi* crops such as wheat were also dropped, since these are harvested well before even the earliest of floods may arrive. The final sample of plots retained comprised 20 very low (VL), 38 low (L), 72 medium low (ML), and 107 medium high (MH) plots[32], 237 in all.

(ii) Establishing harvest dates: Knowledge of the approximate date of harvest at the baseline is of course, critical for this analysis. One problem was that the dataset did not record harvest dates as such. Therefore, approximate harvest dates had to be established on the basis of crop growth stage information. Fortunately, the dataset did record such information at several discrete points in the season (for example, 'hard dough stage', 'harvesting', 'harvested' etc) from which reasonable best guesses could be made. For each of the 237 plots in turn, harvest dates were thus established.

(iii) Establishing crop damage parameters: An extensive literature search was undertaken to establish damage parameters for the boro crop in relation to inundation levels. The existing literature was by-and-large found to be based on experimental studies, with results conditional on a number of control factors such as age of the seedlings at the time of transplanting, temperature regimes prevailing during the growing season, etc. No data on such factors are available for this site[33]. In the end, simple damage parameters established by the Master Plan Organisation (MPO) of Bangladesh were found to be the most synthetic and most easily integrable with the rest of the analysis. These parameters have been used in several previous studies of flood impacts on agriculture in Bangladesh (for example, in Thompson (1989)). Table 6.3 presents this information for Boro.

Table 6.3: Potential crop damage at critical flood depths (cms).

Crop	Crop Stage	Crop losses as % of value		
		20%	50%	80%
HYV boro	heading maturity	60	80	100
Local boro	heading maturity	80	100	130

Source: MPO (1987)

Since this table only provides information at discrete growth stages and water depths (20% crop loss at 60 cm inundation, 50% loss at 80 cm inundation, etc), linear interpolations were established between these discrete data points so that damage estimates could be more continuous with respect to water levels.

(iv) Computing baseline damages: The water heights for the last month prior to harvest in each of the 237 plots were analysed to establish whether the levels were

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[32] 'High' plots are not considered here since they are flood-free by definition.

[33] At any rate, the objective of this modelling exercise, which is one among several separate options being modelled within a short time period, is not to establish such biophysical precision, but rather to generate broader lessons and to capture the bigger picture.

high enough at any time to potentially cause damage to the crop. This had to be done for each plot individually due to the differences in harvesting dates.

(v) Simulating early flood arrival and crop damages: The project GIS stores empirical information on flood spread at the plot level for the period August 1997 to August 1998. A 'water theme time shift' GIS tool can de-couple the flood data, thereby lagging or advancing the flood in relation to production activities at the plot level. Two early flood onset scenarios were simulated – flood onset one and two weeks early respectively. One complication with these scenarios is that this implicitly assumes that the *baseline* floods at that time were 'normal'. The devastating 1998 floods were anything but normal, and there was concern that the results may be biased due to this[34]. However, a study of the literature on the 1998 floods indicates that abnormalities in the 1998 flood by-and-large commenced in late June and early July, affecting mostly the *aman* crop and the unharvested *aus* and jute crops. Nor does the R6756 project GIS document any abnormalities. The baseline flooding data at Charan *in that period* – i.e. the flood onset period - is therefore assumed to be representative of a 'normal' flood event, allowing us to use flood level time shifts to simulate realistic early flood arrival events.

The water heights on individual plots were again used in conjunction with the crop damage parameters to establish crop damage for the early flood scenarios, as in (iv).

(vi) Livelihoods and poverty dimensions:
The design of the GIS gives the ability to interrogate it about the impact of various management scenarios on floodplain residents as a group, and disaggregated according to different wealth (land-ownership) classes. Insights from the cropping pattern and land elevation attributes together with the crop damage estimates, provide general insights on the extent to which early flooding increases the vulnerability of floodplain residents. By further combining these conclusions with spatial and socio-economic information from the GIS on land-ownership by different wealth classes, and the elevation categories of the land they own, it is possible to inquire whether the effects of early flood onset are felt uniformly across the socio-economic classes. Thus the hypotheses of linkages between poverty and increased vulnerability to environmental risks in the livelihoods of the poorest classes can be tested.

(vii) Examining the role of short-duration varieties: Finally, in seeking possible management interventions that might significantly reduce the risk posed by early floods, the question is posed as to whether the use of alternative short-duration varieties in place of the existing varieties would enable harvests early enough to avoid flood damage. This is done simply by comparing varieties currently in use with available alternatives, and would require field testing for validation of the model

6.4 Cropping patterns at Charan beel

As is the trend in several parts of Bangladesh, the traditional *aus-aman-boro* system, corresponding to the *kharif-1 – kharif-2 – rabi* seasons, has been replaced by a *kharif-rabi-1-rabi-2* pattern in Charan. *Aman* is broadcast or transplanted with the start of the flood in July, and is harvested with the beginning of the drawdown in mid-

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[34] Historical water depth data for Charan beel are not available, as there is no BWDB monitoring station of suitable proximity. The EGIS study of Charan (EGIS & Delft Hydraulics 1997) presents another short time series dataset of flood depths, which can be used for comparison.

October//November. The extended *rabi* season commences after the drawdown, with a short fallow in some plots and a short *rabi* crop such as mustard in others. Boro is omnipresent, and is transplanted between December and early March, coming off the land in April/May, prior to the arrival of the next year's floods in June.

The elevation-specific breakdown of major cropping patterns in the sample plots is shown in table 6.4 below. The table clearly illustrates that elevation plays a significant role in cropping pattern choice at Charan. Very low plots are completely given over to *rabi* season production, being too deeply flooded for *aman* production in the *kharif* season. 55% of the VL plots are devoted to a single boro crop, while the other 45% manage to include a short mustard crop prior to boro. Mustard is a low-input catch crop that grows quickly, the proceeds from which are used by farmers to finance the input-intensive boro crop. It is sown right after flood drawdown using residual soil moisture and minimal inputs. Subsequent to the mustard harvest, the land will be soaked and puddled in advance of transplanting.

Table 6.4: Cropping patterns on sample plots at Charan beel*

Cropping Pattern	**VL** (20 plots)	**L** (38 plots)	**ML** (72 plots)	**MH** (107 pl)	**Total** (237 pl)
Fallow/Fallow/Boro	55.00%	42.11%	23.61%	20.56%	27.85%
Fallow/Mustard/Boro	45.00%	39.47%	59.72%	39.25%	45.99%
Fallow/BAman/Boro	0.00%	0.00%	0.00%	4.67%	2.11%
BAman/Fallow/Boro	0.00%	7.89%	4.17%	1.87%	2.95%
BAman/Mustard/Boro	0.00%	10.53%	11.11%	19.63%	13.92%
Mixed/Mustard/Boro	0.00%	0.00%	1.39%	0.93%	0.42%
TAman/Fallow/Boro	0.00%	0.00%	0.00%	11.22%	0.84%
TAman/Mustard/Boro	0.00%	0.00%	0.00%	1.87%	0.84%
					100.00%

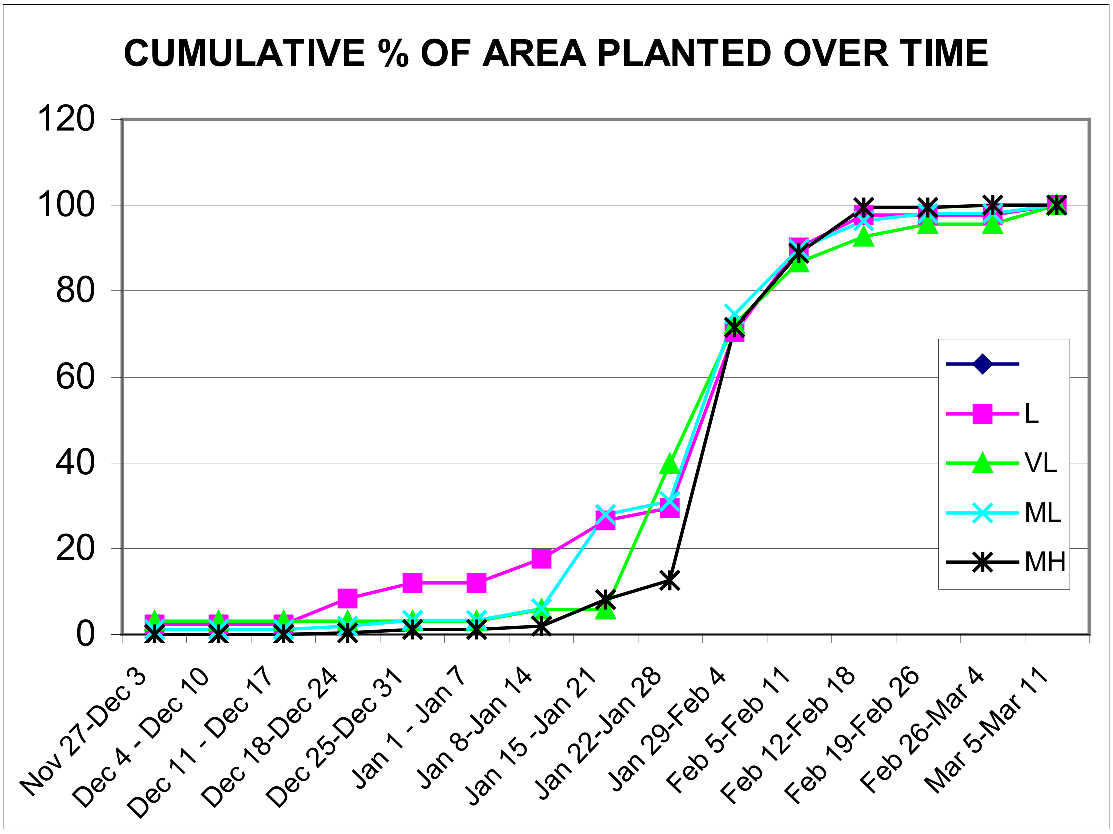
* The sequence used here is based on the flood year rather than the calendar year.

The increase in cropping intensity in response to elevation increases is clearly seen. Low plots are still dominated by fallow/fallow/boro and fallow/mustard/boro rotations, but some *aman* production is also present. The incidence of single boro cropping declines sharply as elevation increases. ML and MH plots are predominantly double or triple-cropped. Transplanted *aman* is more easily damaged by flooding than broadcast *aman*, and hence is observed only in MH land.

As cropping intensity increases, flexibility in timing the planting of the boro crop is inevitably reduced. Early transplanting of the boro crop, in December or early January, would enable a harvest in late April or early May. Where a mustard crop is grown after drawdown and prior to the boro, however, the transplanting of boro may be pushed into February, resulting in a later harvest and greater exposure to early flood risk. Currently this is a trade-off that farmers need to factor into their decision making: Option 1. is a mustard crop, followed by a *boro* crop**.** The mustard is grown as a cash crop, the seeds can be sold to millers for mustard oil production; the cash thus obtained is immediately invested into the inputs for the proceeding *boro* crop. As the proceeding analysis shows, depending on land elevation, there is risk of loosing some of the crop due to flood damage. Option 2. is a *boro* crop alone. The more flexible timings permitted by a single *boro* crop mean that there should be negligible flood damage risk, however the crop is also more expensive (less profitable) as greater levels of credit will be needed to supply the necessary inputs.

Tables in the appendix present a breakdown of the planting dates for our sample plots by land elevation categories. The information is summarised in figure 6.1 below.

Figure 6.1: Timing of boro transplanting, by elevation classes at Charan beel



As seen from the diagram and the appendix tables, higher proportions of area are transplanted later in the *rabi* calendar as land elevation increases. About 10% of the low land is planted by end-December, while there is very little planting in December in the other land types. The planted proportion for Medium High lands is only a little over 10% until late January. In the last week of January and the first week of February, there is a rapid surge in planting across land types. Planting continues through February, and is more or less complete by the end of the month, except for a few plots that are planted in early March.

Very low lands appear somewhat anomalous to this pattern, with little planting occurring until the third week of January. Two possible explanations exist for this: first, being immediately adjacent to the receding *beel,* VL lands drain slower than average and are the last to be exposed if they are even ever completely exposed. Planting may be delayed due to this factor, even if the land was previously fallow. Second, VL lands are more likely than other land types to grow local varieties of *boro*. Local varieties are usually of short enough duration to be harvested well before flood arrival, even if planted late, or have some ability to elongate to cope with some early onset flooding. They are however low yielding.

Table 6.5 below shows the temporal distribution of harvest according to land type.

Corresponding to earlier planting of L lands compared to other land types, a greater proportion of L lands are also harvested earlier. Boro crops on ML and MH lands, being least susceptible to flood damage, are more likely to be harvested late in the summer, with about 66% of the crop on these land types still standing on 20 May. Across land-types, the bulk of harvest occurs in May, especially in the last week. By the first week of June, all plots have been harvested.

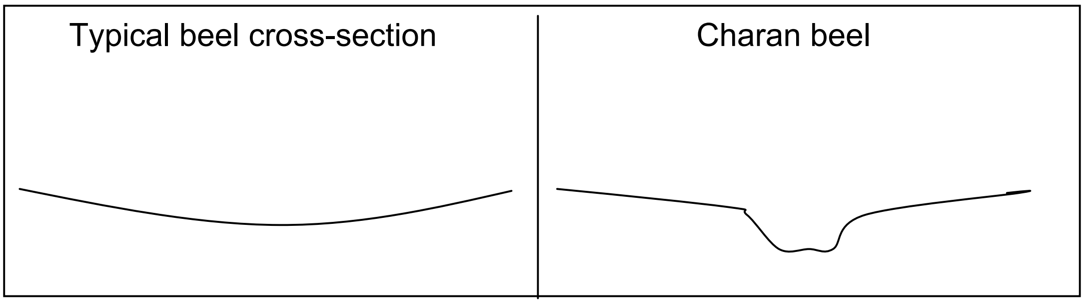
Table 6.5: Harvest times by land elevation at Charan

Harvest Dates	**VL**	**L**	**ML**	**MH**	**Grand Total**
25-27Apr-98	6.00%	17.53%	4.18%	1.38%	4.85%
04-06 May-98	0.00%	0.00%	5.43%	1.13%	2.22%
06-08 May-98	31.02%	9.15%	3.59%	1.26%	5.01%
11-13 May-98	0.00%	0.00%	0.00%	0.82%	0.40%
16-18 May-98	8.19%	33.89%	19.97%	28.61%	25.39%
22-24-May-98	54.79%	34.40%	60.79%	59.62%	56.07%
31 May - 02-Jun-98	0.00%	5.03%	6.05%	7.17%	6.06%
Grand Total	100.00%	100.00%	100.00%	100.00%	100.00%

6.5 Flood Spread at Charan Beel

Over the dry-season, the Charan beel area steadily dries up until only the small area of the perennial beel remains inundated. Thus there is a temporal decline in flooded areas as well as depths from drawdown onwards until the start of May, with much of the area drying up early in the winter. Figure 6.2 in the appendix shows the flood extent on 11 May, when the water spread is at its lowest[35]. The next figure, for 23 May[36], shows that the water levels have already started gradually increasing in the 3rd week of May, and the lowest plots close to the perennial part of the beel have been inundated.

The water spread results from the GIS-based counterfactual simulations are illustrated in the next two figures, the first where the flood arrives one week early and the second where it arrives two weeks early. As can be seen, the *areal extent* of the flood spread seems to remain more or less constant at Charan at this critical period even when the flood arrives a week or two early. The reason for this is the particular



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[35] The water cover/depth stays at this minimum level for well over a month.

cross-sectional profile of the *beel*, which results from its morphology. *Beels* are depressions (backswamps) formed when the rivers were laying down the delta that is Bangladesh; these features are generally gently sloping saucer-like depressions. Charan *beel* was formerly a river course, which became silted in sections. Charan is thus once of a chain of beels in a linear arrangement along the previous water course, though it is not an ox-bow lake. Being a former river channel, the central perennial part of the beel is more steep sided than many beels, seen in the sketch above. The flood much reach a certain depth before it overtops this channel like section, where upon it can rapidly spread to cover the floodplain area of the beel.

It would be misleading, however, to conclude from this that early flood arrival does not pose a threat to the boro crop. Table 6.6 below presents the average water depth on the sample plots for the baseline of 23 May, compared to when the flood arrives 1 and 2 weeks early. Medium high plots are seen to stay flood-free even with a two-week early arrival of floods. VL plots on the other extreme, are seen to be very vulnerable to even a short advance in flood timing. The average flooding on VL plots on 23 May when the flood arrives just a week early, is 1.36 metres, a depth that is enough to almost completely destroy any standing crop.

Table 6.6: Average water heights (metres) for sample plots by land elevation

	VL	L	ML	MH	All Plots
Average of 23May98 water height	0.026	0.009	0	0	0.0021
Average of 23May98, 1 wk early	1.36	0.271	0	0	0.15
Average of 23May98, 2 wks early	2.33	1.13	0.18	0	0.43

6.6 Estimates of crop damage due to early flooding

The methodology outlined previously, using simulated water levels and crop damage factors was applied, and the results are presented below. 45% of the VL plots suffer some form of damage even from a one week early flood. Significantly, when the damage occurs, it is likely to be substantial. 40% of the VL plots are almost completely damaged by a one week early flood. Evidently, the low plots flood rapidly and deeply, as was previously indicated in table 6.6. The L plots on the other hand, are largely unaffected by a 1 week early flood. A two week early flood would however cause significant damage to about a quarter of the low land boro crop. The ML and MH plots remain largely unaffected even by a two week early flood.

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[36] 23 May is chosen for the illustration of our early flood arrival simulation here because a good proportion of the boro crop in the area is harvested in 22-24 May, as seen before.

Table 6.7: Crop damage estimates by land elevation

Very Low Land Crop Damage: % of Plots in Damage Categories					
	No damage	20% to 40%	40% to 60%	60% to 80%	80% or higher
Baseline Flooding	100%	0%	0%	0%	0%
1 Week Early	55%	0%	5%	0%	40%
2 Weeks Early	50%	0%	0%	0%	50%

Low Land Crop Damage: % of Plots in Damage Categories					
	No damage	20% to 40%	40% to 60%	60% to 80%	80% or higher
Baseline Flooding	100%	0%	0%	0%	0%
1 Week Early	92%	3%	0%	0%	5%
2 Weeks Early	61%	3%	11%	0%	26%

Medium Low Land Crop Damage: % of Plots in Damage Categories					
	No damage	20% to 40%	40% to 60%	60% to 80%	80% or higher
Baseline Flooding	100%	0%	0%	0%	0%
1 Week Early	100%	0%	0%	0%	0%
2 Weeks Early	90%	3%	1%	1%	5%

Medium High Land Crop Damage: % of Plots in Damage Categories					
	No damage	20% to 40%	40% to 60%	60% to 80%	80% or higher
Baseline Flooding	100%	0%	0%	0%	0%
1 Week Early	100%	0%	0%	0%	0%
2 Weeks Early	100%	0%	0%	0%	0%

With a one-week early flood being a high-probability event, the VL lands, and to a lesser extent, L lands, are seen to be very exposed to early flood damage at Charan beel. The aggregate estimates, however, do not provide a clear idea of whether there is any specific pattern to the damage. A profile of damaged vs undamaged plots could provide a better idea in this regard. Since the sample numbers of very low and low plots are small, it is instructive to look at information at the plot level. We present such information in table 6.8 below. Note that varietal information was not available for all boro-cropped plots in the database.

The plot-level information for VL lands is quite revealing. The plots undamaged by one and two week early floods are exclusively single-cropped with Boro. The majority of these are planted before January 25, and are harvested around the 7th of May, well before even an early flood arrival. The exceptions that are planted in February are local varieties with short durations, which are still able to come off the land ahead of the early flood danger time zone. This is in marked contrast to the damaged plots, where almost all plots are double-cropped with mustard preceding boro. This often pushes planting time into early February, and inevitably delays harvest until the last week of May. At the baseline, in a normal flood year, harvest at this time is in advance of flooding. But when the flood arrives even a week early, damage to these crops is in excess of 80%. Note also that the damaged VL plots are mostly planted to the older generation of long-duration HYV Boro such as IR8.

The plot level information for the L lands is presented in the appendix rather than in text since it is less compact. With L lands, the connection between cropping intensity and risk of flood damage is much less clear-cut. A number of single cropped plots are exposed to damage, while a number of plots with mustard preceding boro are harvested earlier in May and in advance of the danger period. As a general rule, however, all plots planted by the last week of January appear to be flood risk-free, and as for VL plots where mustard precedes boro, there is an increased chance of damage.

Table 6.8: Plot-level damage information for VL lands

			VL: Undamaged Plots					
Plot ID	**Area (m^2)**	**Variety**	**Planting Date**	**Harvest Date**	**Pattern***	**Baseline Damage**	**1 wk early**	**2 wks early**
10937	1123	BR 11	03-Dec-97	06-08-May-98	F/F/B	0	0	0
10938	1305		24-Jan-98	06-08-May-98	F/F/B	0	0	0
22173	1409		24-Jan-98	06-08-May-98	F/F/B	0	0	0
22174	1334		24-Jan-98	06-08-May-98	F/F/B	0	0	0
22175	1681		24-Jan-98	06-08-May-98	F/F/B	0	0	0
22176	2389		24-Jan-98	06-08-May-98	F/F/B	0	0	0
10345	532.6		07-Feb-98	06-08-May-98	F/F/B	0	0	0
22110	507.5	Local	18-Feb-98	25-27-Apr-97	F/F/B	0	0	0
22177	1696	Local	18-Feb-98	25-27-Apr-97	F/F/B	0	0	0
22121	1616	Kuinal (Local)	05-Mar-98	06-08-May-98	F/F/B	0	0	0
			VL: Damaged Plots					
Plot ID	**Area (m^2)**	**Variety**	**Planting Date**	**Harvest Date**	**Pattern***	**Baseline Damage**	**1 wk early**	**2 wks early**
20537	1016	IR 8	14-Jan-98	22-24-May-98	F/F/B	0	80-100%	80-100%
21659	1970		24-Jan-98	22-24-May-98	F/M/B	0	80-100%	80-100%
21661	2341		24-Jan-98	22-24-May-98	F/M/B	0	80-100%	80-100%
22027	3614	IR 8	01-Feb-98	22-24-May-98	F/M/B	0	80-100%	80-100%
21948	1921	IR 8	03-Feb-98	22-24-May-98	F/M/B	0	42%	80-100%
22045	2781	Sharkari/BR 16	03-Feb-98	22-24-May-98	F/M/B	0	80-100%	80-100%
22046	3700	Kaora	04-Feb-98	22-24-May-98	F/M/B	0	80-100%	80-100%
22004	3009	Sharkari/BR 16	05-Feb-98	16-18-May-98	F/M/B	0	0	80-100%
22050	1728	Sharkari/BR 16	05-Feb-98	22-24-May-98	F/M/B	0	80-100%	80-100%
22002	1051		19-Feb-98	22-24-May-98	F/M/B	0	80-100%	80-100%

F=Fallow, M=Mustard, B=Boro

6.7 Vulnerability to early flooding by socio-economic category

Given the overall orientation of this study, it is particularly important to determine whether there is any empirical evidence that the poorer classes are more exposed to early flood risk than more well-to-do classes. One way of approaching this would be to take the *particular* set of ‘damaged’ vs ‘undamaged’ VL and L plots above, and determine empirically if the damaged ones are more likely to belong to poorer households or not. This did not prove to be possible, however, because of the lack of a complete link between cropping and household information in the dataset, as discussed above. For some of the plots in the above set, ownership data were not available. Hence, a more general question is posed: given that VL and L lands are by-and-large found to be the only types exposed to early flood risk, is there evidence that these lands types (in *general*) are more likely to be owned by poorer households? Additionally, typically what proportion of the land portfolio of poorer households is made up of VL and L lands? The dataset from Charan contains complete plot ownership records of a household sub-sample stratified by land-ownership classes that enables this analysis. In order to avoid any potential distortions arising from small samples, the 7 socioeconomic classes in table 6.2 were collapsed into 4 for this analysis: (almost) landless (<0.5 acres), marginal and small (0.5 to 2.5 acres), medium (2.5 to 7.5 acres), and large (>7.5 acres).

The distribution of land ownership by social class across land elevations[37] is shown in table 6.9. High land comprises over 50% of the total land area held in the sample. This sample value is generally reflective of elevations around Charan beel, where lower lands are concentrated around the beel, with elevations generally increasing as distance from beel increases, and households operating lands in a large surrounding area. The actual area of VL and L land is relatively small (about 20% of total), and this skewness in the distribution of elevations implies that there is a natural hedge available against early flood risk at Charan. However, if particular classes are found to hold significantly disproportionate amounts of L & VL land, the hedge available to them would be correspondingly low.

The last column in table 6.9 shows the % of VL and L land area in total land owned by each category. There does appear to be a connection between socio-economic class and the distribution of land-ownership by elevation classes. The nearly landless own disproportionate amounts of land potentially vulnerable to early flooding (30%) compared to the average (21%). The proportion of L & VL land in the portfolio of marginal & small and medium classes is roughly similar to the average. The large farmers, however, own practically no VL and L lands, their portfolios almost exclusively comprised of the flood-free MH and H land. This empirical connection points to elevation makeup being a further inequalising factor in the floodplains of Bangladesh. The gulf in the wealth status of the landless and the large farmers is already substantial, with a large farmer owning over fifteen times the land owned by a nearly landless floodplain dweller. But with the largest farmers owning practically no low land in Charan, and the poorest owning disproportionate amounts, at least three further factors contribute to an even wider gulf: (i) higher elevation lands usually provide three crops in a year, while lower elevation lands are at most double-croppable, (ii) with flood risk being minimal in higher elevation lands, there is more scope for growing high-valued crops such as vegetables and spices, and (iii) lower elevation land is exposed to early flooding risk, while higher elevation lands are not.

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[37] Beel land ownership is not included in this analysis. Beel lands are permanently submerged by definition, and cannot be utilised for crop production. Their value as assets is therefore fundamentally different from land in other elevation classes.

Table 6.9: Aggregate land ownership by socio-economic class (acres)

SECLASS	VL	L	ML	MH	H	Grand Total	L&VL as % Of total
Landless	1861	358	287	989	3713	7212	30
Marginal & Small	3895	443	1391	4361	8096	18191	23
Medium	1073	481	760	1649	4949	8915	17
Large	0	0	70	149	1493	1713	0
Grand Total	6830 (18%)*	1284 (3%)*	2511 (7%)*	7151 (19%)*	18300 (51%)*	36079	

* % of grand total (36079 acres)

Aggregates by social-class, however, do not provide a complete picture of risk exposure within each class. Even though households within a wealth class own roughly similar amounts of land, it is possible that the elevation distribution within a land class can be substantially skewed. In table 6.10 below, the elevation-wise breakup of the household with the most percentage of its total land holdings in VL and L lands is presented. The indication is that even though the overall land distribution around Charan beel is dominated by higher elevation lands, there do exist landless and marginal households that are extremely exposed to early flood risk, with over 80% of their land ownership in VL and L elevations. In contrast, even the most 'exposed' of medium farmers do not have more than 35% of their land in these categories. There are practically no rich households that are likely to be affected by one and two week early floods.

Table 6.10: 'Most vulnerable' households by socio-economic category

	VL	L	ML	MH	H
Landless	82%	2%	8%	2%	6%
Marginal & Small	83%	4%	1%	6%	6%
Medium	24%	9%	0%	49%	18%
Large	0%	0%	31%	58%	11%

6.8 Short-duration varieties

One approach to managing early flood risk to the boro crop involves the construction of submersible embankments. Submersible embankments, by virtue of their low heights, do not interfere with normal monsoon floods and the various benefits they bring by allowing overtopping by floodwaters. At the same time, they are able to prevent early but low-volume flooding, allowing safe harvest of the boro crop. A compelling argument has been made by FAP 17, however, that early *riverine* flooding is not a significant problem in the North-Central area. This was based on an examination of historical data on the dates of first entry of Jamuna river water into the floodplain in Northcentral Bangladesh. In 12 out of 16 years, first floods were found to have arrived after 14 June, well after the boro harvest. Even in the occasional year when the floods were early, they generally arrived *after* 31 May (FAP 17, 1995). The early floods experienced in Charan beel and other such sites in the North-Central area then are likely due to early local precipitation events, which cannot be controlled by the construction of submersible embankments.

An alternative way to manage this risk is by adjusting the cropping calendar during the year so that the boro crop can he harvested from a week to two weeks early. It can be seen from the simulation results for VL plots in table 6.8 that the bulk of the early flood damage happens when plots harvested during the period 22-24 May period are visited by early floods. At the baseline itself, *i.e.*, in the period 22-24 May, water levels are not high enough to cause damage to any of the plots. Thus if these plots were harvested even a week earlier, *i.e.*, in the 15-17 May period, a one-week early flood would cause no damage whatsoever to these plots. In the case of the L plots, the risk of damage is principally from *two*-week early floods, again predominantly on plots harvested around 22-24 May. As before, a one-week earlier harvest would eliminate damage from even the relatively low-probability two-week early flood.

Opportunities to adjust the cropping calendar in order to achieve an earlier boro harvest potentially exist throughout the crop year. However, as seen from the simulation tables, damage is largely restricted to VL and L plots that are at most double-cropped, involving no *aman* production. Thus the *kharif* season does not seem to offer an opportunity to advance the calendar. Mustard is almost exclusively the pre-boro crop in double-cropped plots. As seen before in the case of VL plots, it is the set of plots double-cropped with mustard and boro that stand most exposed to early flood damage. Therefore it is worth investigating whether opportunities exist to squeeze the crop calendar in the early *rabi* period. However, an investigation of the mustard varietal information in the database revealed that a local mustard variety, Tori-7 was predominant in the Charan area. Tori-7 is a low-yielding variety that provides only about 0.95 -1.1 tonnes per hectare. Several HYV alternatives exist that could practically double the yield, in particular BARI sarisha-7 and BARI sarisha-8, which provide about 2 – 2.5 tonnes per hectare (Mondal, *et. al.*, 2001). However, Tori-7 can be grown in 70-80 days, while all the HYVs take upwards of 90 days. Thus, far from providing opportunities to shorten the cropping calendar, the available alternatives in fact would tend to elongate it. In fact, an extension programme undertaken in the Tangail area that attempted to popularise HYV mustard varieties in place of Tori-7 was not successful, principally because the alternatives were of longer duration (FAP 20, 2000).

The opportunities for contraction of the cropping calendar then seem restricted to the boro crop itself. A look at the varietal composition in table 6.8 for VL land and appendix table 6.13 for L land reveals that there does indeed appear to be scope for mitigating early flood risk by using shorter-duration boro varieties. Boro grown on VL and L plots at Charan is primarily of three varieties:IR8, or ‘IRRI rice’, BR16, and BR11. Table 6.11 below presents basic information on the growth duration (including seedbed period) and experimental grain yields for these varieties and some potential replacement varieties. The widespread prevalence of IR8 in lowland plots in Charan is somewhat surprising, since it is a variety dating back to the late 1960’s which has played a significant role in the green revolution, but has since been widely supplanted by improved varieties developed later. Quite possibly, its strong presence at Charan points to inadequate extension services in the area. With a growth duration of 170 days, IR8 is of longer duration than most available alternatives. The other two prominent HYVs observed at Charan, BR11 and BR16, also have relatively long durations (165 days). At least two attractive alternatives exist that can provide comparable yields and reduced durations in the field. BR 26 and BR28 reduce the field duration by over two weeks compared to the existing varieties, and do not suffer a significant disadvantage in terms of yields. BR29 enables a slightly earlier harvest compared to IR8, BR11 and BR16, and significantly higher yields.

It is important to note that the experimental results reported in Table 6.11 can differ significantly from what is achieved on farmer's fields. This is particularly true of maximum yields, and there is a significant amount of divergence in variety-specific yield estimates across studies. In general, however, the evidence points towards significant advantages in moving away from the traditional HYVs such as IR8, as well as the older generation of BRRI-developed HYVs such as BR11, towards the new generation of shorter-duration, higher-yielding varieties. FAP20 (2000), for instance, also found that IR8 was the standard local variety in Tangail, and suggested that BR29 and BR26 could enable significant improvement. For instance, the on-farm demonstration of FAP20 found that the mean *field* duration of BR26 was about 10 days less than that of IR8, but yields were about 1.3 t/ha higher.

Table 6.11: Growth duration and yield potential of some important boro varieties in Bangladesh

Variety	Growth duration (days)	Grain yield (t/ha)
BR 11*	165	6
BR 14	160	6
BR16	165	6
BR 26**	145	5.8
BRRIdhan 28	140	5.8
BRRIdhan 29	160	6.5
BRRIdhan 36	140	5.5
IR8	170	5.5

*Originally released as *aman* variety, but also grown as boro.
**Originally released as *aus* variety, but also grown as boro.
Sources: Jashim and Chowdhury (2001); Salam (1992), FAP20 (2000), BRRI (1997)

6.9 Conclusions

Whilst the north central region of Bangladesh is not generally characterised as being badly affected by early onset and flash flooding in the same way as the haor basin, the boro dependent cropping pattern in the region does mean that rabi season crops growing on low (L) and very low (VL) lying land maybe susceptible to damage from early onset flooding.

The re-analysis of the GIS data from field studies at Charan Beel in the north central region demonstrates that the most important cropping patterns in the floodplain around the beel are fallow/fallow/boro in the kharif 1, kharif 2 and rabi seasons respectively, accounting for 27.9% of sampled plots, and fallow/mustard/boro accounting for 46.0% of sampled plots. These two patterns are the only ones found on VL land and represent the majority of patterns on L land. The risk with these patterns on the lower-lying land classes, which are the first to be flooded, is that if an early onset of flooding occurs prior to the boro harvest, crop damage results.

Charan Beel exhibits a slightly unusual cross-sectional profile in that it has a deeper 'U' section in its centre than many beels. This limits the extent of the early spread of the flood (though not the depth). Nonetheless, VL and L plots are inundated by early onset flooding, and a proportion – those that still have standing crop at this time – experience crop loss through flood damage. The model shows that 45% of VL plots suffer some form of damage if the flood arrives only one week early. Also, when this damage occurs, it is usually substantial. The very large majority of VL plots whose crop is damaged are characterised by a double crop cropping pattern (fallow/mustard/boro), the boro crop being those planted after the end of January, and mostly with older HYVs, such as IR8. Such plots are mostly harvested after 7th May, and so are prone to early onset flood damage. The biophysical factors that cause late harvesting appear to be (i) preceding the boro crop with mustard, and (ii) using older, long duration, varieties. Having mustard in the crop rotation seems to delay the planting date for boro sufficiently to expose it to the risk of flood damage before harvest.

In considering means to minimise the risk of early onset flood damage, the use of submersible embankments and other FCD structures does not present a solution as the hydrological evidence is that most of the critical early flood is a result of impounded rainfall. However analysis of the duration of crop varieties offers more potential. Reducing the duration of either the mustard or boro by one or two weeks would allow the boro harvest to be moved forward in the season sufficiently to avoid early onset flooding. Modern varieties of mustard yield much higher than currently used local ones such as Tori-7, but have a duration of 10 to 20 days longer, and are therefore not a solution. In contrast a number of boro varieties exist that have durations of as much as 30 days less than the commonly used IR8, while demonstrating an equal or slightly better yield potential.

Much agricultural research is recognised to have disproportionately benefited larger farmers. The study thus examined how the early onset flood damage problem affected different wealth groups of farmer. Landless and small & marginal farmers are found to own disproportionate amounts of flood prone land (low-lying) land, with over 80% of their land-holding classed as L and VL.

Thus, it may be concluded that the poorer groups of farmers are most prone to their boro crop being damaged by early onset flooding. They are particularly vulnerable to the risk of early flooding not only because they own disproportionate amounts of lower elevation plots, but also because they are likely to be most constrained with regard to having to grow an early *rabi* crop like mustard to finance the *Boro* that follows. Yet evidence from Charan shows that this is not a problem that will require any new investments in technology. Requisite technology in the form of a new generation of shorter duration *Boro* varieties has been available for some time now, but is apparently failing to reach this group. A programme of farmer-based research on using existing shorter duration boro varieties could go some way in ameliorating this situation.

6.10 Appendix

Figure 6.2: Water cover at Charan Beel, 11 May

Figure 6.3: Water cover at Charan beel, 23 May

Figure 6.4: Water cover at Charan Beel, 23 May, 1 week early flood

Figure 6.5: Water cover at Charan beel, 23 May, 2 weeks early flood

Table 6.12: Boro transplanting dates by land elevation class

Boro Transplanting: Very Low Land

Planting Week	Area Planted	% of Total Area	Number of Plots	% of Number of Plots
Nov 27-Dec 3	1123	3.1	1	5
Dec 4 - Dec 10	0	0.0	0	0
Dec 11 - Dec 17	0	0.0	0	0
Dec 18-Dec 24	0	0.0	0	0
Dec 25-Dec 31	0	0.0	0	0
Jan 1 - Jan 7	0	0.0	0	0
Jan 8-Jan 14	1015.5	2.8	1	5
Jan 15 -Jan 21	0	0.0	0	0
Jan 22-Jan 28	12428.1	33.8	7	35
Jan 29-Feb 4	12015.3	32.7	4	20
Feb 5-Feb 11	5269.3	14.3	3	15
Feb 12-Feb 18	2203.2	6.0	2	10
Feb 19-Feb 26	1051.1	2.9	1	5
Feb 26-Mar 4	0	0.0	0	0
Mar 5-Mar 11	1616.4	4.4	1	5
Grand Total	36721.9	100	20	100

Boro Transplanting: Low Land

Planting Week	Area Planted	% of Total	Number of Plots	% of Number of Plots
Nov 27-Dec 3	1959.8	2.4	2	5.3
Dec 4 - Dec 10	0	0.0	0	0.0
Dec 11 - Dec 17	0	0.0	0	0.0
Dec 18-Dec 24	4898.1	6.0	2	5.3
Dec 25-Dec 31	3042.2	3.7	2	5.3
Jan 1 - Jan 7	0	0.0	0	0.0
Jan 8-Jan 14	4559.3	5.6	1	2.6
Jan 15 -Jan 21	7323	9.0	2	5.3
Jan 22-Jan 28	2230.1	2.7	2	5.3
Jan 29-Feb 4	33432.6	40.9	15	39.5
Feb 5-Feb 11	16200.6	19.8	7	18.4
Feb 12-Feb 18	6163.7	7.5	3	7.9
Feb 19-Feb 26	0	0.0	0	0.0
Feb 26-Mar 4	0	0.0	0	0.0
Mar 5-Mar 11	1926.3	2.4	2	5.3
		0.0		
Grand Total	81735.7	100	38	100

Boro Transplanting: Medium Low Land

Planting Week	Area Planted	% of Total Area	Number of Plots	% of Number of Plots	
Nov 27-Dec 3	2071.3	1.2	2	2.8	
Dec 4 - Dec 10	0	0.0	0	0.0	
Dec 11 - Dec 17	0	0.0	0	0.0	
Dec 18-Dec 24	1139.6	0.6	1	1.4	
Dec 25-Dec 31	2649.3	1.5	1	1.4	
Jan 1 - Jan 7	0	0.0	0	0.0	
Jan 8-Jan 14	4556.7	2.6	4	5.6	
Jan 15 -Jan 21	38846.2	22.0	13	18.1	
Jan 22-Jan 28	5426.8	3.1	2	2.8	
Jan 29-Feb 4	76898.1	43.6	27	37.5	
Feb 5-Feb 11	26625.4	15.1	12	16.7	
Feb 12-Feb 18	11612.4	6.6	5	6.9	
Feb 19-Feb 26	3166.7	1.8	1	1.4	
Feb 26-Mar 4	0	0.0	0	0.0	
Mar 5-Mar 11	3271	1.9	4	5.6	
Grand Total	176263.5	100	72		

Boro Transplanting: Medium High Land

Planting Week	Area Planted	% of Total Area	Number of Plots	% of Number of Plots	
Nov 27-Dec 3	0	0	0	0	
Dec 4 - Dec 10	0	0	0	0	
Dec 11 - Dec 17	0	0	0	0	
Dec 18-Dec 24	1256.9	0.4	1	0.9	
Dec 25-Dec 31	1740.8	0.6	2	1.8	
Jan 1 - Jan 7	0	0	0	0	
Jan 8-Jan 14	2459.8	0.8	1	0.9	
Jan 15 -Jan 21	17109.2	6.1	7	6.5	
Jan 22-Jan 28	12392.9	4.4	4	3.7	
Jan 29-Feb 4	163136.7	58.8	65	60.7	
Feb 5-Feb 11	47749.1	17.2	16	14.9	
Feb 12-Feb 18	29863.1	10.7	10	9.3	
Feb 19-Feb 26	0	0	0	0	
Feb 26-Mar 4	1419.8	0.5	1	0.9	
Mar 5-Mar 11	0	0	0	0	
Grand Total	277128.3	100	107	100	

Boro Transplanting: All Land					
Planting Week	**Area Planted**	**% of Total Area**	**Number of Plots**	**% of Number of Plots**	
Nov 27-Dec 3	5154.1	0.9	5	2.1	
Dec 4 - Dec 10	0	0.0	0	0.0	
Dec 11 - Dec17	0	0.0	0	0.0	
Dec 18-Dec 24	7294.6	1.3	4	1.7	
Dec 25-Dec 31	7432.3	1.3	5	2.1	
Jan 1 - Jan 7	0	0.0	0	0.0	
Jan 8-Jan 14	12591.3	2.2	7	3.0	
Jan 15 -Jan 21	63278.4	11.1	22	9.3	
Jan 22-Jan 28	32477.9	5.7	15	6.3	
Jan 29-Feb 4	285482.7	49.9	111	46.8	
Feb 5-Feb 11	95844.4	16.8	38	16.0	
Feb 12-Feb 18	49842.4	8.7	20	8.4	
Feb 19-Feb 26	4217.8	0.7	2	0.8	
Feb 26-Mar 4	1419.8	0.2	1	0.4	
Mar 5-Mar 11	6813.7	1.2	7	3.0	
Grand Total	571849.4	100	237	100	

Table 6.12: Plot-level damage information for L lands

			L Undamaged Plots					
plot id	**AREA**	**Variety**	**Planting Date**	**Harvest**	**Pattern**	**baseline**	**1 wk early**	**2 wks early**
20497	811.9		29-Nov-97	25-27-Apr-98	F/F/B	0	0	0
20499	1148		29-Nov-97	25-27-Apr-98	F/F/B	0	0	0
20550	1875	BR11	19-Dec-97	25-27-Apr-98	F/F/B	0	0	0
20577	3023	BR11	19-Dec-97	25-27-Apr-98	F/F/B	0	0	0
21952	1539	BR11	27-Dec-97	25-27-Apr-98	F/F/B	0	0	0
20652	1503		29-Dec-97	16-18-May-98	F/F/B	0	0	0
10332	4559		14-Jan-98	25-27-Apr-98	F/M/B	0	0	0
10333	6004		19-Jan-98	6-8-May-98	BA/M/B	0	0	0
21961	1319		19-Jan-98	16-18-May-98	F/F/B	0	0	0
22108	1473		24-Jan-98	6-8-May-98	F/F/B	0	0	0

30184	756.7	IR 8	27-Jan-98	16-18-May-98	BA/F/B	0	0	0
40380	1242	IR 8	01-Feb-98	16-18-May-98	F/M/B	0	0	0
22136	1375	Local	03-Feb-98	25-27-Apr-98	F/M/B	0	0	0
20505	3475		03-Feb-98	16-18-May-98	F/M/B	0	0	0
21946	4990	IR 8	03-Feb-98	16-18-May-98	F/M/B	0	0	0
21947	3194		03-Feb-98	16-18-May-98	F/M/B	0	0	0
21956	3153	IR 8	03-Feb-98	16-18-May-98	F/F/B	0	0	0
30186	1473	BR11	04-Feb-98	16-18-May-98	BA/M/B	0	0	0
30185	462.1	Sharkari/BR 16	05-Feb-98	16-18-May-98	BA/F/B	0	0	0
20500	3375	IR 8	06-Feb-98	16-18-May-98	F/F/B	0	0	0
21691	2397	IR 8	13-Feb-98	22-24-May-98	F/M/B	0	0	0
10732	306.3	Local	10-Mar-98	22-24-May-98	F/F/B	0	0	0
			L Damaged Plots					
plot id	**AREA**	**Variety**		**Harvest**	**Pattern**	**baseline**	**1 wk early**	**2 wks early**
10927	2736		29-Jan-98	22-24-May-98	F/F/B	0	0	80-100%
10928	1767		29-Jan-98	22-24-May-98	F/F/B	0	0	80-100%
22025	2010	Kaora	01-Feb-98	22-24-May-98	F/M/B	0	0	80-100%
20459	1812		01-Feb-98	31-May-2-June-98	F/M/B	0	80-100%	80-100%
22006	2753	Sharkari/BR 16	03-Feb-98	16-18-May-98	F/M/B	0	0	57%
21951	2207	IR 8	03-Feb-98	22-24-May-98	F/M/B	0	0	80-100%
30191	748.4	IR 8	03-Feb-98	22-24-May-98	BA/M/B	0	0	50%
40371	499.2	IR 8	04-Feb-98	22-24-May-98	F/F/B	0	0	80-100%
21660	2096	BR 11	05-Feb-98	22-24-May-98	F/M/B	0	27%	80-100%
21992	2157	Sharkari/BR 16	05-Feb-98	22-24-May-98	F/M/B	0	50%	80-100%
30189	1564	IR 8	05-Feb-98	22-24-May-98	BA/F/B	0	0	42%

20475	1968	IR 8	06-Feb-98	22-24-May-98	F/M/B	0	0	80-100%
22023	4580	Sharkari/BR 16	07-Feb-98	22-24-May-98	F/M/B	0	0	27%
22037	1464	IR 8	13-Feb-98	22-24-May-98	BA/M/B	0	0	20%
22069	2303	BR 14	13-Feb-98	31-May-2-June-98	F/F/B	0	80-100%	80-100%
22148	1620	Local	10-Mar-98	22-24-May-98	F/F/B	0	0	50%

References

- Barr, J. J. F. 2000. Investigation of livelihood strategies and resource use patterns in floodplain production systems in Bangladesh. Project final technical report to DFID-NRSP.

- Brammer, H. 1997. Agricultural development possibilities in Bangladesh. Dhaka: The University Press Ltd.

- BRRI. 1997. BRRI annual report for 1997. Dhaka: BRRI.

- EGIS & Delft Hydraulics 1997. Regional environmental profile - Bangshi-Dhaleswari-Kaliganga Region . Dhaka: EGIS & Delft Hydraulics.

- FAO & UNDP 1988 Land resources appraisal of Bangladesh for agricultural development. Report No. 2 Agro-ecological zones of Bangladesh. Technical Report No. 5, FAO, Rome.

- FAP17. 1995. Final Report Main Volume.

- FAP20. 2000. CPP Tangail. Final Report. Annex D-F.

- Jashim, U. A., Chowdhury, J.U. 2001. Rice research in Bangladesh in retrospect. *Advances in agronomic research in Bangladesh* 5:35-56

- Mondal, M. R. I., Hossain, M.A., Begum, F., Ali, M.H. 2001. Oilseeds production in Bangladesh: constraints and opportunities. *Advances in agronomic research in Bangladesh* 5:73-92

- MPO. 1987. Crop production limitations in Bangladesh, technical report no. 1. Dhaka: Master Plan Organization.

- Office of Field Services 1993. *Agroecological Zones at Thana Level*. Office of Field Services, Department of Agricultural Extension, Dhaka.

- Salam, M. U. 1992. A systems approach to the study of potential production of Boro rice in the Haor region of Bangladesh. Ph.D. thesis. Reading: University of Reading

- Salam, M. U., et al. 1994. Potential production of Boro rice in the Haor region of Bangladesh: Part 2. Simulation experiments on the effects of management variables and flooding time. *Agricultural Systems* 46:279-293

- Thompson, P. 1989. The impact of flood control on agricultural development in Bangladesh. Middlesex: Flood Hazard Research Centre

Chapter 7: Flood season water control

7.1 Introduction

In Bangladesh, the livelihoods of over a hundred million people depends critically on floodplain development policies. Agriculture is the largest economic sector in the country, accounting for 32 per cent of the GDP and employing over 60 per cent of Bangladesh's labour force. This sector has been the primary target of development programs, and floodplain management policies have traditionally been specifically designed to increase agricultural output, with the goal of achieving self-sufficiency in rice production. Levees are built to reduce damages from annual floods and to allow for intensive rice cultivation. Beginning in the mid-1960s, over 7500 km of embankments have been built. About 23% of the country, or 40% of cultivated land, is now protected by about 200 flood control structures (Rahman *et. al.*, 1994; Sultana and Thompson 1997). More than 7900 hydraulic structures, including sluice gates and regulators, control the flow of water in and out of embanked floodplain areas. The numerous studies under the Flood Action Plan have together invested hundreds of millions of dollars in researching and implementing regional FCDI schemes.

The often emotion-charged debate over the desirability of large-scale flood control is now well documented, as is the notion that FCDI structures benefit the agricultural sector only at the cost of the fisheries sector. Engineering innovations such as compartmentalisation and 'fish-friendly' sluice gates that may continue to provide agricultural benefits while softening the impact on the fishery have also been researched and are likely to be part of the structural package for floodplain development in the future. In the short to medium run, however, floodplain managers must work within the constraints imposed by extant, traditional FCD structures. The one aspect of these structures that is amenable to direct control, affecting the livelihoods of the people within them, is the mode of operation of sluice gates and regulators.

In a previous chapter on water retention, we have noted that dry season water management is typically carried out mostly for the benefit for the agricultural sector. The same is often true of flood season water control. Within embanked floodplain areas, water levels are determined by local rainfall, water pumped in (if pumping structures exist), and water that is let in through sluice gates. When the floodwaters begin to rise in May and June, some remnant Boro plots may not yet be harvested, and will be susceptible to flood damage as seen in an earlier chapter. Even the deepwater-Aman crop, adapted to deep flooding, will not tolerate rapid and continuous increases in water heights in June and July. Thus BWDB sluice gate managers will often keep sluice gates closed for much of the May-June period, perhaps opening gates for only a few day in between to allow enough water to benefit the growing crops. For example, the 'Fisheries Dynamics…' in its study of sluice management at the PIRDP, found that in 1995, the Talimnagar sluice gate was open for only four days in the May-June period (Hoggarth and Halls, 1997). In such a pattern of operation, the flood pulses from the main rivers will be kept out of the embanked floodplains. One finding of the 'Fisheries Dynamics…' study was that, while FCD structures generally lower fishing productivity within by reducing accessibility for fish, several species are indeed to able to pass through gates when open. The conclusion was therefore that more balanced sluice gate management would probably imply more frequent and more prolonged sluice openings.

This aspect of the project studies agriculture and fisheries production in one framework in order to understand the tradeoffs between these sectors in the context of early flood-season sluice management. A key point of investigation is whether typical sluice control practices generate sufficient agricultural returns to justify lost floodplain returns from fisheries, when the latter sector is appropriately valued. In doing so, we bring together data and parameters generated by various previous studies. Inevitably, some of the data are ‘patchy’, and sometimes extrapolations across regions becomes necessary. Additionally, several segments of the modelling rely on simplistic representations since disciplinary details are extremely difficult to maintain when the analysis calls for integration across disciplines. Nevertheless, it is felt that the analysis eventually provides some useful broad insights.

We do not have the means to directly address the engineering aspects of sluice gate structures, nor is this necessarily a fruitful line of enquiry for our purposes. Gates come in a variety of sizes, and can have differing numbers of vents with various aperture sizes. Simulations generated on the basis of specific gates would require hydrological engineering expertise far beyond that available in our team. In any case, analysis of several specific water control structures has been done during the course of the FAP studies, usually on the basis of hydrological simulations produced by the Surface Water Modelling Centre, Dhaka[38]. Also, our objective here is to investigate sluice control in a far more broad and generic way than would be the case if the analysis were tied to the engineering specifics of particular water control structures.

Instead, we cast the investigation in terms of the shapes of hydrographs. The eventual effect of typical flood season sluice management as described above is to delay and smoothen the hydrograph compared to what would be observed if the embankment did not exist (Hoggarth and Halls, 1997). This modification of the ‘inside’ hydrograph changes the area of floodplain land exposed to flooding and the corresponding areas in each flood land type. This is taken as the point of departure, and the analysis proceeds by considering the effects on the amount of land within the scheme flooded to various depths, and the consequent effects on agriculture and fisheries. The FPFMODEL, which has served us well in previous sections, cannot be used here since the fisheries specification in that model is not on the basis of flooding depths. Flooding depth of land dictates agricultural production possibilities in flood season floodplain agriculture in Bangladesh, and is arguably the only basis around which the agricultural and fisheries sectors can be integrated in models.

7.2 Overview of the Floodplain Management Model

This section presents the empirical floodplain management model (FMM) and the methodology used to solve the model. A floodplain management model, based on non-linear mathematical programming is developed in which expected net returns from agriculture and fisheries are jointly maximized. This approach is similar to the more widely known approach of optimising farm plans on the basis of linear programming. There, the problem is envisaged as one where farmers allocate available land on the farm to various enterprises based on a profit-maximisation motive, and subject to various constraints. Here, the characterisation is in terms of a floodplain planner allocating land within a region to fisheries and/or agricultural production (including various enterprises within the agricultural sector) on the basis of maximisation of net returns jointly from the two sectors. The optimisation is subject to

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[38] We did investigate the feasibility of obtaining such simulation inputs for this project from SWMC, but found that the cost would be prohibitive (in the tens of thousands of pounds) given this project’s budget.

several constraints and parameteric restrictions, including those relating to crop damage and blockage of fish migration by FCD structures. For each sluice management strategy the model is run once and estimates of maximised net returns, returns to each sector and optimal profiles of land allocation are obtained. Then these outcomes from each discrete strategy are compared to gauge the desirability of particular strategies.

Although regional programming models are probably less well known than farming systems programming models, they have been used successfully in several development projects worldwide, including several world bank research projects[39]. In the context of Bangladesh, Ahmed (1991; 1992) has used non-linear programming to determine the total benefits obtainable from the management of *riverine* fisheries, with an empirical setting considering Bangladesh as a whole. Islam (2000) developed the programming FMM model to investigate the effects of building large-scale flood control structures in Bangladesh. The FMM model used here has been adapted from that work, though the model and its use here are substantially different from the earlier work in many ways. Firstly, the model has been re-calibrated to data from a different geographical area. Secondly, the model is used here to examine short-term water control strategies rather than to debate the actual value of flood control structures themselves. Thirdly, the fisheries specification is quite different, with basic relationships re-estimated using fresh, extensive data available from the Compartmentalisation Pilot Project (CPP) (De Graaf, *et. al.*, 2000). Fourthly, important features missing from the original model, such as parameters relating to crop damage and fish yield reduction due to blockage from FCD structures, have been explicitly included.

Extent of flooding of land to various depths is taken to be the basis for both agricultural and fisheries productivity in the FMM. For the agricultural sector, this is well established in Bangladesh, and even government categorisation of various land-types is on the basis of flooded depths during typical years. In the fisheries literature this is less common. However, a study by EGIS (1997) broached the idea of flood depth classes serving as a useful way to categorise fish habitats in Bangladeshi floodplains. De Graaf, *et. al.* (2001) have recently also used land categories defined by flooding depth as the basis for integrating the agricultural and fisheries sectors within the CPP. In terms of broad philosophy regarding integration, our study here is therefore similar in spirit to theirs. We also utilise some of the fisheries data generated and used by that study. The goals of the studies as well as most of the specifics are different, however. Their objective was to examine productivity under compartmentalisation, with considerable attention paid to the engineering specifics of the project. Our objectives, as explained above, are more generic, and we use a rather simpler hydrological module, while approaching the problem explicitly as an optimisation exercise.

The land use model presented here incorporates the effects of flooding and the differences in productivity based on flood land type, as categorized by the depth of flooding at any given time. The flood land types are as defined in Table 7.1. These are based on standard classification used in Bangladesh. Agriculture and fish production are modeled to vary with these flood land types.

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[39] Indeed, the software used for implementing our programming model, GAMS, was developed by World Bank economists working on regional development problems.

Table 7.1: Flood Land Types Defined on the Basis of Flood Depth (Source: MPO 1987)

Flood Land Type	Flood Depth	Flooding Condition	Note: Type of crop grown in wet season
F_0	0-30 cm	Intermittent	HYV rice
F_1	30-90 cm	Seasonal	Local and HYV rice
F_2	90-180 cm	Seasonal	Local varieties of rice
F_3	180-300 cm	Seasonal	Local varieties of rice
F_4	Greater than 300 cm	Seasonal deepwater body	No crops grown in the wet season.
F_5	Greater than 300 cm	Perennial deepwater body; permanent backwater lakes (beels).	No crops grown in the wet season. Some areas may be drained for agriculture in the dry season.

This is based on land types F0-F4 used in Bangladesh. For our purposes we have separated out beels from F4 and classified them separately. The above categorisation of land in Bangladesh is based on *maximum* flooding that may occur on that land in the course of a certain flood return period. For instance, F1 land will have a maximum flood depth between 30 and 90 cm at a certain time in the defined return period, but may well have a flood depth below 30 cm the rest of the time. Thus a piece of land designated as F1 will remain so unless the long-run flooding profile changes. In the FMM model, however, we use a more variable definition. If a plot of land at a particular point in time is flooded between 0 and 30 cm, it is categorised as F0 for that time. If at a different date the same plot of land is flooded between 30 and 60 cm, it is categorised as F1 for that period of time. The reason for this variable definition is that it makes our analysis easier given the set up of the FMM. However, since this can potentially cause confusion, we use the alternative definition L0…L5 later in our work. The 'variable status' definition of L0…L5 must be kept in mind so that no confusion arises.

An annual model is used which is reasonable to do for both these sectors. Crop choice and cropping pattern are based on the net returns and the available area of land in each flood land type in each season, which is then aggregated up to a year. Floodplain fisheries are assumed to follow an annual cycle, where new recruits migrate from the river to the floodplain at the beginning of each flood season and the adults leave with the receding floods. As in the modelling of De Graaf *et. al.* (2001), the empirical modelling of the fishery is not dynamic, and is purely on a yield-per-recruit basis, with no consideration of recruitment issues. Management strategies are examined only for the flood season, and not for the dry season when recruitment becomes proportionally more critical.

7.3 Digital Elevation Model

A Digital Elevation Model (DEM) for the North-Central (NC) region was used to identify the study area of Dhaleswari river floodplain. DEM provides a three-dimensional digital representation of a land surface where x, y, and z coordinates represent latitude, longitude, and elevation above sea-level respectively. DEMs are typically used to represent terrain relief, in this case, a river floodplain. It was used here to estimate areas of floodplain at different elevations.

7.4 Study area

The study area is situated on the East Side of the Jamuna river and primarily on the East Side of the Dhaleswari river that originates from the Jamuna river (see the map in Figure 7.1). The Dhaleswari River passes through the area maintaining east-south direction. On the west side of the study area flows the Lohajong River that originates from the Dhaleswari River from north of the focused area. The Porabari water level station is on the west side of the area. An area of approximately 14 thousand hectares has been purposively selected. Administratively the study area is in three thanas, Tangail sadar, Delduar and Nagarpur covering Silimpur, Atia, Deoli, Elasin, Fazilhati, Sahabatpur and Lauhati Unions. Part of the study area under Atia and Fazilhati union lies within the Tangail CPP.

River system and water flow pattern of the study area

The study area is crisscrossed with an intricate river network as is the case in other parts of the country. There are a number of permanent wetlands (beels) in the area and the associated river floodplain. The Dhaleswari river passes through the south-western part of the study area keeping the Sahabatpur Union and a part of Lauhati union on the south western part of the river and the remaining area lies on the north-eastern side of the Dhaleswari river. The Elanjani River originating from the Dhaleswari River passes through the study area parallel to the Dhaleswari River. Similarly the Lohajong River passes just outside the study area maintaining a southeastern direction parallel to the Elanjani River. The water enters in to the study area through Dhaleswari River and Elanjani River. Overland flow in to the area is limited as the northwestern part is bounded by the Dhaleswari River and the northeastern part is the Tangail compartment that controls water flow. Water from the study area drains through Dhaleswari River and Elanjani River after being filled the wetlands and the lower pockets. Water flowing out of the area through overland flow seems limited, as the southern border of the study area is comparatively higher elevated.

Figure 7.1: Map of study area

Elevation of the area

Elevation data of the study area has been collected from the national database maintained by BWDB. Digital Elevation model (DEM) has been developed maintaining a 300m by 300m grid. Accordingly one pixel in the model represents 300m by 300m land on the ground i.e. 9 hectares (ha). Elevation of a pixel is considered the same across each nine hectare unit. This is a very rough approximation, but is adequate for our broad-based regional simulation exercise. Lowest elevation found in the study area is at 7.5m (PWD) and the highest elevated area is at 11.7 m (PWD) from the mean sea level. Total area is about 14,301 ha encompassing 1,589 pixels. Besides having scattered lower elevated pixels over the entire floodplain, the lower elevation areas are generally concentrated in Silimpur, Atia and Elasin where there are a number of beels. Over 18 percent of the study area (2,646 ha) lies between 7.5 to 9 m, while over 75 percent (10,836 ha) lies between 9 to 11m. The remaining 6 percent of the study area (819 ha) are higher than 11 m. Table 7.2 shows the distribution of the study area by elevation (m), numbers of pixels at 10 centimetre intervals and area in both square metres and hectares.

Table 7.2: Area elevation distribution at decimeter interval of the study area

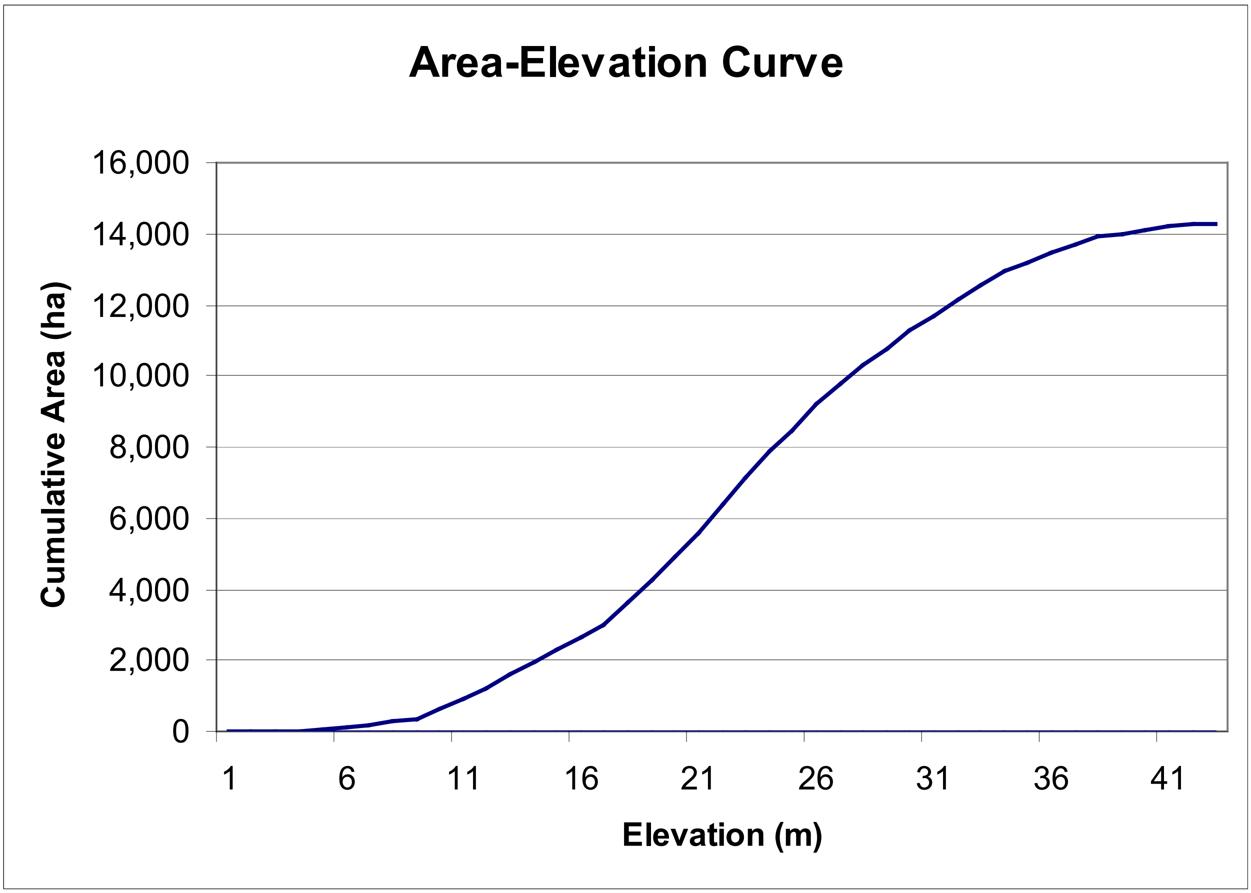
Area Elevation (meter)	*Area Elevation (decimeter)*	*Pixel no.*	*Area (sqm)*	Area (ha)
7.5	75	1	90000	9
7.6	76	0	0	0
7.7	77	1	90000	9
7.8	78	1	90000	9
7.9	79	6	540000	54
8	80	4	360000	36
8.1	81	7	630000	63
8.2	82	10	900000	90
8.3	83	11	990000	99
8.4	84	29	2610000	261
8.5	85	30	2700000	270
8.6	86	33	2970000	297
8.7	87	44	3960000	396
8.8	88	40	3600000	360
8.9	89	38	3420000	342
9	90	39	3510000	351
9.1	91	41	3690000	369
9.2	92	69	6210000	621
9.3	93	69	6210000	621
9.4	94	69	6210000	621
9.5	95	79	7110000	711
9.6	96	87	7830000	783
9.7	97	88	7920000	792
9.8	98	79	7110000	711

9.9	99	68	6120000	612
10	100	82	7380000	738
10.1	101	61	5490000	549
10.2	102	56	5040000	504
10.3	103	54	4860000	486
10.4	104	60	5400000	540
10.5	105	44	3960000	396
10.6	106	49	4410000	441
10.7	107	44	3960000	396
10.8	108	45	4050000	405
10.9	109	27	2430000	243
11	110	33	2970000	297
11.1	111	27	2430000	243
11.2	112	21	1890000	189
11.3	113	9	810000	81
11.4	114	11	990000	99
11.5	115	11	990000	99
11.6	116	7	630000	63
11.7	117	5	450000	45
Total				14,301

Source: computed from DEM.

Figure 7.2 shows the area-elevation relationship for the modelled floodplain area in the Bangshi-Dhaleswari floodplain. The figure shows the cumulative floodplain area at each land elevation. The cumulative area, up to any given elevation, can be used to calculate the area flooded for that water level. We do this by using this area-elevation information combined with historical water level data (that is, the flood hydrographs). This gives us the depth of flooding and the floodplain area in each flood land type (depth class), which is an important determinant of floodplain production as explained in earlier sections, as both agriculture and fisheries production are modelled on the basis of this relationship.

Figure 7.2: Area-Elevation Curve



7.5 Empirical Fisheries Model

First, we develop a model of fisheries production that associates output to floodplain characteristics, such as area and depth of flooding, and stresses the importance of this relationship. Given the evidence that fish production is dependent upon floodplain for habitat and nurseries, we model explicitly the effect of flooded area on fish production. We do not model fish stock dynamics explicitly here. We focus on the value of fish production and do not keep track of the stock dynamics.

We start with the Schaefer specification, which is commonly used in the fisheries literature (Clark, 1976.) The fish harvest or catch function is given by:

$$Q_t = aS_tE_t \tag{7.1}$$

where, $a > 0$. This specification assumes constant marginal returns to both stock, S, and effort, E. However, it has been shown that the production function of a fishery eventually exhibits decreasing marginal returns to both input factors. Decreasing returns with respect to effort can be explained well by the effect of congestion, where, beyond a certain level of E, any further increases in effort lowers catch per unit effort, due to congestion. Decreasing returns with respect to stock can be explained by gear saturation, where catch increases proportionately with stock up to a certain capacity level of fishing gear, such as nets, beyond which gear saturation reduces catchability (Clark, 1976). We thus have:

$$Q_t = aS_t^{\phi} E_t^{\delta} \tag{7.2}$$

where, $0 < \phi < 1$ and $0 < \delta < 1$. That is, catch Q is increasing in both stock and effort and exhibits decreasing marginal returns to both input factors. Finally, for simplicity, the units of the production function are normalized so that E is equal to one:

$$q_t = bS_t^{\phi} \tag{7.3}$$

where, $b > 0$.

Next, we introduce the stock function. Typically, fisheries stock is modeled as a dynamic function of growth and harvest. The change in stock at any time *t*, is given by the growth in stock minus the harvest. The growth function gives the natural rate of increase of stock, S, and can be thought of as the "natural" production function. Since our purpose here is to measure total annual fish production under different hydrological management scenarios we use a simple static model of fish production in order to measure the "economic" value of fish. We model fish stock, S, simply as a function of floodplain area, A, given that the area of the floodplain in each flood land type that is available to the fishery is an important determinant of fish stock at any given time (Welcomme, 1979; FAP 17. 1994). Using the area of land in each flood land type captures the effects of both the intensity and the duration of flooding. At the beginning of each flood season, adult fish move into the floodplain from the river and spawn. The larvae and juvenile fish use the floodplain habitat to feed and grow and a larger area supports a larger fish stock. We therefore model the effect of floodplain area on stock and area is thus entered into the stock dynamics equation. Evidence from other floodplains suggest that stock is an increasing function of the area flooded but stock per unit area is a decreasing function of the area flooded (Welcomme and Hagborg, 1977). Thus we have the general form stock function:

$$S_t = F(A_{ft}) \tag{7.4}$$

where, $F' > 0,\ F'' < 0,\ and\ F(0) = 0.$ For the empirical analysis we use a specific functional form, which is a common non-linear specification:

$$S_t = cA_{ft}^{\theta} \tag{7.5}$$

where, $c > 0$ and $\theta < 1$. Combining equations (7.3) and (7.5), we get:

$$q_t = \alpha A_{ft}^{\beta} \tag{7.6}$$

where, $\alpha = bc$ and $\beta < 1$. The parameter, α, can be interpreted as a technical efficiency parameter in the fish harvest or production function above.

Finally, we need to account for the fact that higher intensity floods will lead to higher initial stocks and thus higher productivity. This can be done by specifying equation (7.6) for each of the flood land types, *l*. This would imply that for different intensity floods we would not only have different flooded areas, but also different distributions of *l*, which would lead to different fish outputs in the different flood land types. So accounting for *l* leads to:

$$q_{lt} = \alpha A_{flt}^{\beta} \qquad (7.7)$$

where β # 1. Note that fishing is not feasible in land type l_0, since that is dry land. This is the fish production function, which is modeled here explicitly as a function of floodplain area maintained for the fishery. Fish output increases with an increase in flooded area. However at the same time, output per unit area in the floodplain decreases (or remains constant) with an increase in the flooded area. This is expressed in the restrictions placed on the stock function, F, in equation (7.4) above. This relationship has been shown to be true for floodplains in Bangladesh and other tropical floodplains (FAP 20, 1994; Welcomme and Hagborg, 1977).

7.6 Fisheries data and estimation of the catch production function

Data from the North-Central region of Bangladesh are used to estimate equation (7.7) for the floodplain. We used catch and effort data for three years from 1997-1998 to 1999-2000 from the Tangail Compartmentalisation Pilot Project (CPP) fisheries database (De Graaf, *et. al.*, 2000). It could be argued that the CPP is a special kind of flood control structure, and therefore the catch data from CPP cannot be representative of the natural floodplain or the generic embankment structures we consider. However, a major conclusion of data analysis for the CPP was that there is no evidence that CPP has impacted fish catch at all (FAP 20, 2000). Additionally, the data are for a region that is in close proximity[40] to the area modelled here, and the CPP database is a rich database with multi-year catch observations, a rarity. Hence these data are used to estimate our production functions.

In the CPP database, catch by land elevation type is reduced to 4 classes, in a continuum from F_0 (dry land) to F_3 (permanent beels). F_0 has no fish catch, by definition. F_1 catch in the database was found to be occasional and very small compared to F_2 and F_3, and hence was excluded from the analysis. Thus two different 'catch production functions' are estimated, one for F_2 land ('floodplain catch') and the other for F_3 land ('beel catch').

Although the CPP database has data from 1992-93 to 1999-2000, we used only the last three years of data (1997-1998 to 1999-2000) for the estimation, because these appeared to be the most complete data. For instance, for many of the early years, floodplain catch was recorded as zero even in the flood season. Also, for floodplain catch, we used only the data from July to December for each of the three years. This is because floodplain (as opposed to beel) catch generally becomes negligible when the dry-season starts. For beel catch, observations from all months were used.

We estimated a variation of equation (7.7) with effort per unit area (EPUA) appearing as an additional explanatory variable on the right hand side. This is because equation (7.7) assumed effort is normalized and thus we have to account for effort. However, we could not use total effort as it is strongly correlated with total area, and hence we use EPUA. EPUA is calculated simply as total effort divided by total area, where effort is defined as the total number of fishermen. We carried out the

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[40] In fact, there is some overlap between the two regions.

estimation using ordinary least squares log-log version of the equation, and the results are presented in table 7.3 below.

Table 7.3: Regression estimates for Floodplain and Beel catch production functions

Regression estimates for floodplain production function (R-square =0.93)				
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	**0.02**	0.75	0.02	0.98
LNAREA	**0.86**	0.10	8.22	0.00
LNEPUA	**1.24**	0.12	10.01	0.00

Regression estimates for beel production function (R-square=0.93)				
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	**-1.80**	0.56	-3.20	0.00
LNAREA	**1.04**	0.10	10.07	0.00
LNEPUA	**1.38**	0.07	18.97	0.00

The coefficients from these regressions could be directly converted to get the parameter estimates for equation (7.7). For example, we get α and β of equation (7.7) for floodplain land as follows:

$\alpha = \exp(0.02+1.24*\ln(EPUA))$
$\beta = 0.86$.

These estimates are used in the fisheries production function of the FMM. EPUA data from the CPP database varies month to month. Thus we model α to vary from month to month. We use monthly average EPUA, calculated from three years of data (1997-1998 to 1999-2000) from the CPP database to define α for the FMM.

Next, we need a measure of the cost of fishing. Here we only include the variable cost of labour and assume all equipment and gear costs to be fixed costs. The total cost of fishing per hectare is given by the mandays of fishing per hectare multiplied by the cost of one manday of labour. Taka 50 per manday is used as the cost of labour. Note that since a significant proportion of the floodplain fishing is carried out by subsistence fishers whose opportunity cost of labour may be close to zero, accounting for their labour cost may underestimate the value of fish production. For example, we may find that fishing is not optimal in a given land type in a given month because of the high labour cost of fishing (and thus lower fishing profits). However, not accounting for labour costs at all is not a good option as that would inflate our estimate of the value of fish production. Thus, we had to find a good measure of mandays of equivalent labour, given that our effort data gives us the total number of fishermen. We know that not all fishermen fish full days and thus we cannot count them as a full manday of labour. There was nothing in the CPP database that we could use directly to address this issue. Therefore, we relied on survey data from CNRS that had data on how many hours a day fishermen were out fishing in the floodplain and beel. Using this data we calculated a weighted average of hours fished per fisherman per day (weighted by the three different types of fishermen, subsistence, part-time and full-time). For floodplains this came out to be half of each day spent fishing and for beels a quarter of each day spent fishing (this is based on approximately 4 hours per day on average spent fishing in the floodplain and approximately 2 hours per day on average spent fishing in the beels).

Finally, we needed data on fish prices to calculate total revenues from the fisheries sector. Fish prices are reported in Table 7.4. The fish types are carp, catfish, shrimp, snakeheads, and small fish. These cover the range from high market value to low market value fish types that are common to the area and are found in both the wet and dry seasons.

Table 7.4: Fish Prices (Source: Minkin, 1995)

Fish Type	Price
	(Taka* per kg)
Small fish	86.58
Carp	104.84
Catfish	117.83
Snakeheads	88.74
Shrimp	76.16
*expressed in 1998 Taka.	

The fish production function is specified for total fish catch and the fish species types are assumed to be a constant proportion of the total catch. The proportion varies between wet and dry seasons. This specification is equivalent to solving for an aggregate quantity and using a weighted price.

7.7 Fish yield reduction

Next, we add a parameter, μ, which is used to measure the effect of structural changes on fish productivity, as given by catch per unit area. Halls (1998) finds that flood control structures not only reduce fish production because they reduce the area flooded, but that they also reduce in-migration. There are two types of effects on fish production of a structural change in the floodplain. The first is a loss of fish production resulting from a reduction in the area flooded and the corresponding reduction in fishing area. The second is a loss resulting from a reduction from reduced accessibility. Halls' results suggest that floodplain fish productivity is reduced by as much as 50 percent due to the FCDI project. This reflects the partial inaccessibility of the floodplains inside the embankment by migratory fish species. The effect of the structure itself is to reduce productivity by 30 percent – there are further decreases in productivity based on the number of days the gates are closed. This estimate is obviously for a different area and is based on sparse data – however, little additional information is available on this aspect, and ignoring it may seriously bias results. We therefore include a parameter, μ, to capture this effect. A value of one for μ is used for the base model with no structural change, reflecting full fish productivity. A value of 0.7 was used in the different sluice gate scenarios to indicate a 30 percent reduction in productivity. Further decreases in fish production due to the timing of sluice gate closures are implicitly accounted for in the FMM due to the fact that different timings of gate closures lead to changes in the area flooded which in turn changes fish production.

7.8 Empirical Agricultural Model

For computational ease, the agriculture sector is modeled using simple production technologies. These are characterized by linear input-output coefficients which vary by crop. Eleven agricultural crops are specified in the empirical model. These are the most common varieties of crops and fish produced in the floodplain. The crops include wheat, jute, pulses, mustard and seven varieties of rice: HYV Aus, Local Aus, HYV T. Aman, DW T. Aman, DW B. Aman, HYV Boro and Local Boro. Crops are specified based on their suitability to different land types and seasons. We assume here that there are constant returns to scale in agriculture.

It is important to note that individual farmers might face other constraints in determining crop choice, such as credit, capital costs, labour, etc., which are not explicitly modeled here[41]. This abstraction might lead certain crops, particularly high-yielding varieties of rice, to be chosen more often in the model than in practice. This is not necessarily a problem if we are interested in finding the maximum potential returns from the floodplain, as long as we realize that the agriculture returns will always be somewhat inflated across all the model scenarios.

Agriculture data used in the study are from two sources: a Tangail Compartmentalization Pilot Project Report (FAP 20, 1992) and the Yearbook of Agricultural Statistics (BBS, various years). These provide detailed information on agriculture in the North-Central region, such as, crop types, cropping pattern, growing season, water tolerance, crop yields as well as production costs and crop prices. All cost and price data are converted to 1998 Taka. Table 7.5 shows the crop yield, costs and prices data used in the study.

Table 7.5: Crop Yields, Prices and Production Costs

Crop	*Yield*	*Price*	*Variable Costs*
	(Tonne per ha)	(Taka* per tonne)	(Taka* per ha)
HYV Aus	2.748	7,873	11,349
Local Aus	1.450	7,873	7,318
HYV T. Aman	3.244	8,353	11,630
DW T. Aman	1.813	8,353	8,085
DW B. Aman	1.523	8,353	7,557
HYV Boro	4.467	8,055	18,677
Local Boro	2.921	8,055	10,134
Jute	1.727	10,390	9,822

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[41] The feasibility of including such constraints was explored. However, there is very little quantified information of the sort that could be used in a model such as ours. The few studies that do exist are mostly qualitative in nature, and findings often vary practically from village to adjacent village, defying characterization on a regional basis.

Mustard	0.859	17,472	5,135
Pulses	1.063	19,353	4,010
Wheat	2.263	8,185	9,247
*expressed in 1998 Taka.			

Source: FAP 20, 1992a. Tables 5, 5.2 and 8 in Appendix E; BBS, various years

7.9 Crop Damage Factors

Table 7.6 shows potential crop damages at different water levels – these were also built into the model. This was done by first calculating the maximum flood depth in each flood land type in each time period. Then this maximum flood depth was compared to the critical depths in Table 7.6 – when a critical depth was exceeded, the relevant crop was damaged to the level shown in Table 7.6.

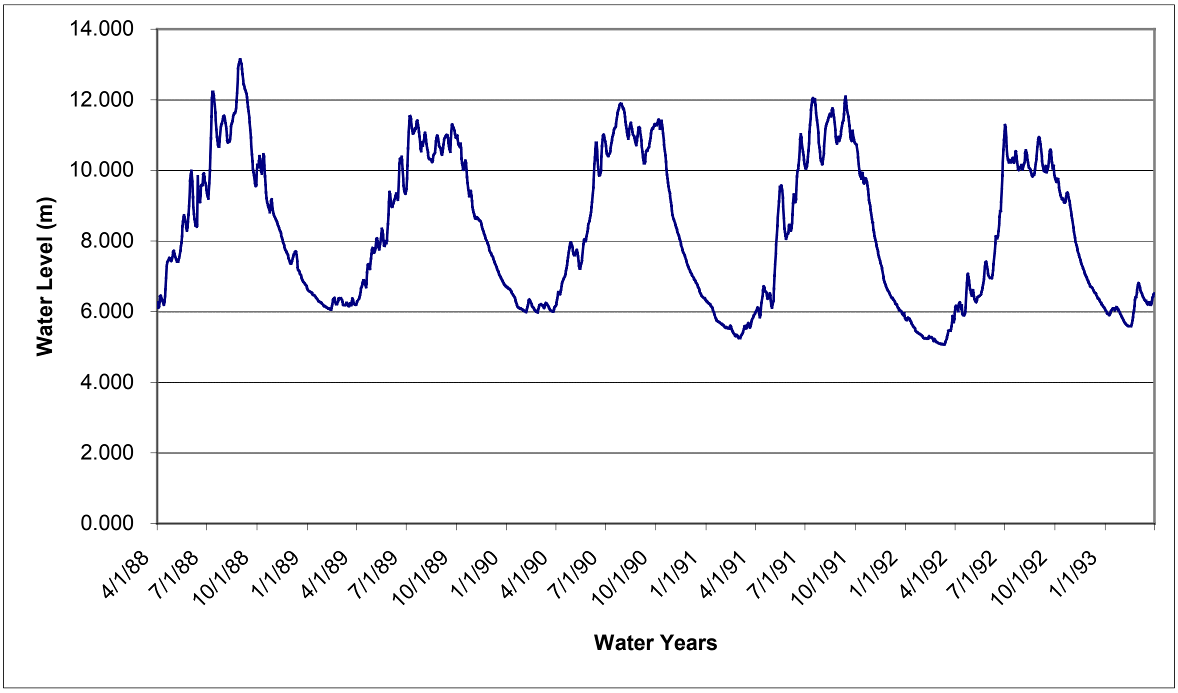
Table 7.6: Potential Crop Damages at Critical Flood Depths (source: MPO (1987))

Crop Losses as a Percentage of Value						
Crop	Flood Condition	Crop Stage	Vulnerable Time	20%	50%	80%
				(Centimetres)		
HYV boro	F3	Heading maturity	1 May - 30 June	60	80	100
	F2	Heading maturity	15 May - 10 June	60	80	100
Local boro	F4	Heading maturity	15 April - 15 May	80	100	130
B. Aus	F2	Heading maturity	1 June - 31 July	80	130	150
B. Aman	F3	Vegetative	1 July - 15 Aug	-	-	150
HYV T. Aman	F1	Seedling	1 July - 31 Aug	-	-	30
		Tillering	1 Aug - 30 Sept	-	-	45
Local T. Aman	F1	Seedling	1 Aug - 15 Sept	-	-	45
		Tillering	1 Aug - 30 Sept	-	-	60
Jute	F1		1 June – 15 June	-	70	-
	F2		1 June – 15 June	-	95	-

7.10 Hydrology data

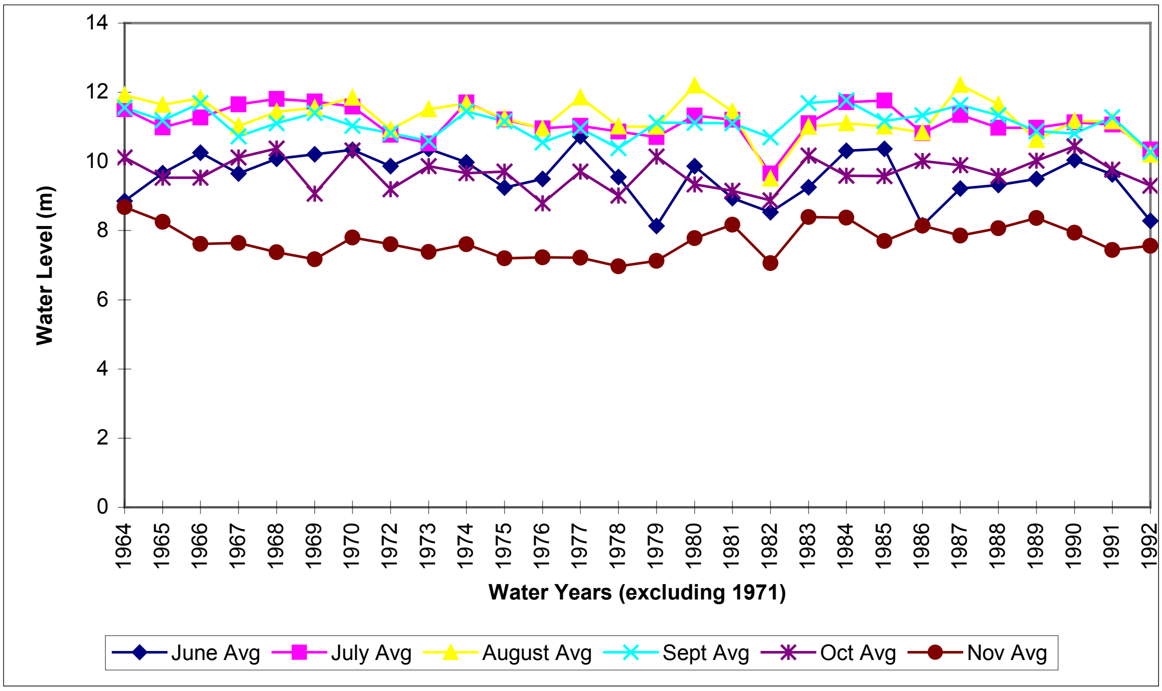
Daily water level data are collected and compiled by the Bangladesh Water Development Board. Data for one water level station, the Porabari station, adjacent to the study site were available for 28 years, from 1964 to 1992, excluding 1971. These data were provided by the Environment and GIS Support (EGIS) Project for Water Sector Planning. Figure 7.3 shows the annual hydrographs for the water years, 1988-1992. The conventional water year in Bangladesh starts on April 1 and ends on March 31. The primary flood season is June-November. Typically, the water level starts rising with the monsoon flood in mid-June and starts falling in mid-October. There is also a short spring flood in late April or early May, which lasts for one to two weeks. The flood peak can be seen in the hydrographs around August of each year. The dry season is typically December-mid May. As can be seen from Figure 7.3, the time series water level data follow a particular pattern of rise and fall, which is repeated approximately every 365 days.

Figure 7.3: Annual Hydrographs showing Daily Water Levels for 1988-1992 Water Years



Before the data were used, a simple trend analysis was done to check for any trends in the historical water level data. This is because the presence of any trends need to be taken into account. For example, in some rivers, the average water level might increase over the years due to increased sedimentation, often caused by levees. A simple linear least squares estimation was carried out to test for the presence of a time trend. We found that the data exhibits no significant time trend that needs to be accounted for. This can also be seen by simply looking at Figure 7.4, where the monthly average water level shows no apparent time trend.

Figure 7.4: Monthly Average Water Levels for 1964-1992 Water Years (excluding 1971)



Source: Computed from raw data

7.11 Modified flood hydrographs

In order to study the effects of alternate floodplain management plans we had to calculate modified flood hydrographs. As explained earlier, management plans include any measures that directly affect the total area of land exposed to flooding and that change the area of land in each flood land type. Management plans analyzed here include a natural floodplain as well as induced water control strategies that alter the natural hydrographs, *i.e.*, sluice gate control. The timing of gate closures directly affects the flooded area, i.e. the area of land in each flood land type, at any given time. This in turn effects both agriculture and fisheries production. Thus, we analyze several options for when the gates are closed and how long they are kept closed. For each of these options, a modified flood hydrograph is calculated for the inside floodplain.

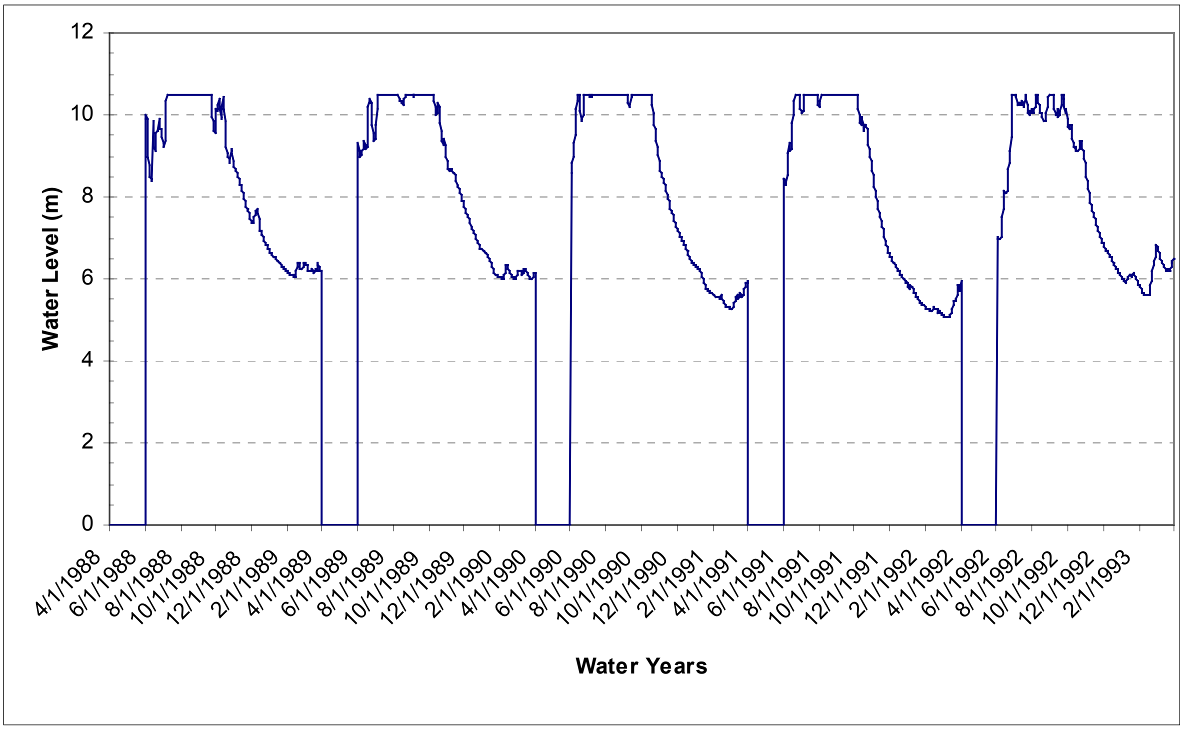
The following ten options are analyzed: (1) sluice gate is kept closed until May 15, opened on May 16 and then closed again when the water level goes above the target water level of (a) 10.5m (b) 10.75m (c) 11m (d) 11.25m (e) 11.5m; (2) sluice gate is kept closed until May 31, opened on June 1 and then closed again when the water level goes above the target water level of (a) 10.5m (b) 10.75m (c) 11m (d) 11.25m (e) 11.5m. These options roughly reflect typical control strategies, where sluice gates are kept closed until variable dates in May or early June, and are opened for limited time periods, until water heights are deemed too excessive. Their overall effect is to delay and smooth the natural hydrograph. Table 7.7 summarizes the different model specifications.

Table 7.7: Summary of Model Specifications

	Date Sluice Gate Closed Until	Maximum Water Level Gate Open To (Meters)
Base Model	No Sluice Gate – Natural Floodplain	
Model 1a	May 15	10.50
Model 1b	May 15	10.75
Model 1c	May 15	11.00
Model 1d	May 15	11.25
Model 1e	May 15	11.50
Model 2a	May 31	10.50
Model 2b	May 31	10.75
Model 2c	May 31	11.00
Model 2d	May 31	11.25
Model 2e	May 31	11.50

To calculate a modified hydrograph for the inside floodplain, we start with the original hydrograph and restrict any increase in water level inside the floodplain while the sluice gate is closed. Then starting on the day the sluice gate is opened (May 16 or June 1), water level inside the floodplain is allowed to rise (as in the original hydrograph) until it reaches the target water level (options a, b, c, d or e as described above) at which point the sluice gate is closed. Thus, the inside hydrograph never goes above the target water level. The modified hydrograph follows the original hydrograph at the end of the flood season when the water level drops below the target level. Figure 7.5 shows the modified hydrograph associated with Model 2a. The chart shows five water years and it is clear how the hydrograph has been modified once compared to the original hydrograph for these five years as shown in Figure 7.3. As can be seen in Figure 7.5, no outside water enters each year until June 1 (since the sluice gate is kept closed until May 31). Also, the peak of the hydrograph is removed and the inside water level never goes above 10.5m. Note that we do not model rainfall explicitly and thus any changes in the inside water level due to rainfall (not already reflected in the river water level) is not taken into account.

Figure 7.5: Modified Hydrographs: Model 2a – Embankment with Sluice Gate Option (Gate Closure until May 31 with Target Water Level of 10.5m)



This approach of defining a modified hydrograph to model each of the management scenario is a simple way of capturing the essential elements of the alternate management options for the flood season without having to go into the engineering and mechanical details of sluice gate operations. All we have to specify are operational details of when the sluice gate is closed and what the target water level is – we do not have to specify how these are actually implemented. This abstraction allows us to focus on what we need – a modified hydrograph brought about by a structural change in the floodplain. This is then an input into the FMM.

7.12 Distribution of flood land types

We next calculated the distribution of areas in each flood land type using the annual hydrographs (both the natural and modified hydrographs) and the floodplain area-elevation data. We assume that any water level higher than the land elevation floods the land. We first calculate the depth of floodplain as the difference between the water level and the land elevation. Then based on the depth classes defined in Table 7.1, we calculate the area of land in each flood land type. This gives us the distribution of flooded land areas for each hydrograph. Figures 7.6a and 7.6b show this area distribution for one year of the natural hydrograph (base model) and a corresponding modified hydrograph (Model 2a). As can be seen, there is slightly less area in the deeply flooded land type, L3, in Model 2a compared to the base model. Note that land type L0 is dry land or land flooded to less than 0.3m – thus much of the land in the floodplain for much of the year is land type L0.

Figure 7.6a: Distribution of Area by Flood Land Type: Base Model with No Structural Change

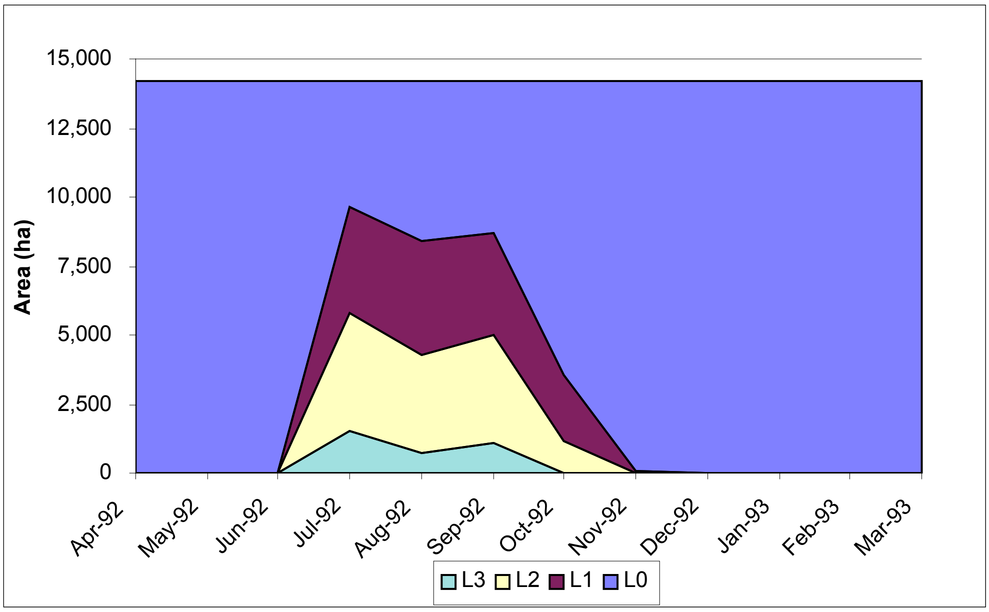
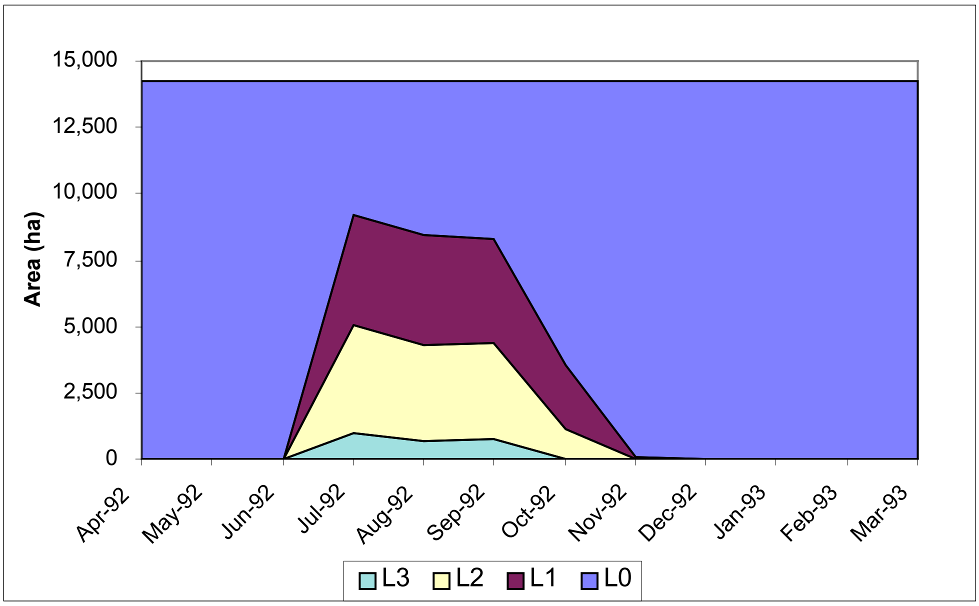


Figure 7.6b: Distribution of Area by Flood Land Type: Model 2A – Embankment with Sluice Gate Option (Gate Closure until May 31 with Target Water Level of 10.5m)



7.13 Empirical Floodplain Management Model

The compact form of the empirical floodplain management model is:

$$\underset{A_{ilt},A_{flt}}{Max} \sum_{i,l,t}(p_i y_{ilt} - c_i)A_{ilt} + \sum_{f,l,t}(p_f q_{flt} - c_f A_{flt}) \qquad (7.8)$$

subject to,

$$\sum_i A_{ilt} + \sum_f A_{flt} \leq A_{lt} \quad for\ all\ l\ and\ t \qquad (7.9)$$

$$q_{flt} = \alpha A_{flt}^{\beta} \quad for\ l_0,\ldots,l_4 \qquad (7.10)$$

$$q_{flt} = kA_{flt} \quad for\ l_5 \qquad (7.11)$$

The objective for the floodplain planner is to maximize the sum of net returns from agriculture and fisheries (equation (7.8)). For analytical convenience, an annual model is used with discrete time increments, *t*, of half-month. We are constrained by the fact that for agriculture, cropping allocations are made on a seasonal basis, whereas, fish catch can vary daily. Thus, an increment of a half-month was chosen as a reasonable approximation. The first term in equation (7.8) is crop returns per hectare multiplied by the area allocated to that crop. This is summed across all crops, land types, and time. The second term is the net returns from fisheries which is given by the revenue from all catch minus the cost. The total cost is given by the cost per hectare of fishing multiplied by the total area allocated to fishing.

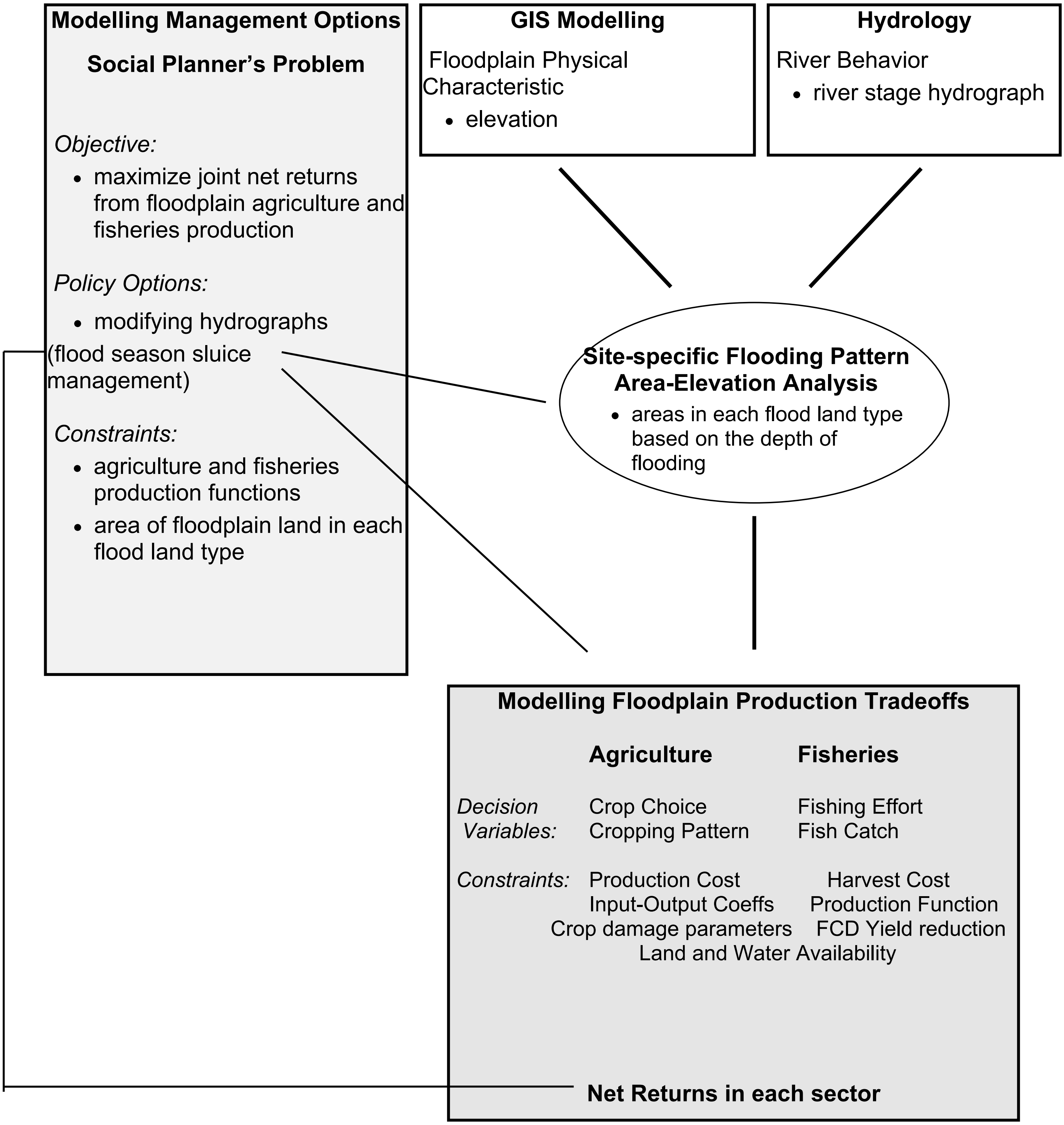
The first constraint, equation (7.9), is the land constraint. It ensures that the sum of optimal lands allocated to agriculture and fisheries production is no greater than the available land in each flood land type in each time period. The last two constraints, equations (7.10) and (7.11), are the fish production functions for the floodplain and beels respectively as explained earlier. Several other conditions are used for the empirical model which specify production parameter and feasibility conditions. These include:

- crop suitability by months/season
- crop suitability by flood land type
- fishing season
- fishing feasibility by flood land type
- area matrix - for total available area by flood land type and month
- vector of crop yields
- vector of production costs
- vector of crop and fish prices

All economic values, including net returns, are expressed as annualized equivalents.

Figure 7.7 presents a schematic of how the different model components come together. The figure reflects the sequencing of the empirical model. Outputs from the GIS and the hydrology components are combined to give the site-specific flooding pattern, that is, the distribution of areas in each flood land type in each month. These are used to solve the floodplain management model which give a distribution of net returns for the specified model scenario.

Figure 7.7: Floodplain Management Model Schematic - Systems and Linkages



7.14 *Results*

The empirical model presented above is numerically solved using non-linear programming techniques. This is solved with hydrology for a natural floodplain as well as the ten different scenarios of sluice gate management as described earlier. Thus there are model results from eleven scenarios: the natural floodplain with the unmodified or natural hydrograph (we refer to this as the base model) and ten modified floodplains with varying sluice gate management options (see Table 7.7 to refer to the model scenarios).

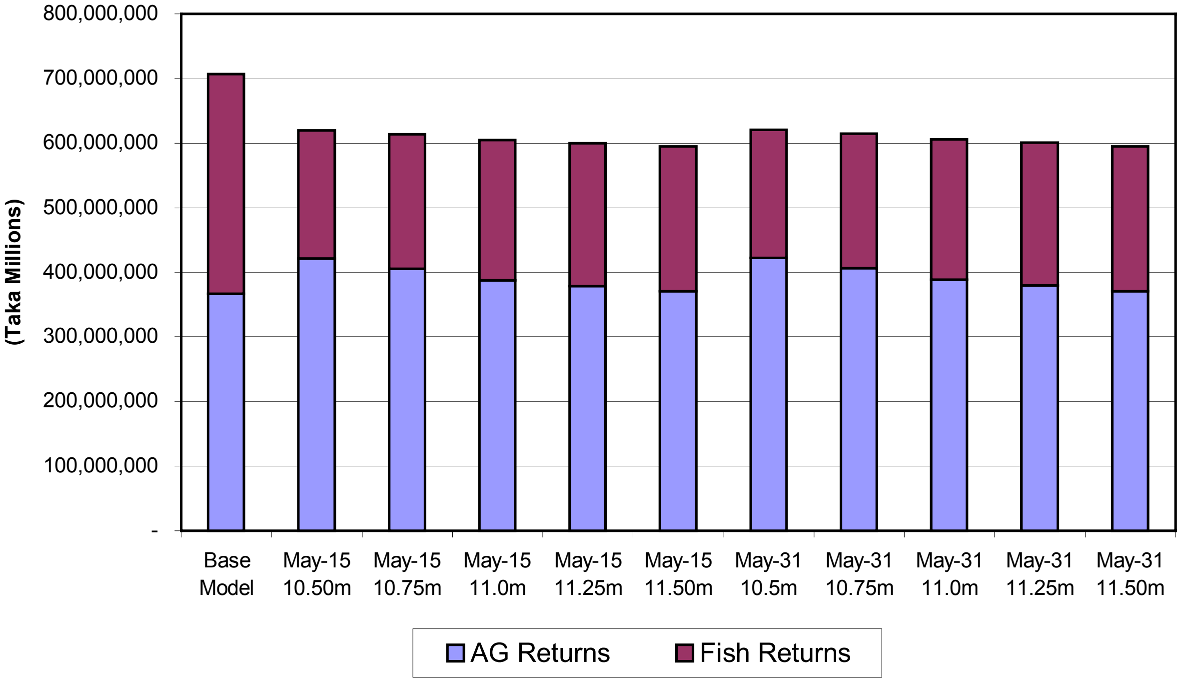
First, comparing what we are most interested in, total returns under the alternate management plans are found to be lower than in the natural floodplain for all years of the model runs. Table 7.8 presents summary statistics of agriculture, fisheries, and net returns from the different models. Figure 7.8 plots the average returns from each of the model scenarios, where averages are taken over the 28 years of each model.

Table 7.8: Agriculture and Fisheries Returns for each Management Scenario (Average over 28 years of Model Results)

Model	Mean		
Scenario	Agriculture Returns	Fisheries Returns	Total Returns
	(Taka)		
Base Model (natural)	367,112,490	340,028,728	707,141,219
Model 1a (May 15, 10.50)	421,306,953	198,711,364	620,018,317
Model 1b (May 15, 10.75)	405,654,305	208,038,291	613,692,596
Model 1c (May 15, 11.00)	387,778,293	217,109,967	604,888,260
Model 1d (May 15, 11.25)	379,112,070	220,907,544	600,019,614
Model 1e (May 15, 11.50)	370,588,258	224,166,352	594,754,610
Model 2a (May 31, 10.50)	421,832,751	198,711,364	620,544,115
Model 2b (May 31, 10.75)	406,180,103	208,038,291	614,218,394
Model 2c (May 31, 11.00)	388,304,092	217,109,967	605,414,058
Model 2d (May 31, 11.25)	379,637,868	220,907,544	600,545,412
Model 2e (May 31, 11.50)	371,114,056	224,166,352	595,280,408

Figure 7.8: Agriculture & Fisheries returns, average over 28 years.

Figure 7.8: Agriculture and Fisheries Returns for each Management Scenario
Average over 28 years of Model Results



There are two dimensions to sluice gates openings and closings in our analysis. The first is the initiation of opening for the first time in the season, *i.e.,* May 15 or May 31. The second is with regard to the target water level. For instance, if sluice gates opening is initiated on May 31, the 'target water level' of 11.5 m will obviously be reached later than a target water level of 10.5 m. Thus the sluice gates would have been open for longer under the former. To avoid confusion between these two dimensions, we note that whenever we speak of longer openings or closures, we are referring to the target water height dimension. When we want to refer to the initiation of opening, we explicitly use the word 'initiation'.

We expect returns from agriculture to be higher and fisheries returns to be smaller under the alternate management plans as compared to the base model. Results from model runs bear this out for the most part. Agricultural returns increase the longer the sluice gates are kept closed, *i.e.,* the lower the target water level. The largest increase of about 15 percent compared to the base model, occurs when the gate is kept closed the longest, to a water level of 10.5 meter. When the gate is kept open to a higher water level of 11.5m, agricultural returns decline since there is greater potential for crop damage, and more area under deeper flooding restricts agricultural possibilities. In fact, in the case when the gate is kept open to a water level of 11.5m, agricultural returns are almost the same as in the case of a natural floodplain – that is, this sluice gate management option does not lead to any significant increases in agricultural production compared to a natural floodplain.

We also find that later initiation of opening, *i.e.,* May 31 instead of May 15, does result in an increase in agricultural production somewhat. However the average increase is not significant (less than half a percent increase in agricultural returns). This is consistent with the fact that much of the *Boro* crop is harvested by May 15. As seen in earlier chapters, it is a relatively small number of plots in the lowest-lying land for which harvest is delayed until late May or early June. Delaying initiation of opening of gates until May 31 thus only provides protection to a small number of plots, and therefore only generates a small increment in agricultural returns. Also, the distribution of areas in each flood land type does not change significantly between a May 15 and a May 31 initiation.

The optimal cropping pattern solved for by the FMM sufficiently matches reality in the floodplain sufficiently for us to build on these results. By cropping pattern we mean the sequence of crops planted in each flood land type in each season. Rice is the dominant crop in the region where the traditional rice crops of Aus, Aman and Boro are grown in the *Kharif-I*, *Kharif-II* and *Rabi* season respectively. Our results reflect this partly, although local varieties of rice are not found to be optimal since HYV crops yield higher returns. Optimal cropping pattern in all the models include HYV T. Aman in the *Kharif II* (monsoon) flood season and HYV Boro, mustard and pulses in the winter dry season. In one way, this is the main shortcoming of the FMM, which allocates land to the highest return crop and crop diversity is not built into the model. However, the observed long-run national trend has been towards just such a development, with expansion of t-aman at the expense of broadcast deepwater aman in the flood season, and HYV Boro dominating winter production.

Optimal cropping pattern allocates only land type L0[42] to agriculture, while allocating all other land types to fisheries production (note that in the winter dry season all land in the floodplain is land type L0; only in the monsoon flood season are there areas of other land types). That is, after taking into account all potential crop damages and the opportunity cost of fisheries production, FMM does not allocate any land type other than L0 to agriculture. The optimal cropping pattern is similar across the eleven model scenarios – only more land is allocated to agriculture in the sluice gate management options compared to the base model, given that there is more drier land (suitable for agriculture) under the sluice gate management options.

The optimal cropping pattern allows us to calculate cropping intensity, which we can compare to existing conditions in the floodplain and across model scenarios. Cropping intensity measures how much of an area is cropped in a given year. For example, a 100 percent cropping intensity implies that all of the area is cropped once in a year, while a 200 percent intensity implies that all of the area is cropped twice in the year. The average cropping intensity in the study area is 194 percent (EGIS, 1997b). For the 28 years of runs of our base model, the cropping intensity ranged from a low of 131 percent to a high of 238 percent, with an average of 184 percent. Optimal cropping pattern from the FMM gives slightly lower cropping intensity than what is currently practiced in the floodplain, although the model result is within 5 percent of what is observed in the region. One possible reason for this small difference is the fact that the base model is for a natural floodplain, while the study area has some areas behind flood control structures. This would imply a higher cropping intensity for those flood protected areas, thus increasing the average reported for the region. However, any persistent difference beyond this implies that current practices in the floodplain allocate more land to agriculture and less land to fisheries production than is optimal.

Table 7.9 presents the average cropping intensity for each of the eleven model scenarios. As expected, the sluice gate management options result in increased cropping intensity. The increase is larger the longer the sluice gate is kept closed, thus creating suitable conditions for increased agricultural production. As can be seen, the cropping intensity in Model 2a ranges from 164 percent to 239 percent,

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[42] Note that this is L0, not F0, as discussed earlier.

with a mean of 209. While in Model 2e, the cropping intensity is similar to that in the base model, ranging from 133 percent to 237 percent with a mean of 186 percent.

Table 7.9: Cropping Intensity for each Management Scenario, Average over 28 years of Model Results

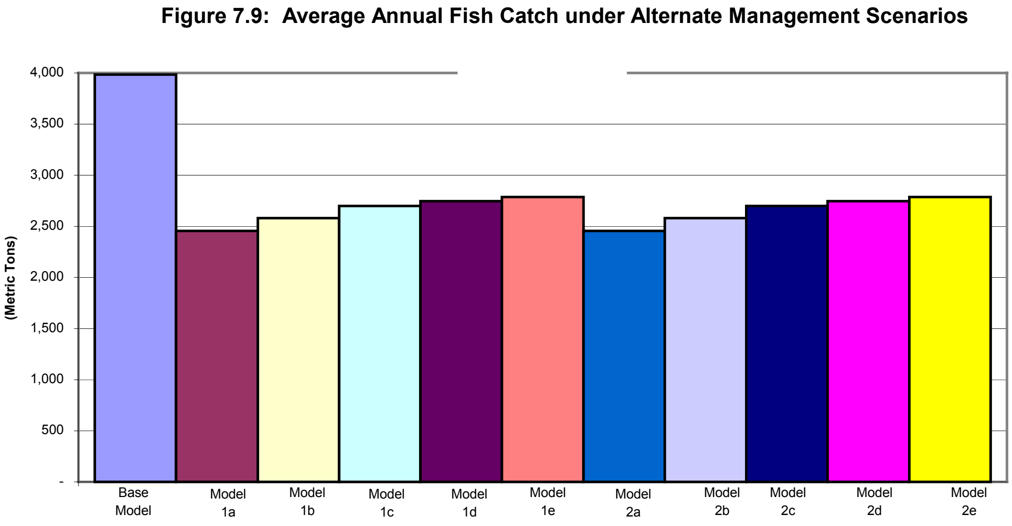
	Cropping Intensity (percent)
Base Model	184.14
Model 1a	208.85
Model 1b	201.66
Model 1c	193.51
Model 1d	189.57
Model 1e	185.71
Model 2a	209.19
Model 2b	202.01
Model 2c	193.86
Model 2d	189.92
Model 2e	186.06

Fisheries returns decrease significantly under the sluice gate management plans compared to the base model of a natural floodplain. We find that the largest decline is of 42 percent (compared to the natural floodplain) when the sluice gate is closed under the most stringent requirement, *i.e.*, as soon as a target level of 10.5 m is reached. When the sluice gate is operated under a more lax condition, *i.e.*, closed only when a water level of 11.5m is reached, fisheries returns are still 34 percent lower than the natural floodplain. This is nevertheless a 13% improvement over the more stringent condition based on 10.5m. In general, given a certain date of initial opening of sluice gates (either 15 May or 31 May), longer openings, corresponding to higher target levels, provide significantly improved catches.

However, the model finds that, given a certain target water level (say, 10.5m) , the date of initiation of opening (May 15 or May 31) does not matter much. This is because the distribution of areas in each flood land type does not change significantly between the two scenarios. That is, the primary loss in fish production is simply from the existence of the embankment, and does not change whether the gate is initially closed until May 15 or May 31. The water levels in May are significantly lower than later in the flood season. It is later in the flood season that target water levels in the range we have considered are reached. Given the relatively low water levels in May, the effect on flooded area from a change between initiation of opening in May 15 or May 31 is low, and hence the observed insensitivity of the results to the date of first opening. Potentially, this phenomenon also reflects a weakness in the model, wherein we have allowed for fish production increases only through the mechanism of increased habitat (flooded land) availability, and have not been able to capture fish migration through sluices.

Table 7.10 presents annual fish catch from all years of the model results. Figure 7.9 shows the average annual fish catch under each model scenario.

Figure 7.9: Average annual fish catch under alternate management scenarios



Overall, however our results indicate that the decrease in fisheries returns is not made up by an increase in agricultural returns under any of the sluice gate management options when compared to a 'natural floodplain'. Thus, total returns are lower than the base model, without even accounting for the cost of the management plan. Doubtless, in individual years when flooding is extreme, the presence of the embankment and judicious operation of sluice gates can prevent disaster. From a long run perspective, however, average returns are higher in the natural floodplain.

When we tradeoff the agricultural and fisheries returns (table 7.7) within the sluice management scenarios, we find that agricultural gains in monetary terms under longer sluice closures do make up for lost fisheries returns in all cases. For instance, Model 1a (opening initiated May 31, open only until 10.50m target level is reached) gives higher agricultural returns than Model 1b (opening initiated May 15, open until 10.75m target level is reached). Model 1a's fisheries returns are indeed lower than under Model 1b, but the agricultural gains make up for this loss. Thus net returns increase under more stringent closures. However, there are two weaknesses in our analysis, discussed before, that may result in underestimation of fishing benefits: (a) We consider only the 'habitat creation' (more flooded area) effects of longer sluice openings and do not take into account improved fish inflow effects of sluice openings, and (b) We have valued fishing costs on the basis of fishing wage rates. Opportunity costs are likely to be considerably lower than the market wage for at least part of the year. Thus we have likely overestimated fishing costs[43], and therefore underestimated fishing benefits. The key result to note form this research is that, although more closures in the early flood season provide increased net benefits,

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[43] Capturing true opportunity costs is an exceedingly difficult task, however, and little data exists to do this.

these increased net benefits are not very large. It is quite possible that correction of these weaknesses would actually result in negligible changes to net returns under longer openings, or even positive returns.

At the very least, there is a clear case for keeping sluices opening through the best part of May. We have seen that returns to agriculture are reduced only marginally by delaying initiation of closure until May 31. Our model has not predicted great increases to fisheries returns when this is accomplished, but in all likelihood this is because of our inability to include fish migration through sluice gates during this period in our model. Migrating fish fry and fingerlings during this early rise in flood waters are likely to significantly enhance productivity if sluices are kept open (FAP 17, 1994). Sluice gate closures in this period likely benefit only a few *Boro* plots in very low lying areas. As FAP 17 (1994, page 54) notes in the context of the PIRDP, '*The closure of the sluices during the period from late Baishak (early May) to late Joisthya (early July) is reportedly aimed at protecting a small amount of boro in the lowest parts of the beel. According to local people, operating schedules are dictated by the fact that most of the boro land is owned (or occupied) by large and powerful landowners who are able to influence sluice gate operation'.*

This aspect also points to the value of integrated floodplain management focussed especially on low-lying plots. If the winter crop on low-lying plots could be harvested by early May, two problems investigated in this report could be solved simultaneously. Early flood risk damage could be avoided as seen in chapter 6. There would also be less pressure on sluice gate managers to keep gates closed until the end of May. Furthermore, if very low plots could actually be 'retired' from winter rice production, they could be used for water retention resulting in improved recruitment, as explored in chapter 5. The pressure of water abstraction, seen in chapter 4, would also be reduced. Retained water on low-lying land would also contribute to implementation of closed areas, as explored in chapter 3.

Table 7.10: Total Annual Fish Catch (Metric Tons)

Year	Base Model	Model 1a	Model 1b	Model 1c	Model 1d	Model 1e	Model 2a	Model 2b	Model 2c	Model 2d	Model 2e
						(Metric Tons)					
Y1	4,915	2,980	3,133	3,289	3,362	3,434	2,980	3,133	3,289	3,362	3,434
Y2	3,948	2,436	2,566	2,688	2,732	2,763	2,436	2,566	2,688	2,732	2,763
Y3	4,150	2,495	2,614	2,751	2,821	2,894	2,495	2,614	2,751	2,821	2,894
Y4	4,642	2,922	3,073	3,198	3,231	3,251	2,922	3,073	3,198	3,231	3,251
Y5	5,026	2,863	3,061	3,278	3,384	3,494	2,863	3,061	3,278	3,384	3,494
Y6	3,520	2,081	2,199	2,331	2,397	2,456	2,081	2,199	2,331	2,397	2,456
Y7	5,003	2,914	3,109	3,308	3,396	3,489	2,914	3,109	3,308	3,396	3,489
Y8	3,174	2,045	2,119	2,186	2,212	2,224	2,045	2,119	2,186	2,212	2,224
Y9	4,049	2,613	2,691	2,767	2,801	2,835	2,613	2,691	2,767	2,801	2,835
Y10	4,213	2,516	2,673	2,831	2,887	2,937	2,516	2,673	2,831	2,887	2,937
Y11	4,136	2,589	2,703	2,820	2,864	2,897	2,589	2,703	2,820	2,864	2,897
Y12	2,644	1,724	1,784	1,835	1,850	1,858	1,724	1,784	1,835	1,850	1,858
Y13	4,316	2,701	2,831	2,929	2,971	3,016	2,701	2,831	2,929	2,971	3,016
Y14	2,846	1,860	1,931	1,981	1,995	2,000	1,860	1,931	1,981	1,995	2,000
Y15	3,788	2,571	2,694	2,775	2,768	2,737	2,571	2,694	2,775	2,768	2,737
Y16	3,656	2,237	2,355	2,463	2,509	2,558	2,237	2,355	2,463	2,509	2,558
Y17	3,321	2,004	2,112	2,235	2,292	2,328	2,004	2,112	2,235	2,292	2,328
Y18	2,250	1,482	1,516	1,547	1,561	1,576	1,482	1,516	1,547	1,561	1,576
Y19	4,870	2,922	3,078	3,257	3,340	3,401	2,922	3,078	3,257	3,340	3,401
Y20	4,035	2,416	2,550	2,689	2,749	2,812	2,416	2,550	2,689	2,749	2,812
Y21	4,059	2,462	2,623	2,746	2,796	2,840	2,462	2,623	2,746	2,796	2,840
Y22	4,526	2,851	2,974	3,086	3,133	3,170	2,851	2,974	3,086	3,133	3,170
Y23	4,491	2,534	2,711	2,919	3,027	3,132	2,534	2,711	2,919	3,027	3,132
Y24											

	3,754	2,321	2,415	2,517	2,568	2,621	2,321	2,415	2,517	2,568	2,621
Y25	4,387	2,837	2,972	3,059	3,074	3,078	2,837	2,972	3,059	3,074	3,078
Y26	5,049	3,040	3,232	3,425	3,507	3,538	3,040	3,232	3,425	3,507	3,538
Y27	4,181	2,582	2,720	2,831	2,877	2,920	2,582	2,720	2,831	2,877	2,920
Y28	2,603	1,801	1,817	1,828	1,829	1,829	1,801	1,817	1,828	1,829	1,829
Average	**3,984**	**2,457**	**2,581**	**2,699**	**2,748**	**2,789**	**2,457**	**2,581**	**2,699**	**2,748**	**2,789**

References:

- Ahmed, M. 1991. A model to determine benefits obtainable from the management of riverine fisheries of Bangladesh. pp. 133. Manila: ICLARM

- Ahmed, M. 1992. Determination of fisheries benefits from floodplain riverine systems in Bangladesh: a mathematical programming approach. *Aquaculture and Fisheries Management* 23:599-622

- Clark, C. 1976. *Mathematical Bioeconomics: The optimal management of renewable resources*.
  New York: John Wiley & Sons.

- de Graaf, G. J., Born, B., Uddin, K.A., Marttin, F. 2001. *Floods, fish and fishermen.* Dhaka: The University Press

- de Graaf, G. J., Dhar, G.C., and Mahera, N.S,. 2000. The CPP fisheries data base, CD-ROM. FMS, Dhaka, Bangladesh

- EGIS. 1997. *Floodplain fish habitat study*, Dhaka: EGIS.

- FAP17. 1994. Supporting volume 13; Village study: Pabna Irrigation and Rural Development Project.

- FAP 20. 1992. *Annex 2: Agriculture.* Compartmentalization Pilot Project, Interim report. Dhaka.

- FAP20. 2000. CPP Tangail. Final Report. Annex D-F.:

- Halls, A. S. 1998. An assessment of the impact of hydraulic engineering on floodplain fisheries and species assemblages in Bangladesh. Ph.D. thesis, Imperial college, University of London, pp 526.

- Hoggarth, D. D., Halls, A.S.H. 1997. Fisheries dyanamics of modified floodplains in southern asia: project final technical report to DfID-FMSP.

- Islam, M. 2001. Floodplain resource management: An economic analysis of policy issues in Bangladesh. *Ph.D. thesis,* Urbana-Champaign: University of Illinois, pp 152.

- MPO. 1987. Crop production limitations in Bangladesh, technical report no. 1. Dhaka: Master Plan Organization.

- Rahman, A. A., Huq, S., Haider, R., Jansen, E.G., ed. 1994. *Environment and Development in Bangladesh*. Dhaka: University Press, Ltd. 524 pp.

- Sultana, P., and Thompson, P. 1997. Effects of flood control and drainage on fisheries in Bangladesh and the design of mitigating measures. *Regulated Rivers: Research and Management* 13:43-55

- Welcomme, R. L. and Hagbord, D. 1977. Towards a model of a floodplain fish population and its fishery. *Env.Biol.Fish.* 2:7-24

- Welcomme, R.L. 1979. *Fisheries ecology of floodplain rivers*. London: Longman.

Chapter 8: Recommendations for Integrated Floodplain Management.

8.1 Introduction

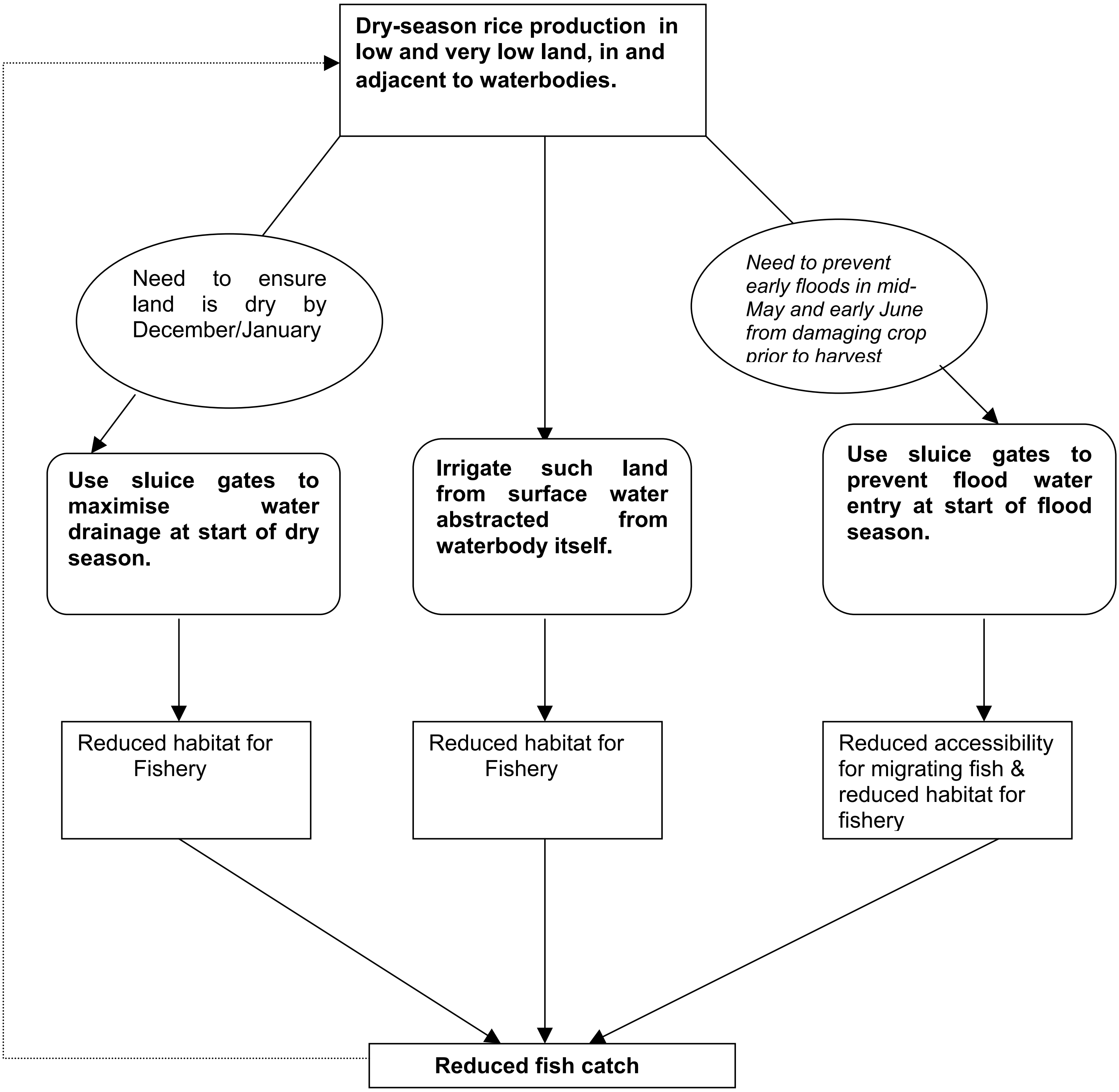
In this chapter, our goal is to bring together the results from the modelling exercises described above to outline a framework for integrated floodplain management. Due to the enormous spatial and temporal variability across floodplain sites in Bangladesh, a cookbook style approach to guidelines is avoided. Adaptation to local conditions is critical for the success of any successful action research in Bangladesh, and in accordance with this, only the over-arching principles emanating from this and prior research is put forth.

A further caveat should be mentioned. The work presented and recommendations made here apply principally to sites that are: (i) hydrologically modified, (ii) situated in the North-central and North-west areas of the country, and (iii) considered ‘open’ fisheries systems. The precursor projects that have provided data and parameters to our modelling have been based in such settings, and it is therefore natural that our results apply particularly to such sites. While some of the modelling results may carry over to sites in other geographical areas and endowed with different hydrological/fisheries regimes, overall generalisation is far more difficult. For instance, flash flooding and deep flooding is characteristic of the North-east, and the cropping systems and fishing and hydrological regimes are adapted to these unique realities. Not all our results, based on data collected in the North-central and North-east, will carry over.

8.2 An integrated view of the management problem

We have investigated the following broad constraints to improved floodplain resource in Bangladesh in this project: (i) Excessive effort levels in fishing leading to reduced fish productivity, (ii) Reduced water levels (due to sluice gate management, both during the flood season and ahead of the dry season, and water abstraction for dry-season rice irrigation) leading to reduced fish productivity, and (iii) Early flood arrival events damaging dry-season rice crops prior to harvest. Collectively, these represent some of the major NR-related constraints in hydrologically modified floodplain sites. Although we have studied these aspects and derived lessons for floodplain management for each aspect in isolation in previous chapters, there are strong systems linkages binding at least some of these constraints. Understanding these linkages also provides a key to integrated floodplain management. This linkage is outlined in the diagram below and discussed subsequently.

Figure 8.1: The systems implications of lowland winter rice production



Dry season rice production in the beel/very low lands thus lies at the heart of the problems studied here. Firstly, sluices are opened to maximise drainage out of the floodplain at the end of the flood season, so that lowland will sufficiently dry out for rice cultivation. Secondly, proximity to the waterbody encourages the subsequent irrigation of such plots from the residual water in the waterbody. Thirdly, low-lying rice plots are most susceptible to damage from early flooding prior to harvest, which leads to pressure being put on sluice gate authorities to keep gates closed in the early flood season. Dry season water retention is key to the floodplain fishery, *i.e.*, the 'habitat effect' is strong in the dry season, and the drainage and irrigation aspects described above rapidly dessicate the habitat available to the fishery. Our results show that this 'habitat effect' is relatively low in the early flood season – *i.e.,* floodplain water level reduction due to early flood season sluice closure does not impact the fishery excessively. However, other work (Halls, *et. al.*,1998; DeGraaf *et. al.*, 1999) shows that there is nevertheless a 'migration effect', whereby migratory species and their developing larvae are blocked from entering the floodplain by the sluice gates. The net effect is reduced fish catch, upon which the poorest disproportionately depend.

An additional point needs to be noted. Once the trend for very low land dry season rice production is established, there is an impetus for accelerated deterioration of the fishery. As the water levels and the value of the fisheries decline, there is correspondingly less incentive to protect the waterbodies and the fisheries, both for the government and local communities. Weakened protection encourages further encroachment of farming interest on the water cover (this is indicated by the broken line/arrow leading from 'reduced fish catch' to 'dry season rice production on low land' in the diagram above). Also, other trends are contributing to the perpetuation and acceleration of the interlinked chain of problems described above. For instance, cheaper and more mobile LLPs are now available, and these are able to exploit even the shallower waterbodies in an economically viable way.

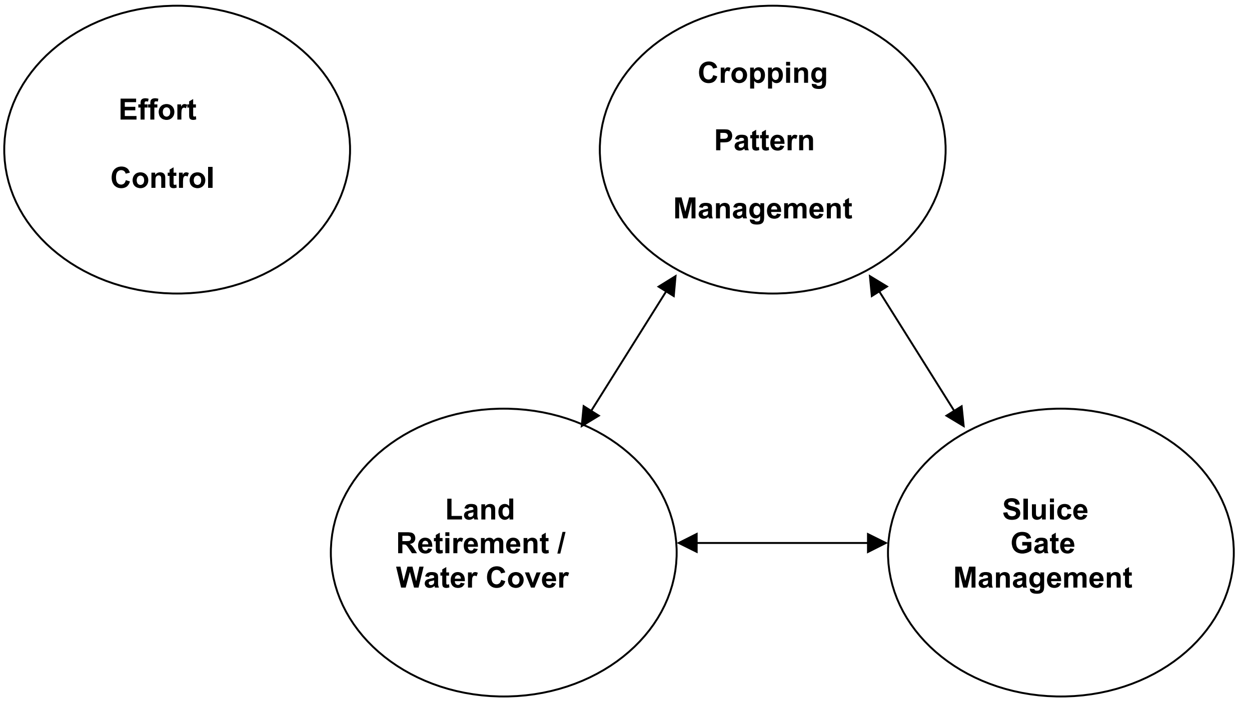
Somewhat separate from the interconnected issues specified above is the problem of excessive effort in the fisheries. This is inevitably the consequence of steady population growth in a poor, land constrained economy. Yet even this aspect has a connection to the dessication of waterbodies due to dry season rice production. Reduced water levels improve 'catchability' for even inexpensive, labour intensive gear. This is likely to encourage further effort in the fishery, at least in the short-run, further undermining the long-run productivity of the fishery.

Existing social power structures serve to enable these trends. A small number of large landowners may have disproportionate influence on the system. As FAP 17 (1994, page 54) notes in the context of the PIRDP, '*The closure of the sluices during the period from late Baishak (early May) to late Joisthya (early July) is reportedly aimed at protecting a small amount of boro in the lowest parts of the beel. According to local people, operating schedules are dictated by the fact that most of the boro land is owned (or occupied) by large and powerful landowners who are able to influence sluice gate operation'.* In contrast, professional fishers have low social standing and are disorganised, and hence are forced to accept and adapt to changes in the system rather than help shape it.

8.3 Strategy for Integrated Management

Since dry season rice production in very low land is found to be at the heart of NR constraints to floodplain livelihoods, it is likely that the key to sustainable and equitable management of floodplains would also be found in the same aspect. The interlinked system of strategies proposed is outlined in figure 8.2. A four-pronged strategy is envisaged. As mirrored in the above integrated description of the problem, strong interlinkages bind elements of the system; effort control, however, can be viewed as largely independent of the other three elements.

Figure 8.2: Integrated Management Strategy



Cropping Pattern Management:

Cropping patterns for high and medium lands: Although our major preoccupation is with low-lands, exploring possibilities for diversification out of winter rice for higher elevation lands is a first step. Our simulation results have shown that *boro* irrigation from surface water has a strongly negative effect on fish catches due to the high water requirement for winter rice. There is even a danger of recruitment failure and complete collapse of the fishery. While there is always some scope for water savings in the irrigation process, the evidence points towards the *extent* of *boro*, rather than the amount of water applied to the boro crop in Bangladesh, as characterising the problem. In exploring diversification out of winter rice, it is natural to turn to higher elevation plots first, since they have a comparative *disadvantage* in *boro* production, and are prime targets for diversification. This is due to the higher water requirement for higher elevation plots, which do not retain significant moisture after flood drawdown. As Biswas and Mandal (1995) opine, there is little justification for continued *boro* production in higher elevation plots.

Higher elevation plots are ideally suited for winter diversification into a variety of spice and vegetable crops, providing significantly higher returns than patterns involving *boro* in the winter. Most importantly, since their water requirements are considerably lower than for *boro*, there is significant scope for water savings and reduction in the pressure on the fishery. However, in spite of the economic advantages to diversification, it is frequently observed that *boro* is the winter crop of choice in higher elevation lands. In the Charan *beel* area data we have analysed, for instance, *boro* is the *rabi* crop in 100% of Medium High lands. A variety of spice and vegetable alternatives could take the place of *boro* in high and medium lands, depending on local suitability.

Cropping patterns for low lands: Generally, as elevation decreases, the rationale (comparative advantage) of *rabi* alternatives compared to *boro* rice decreases. The higher moisture retention of low elevation land reduces the water requirement and improves the relative profitability of *boro.* In fact, the moisture retention of low lands may be excessive for many *rabi* alternatives such as vegetables. Additionally, with local diets built around rice, and given the difficulty of obtaining crops in low lands in the flood season, *boro* in *rabi* appears a logical choice. Hence there has been little discussion of *rabi* diversification in lower elevation land in prior literature.

In areas particularly constrained by declining fish productivity, however, the potential for *rabi* diversification in lower land is worth investigating. Prior to the spread of small-scale irrigation and *boro*-based cropping patterns, low land cropping patterns built around deepwater rice in the *kharif* and an assortment of non-rice crops in the *rabi* were widely prevalent. Some studies (Catling, 1992; FAP 17, 1994) have reported a return to such patterns in parts of the country, primarily due to temporal decline in *boro* yields and faulty irrigation systems. Data we have analysed for the northwest area have shown that deepwater rice in combination with *rabi* crops like onion are financially attractive compared to the single crops of *boro* that are widespread in low elevation plots now. These patterns are thus capable of providing rice for household subsistence as well as reasonable farmer profits.

System benefits of *rabi* diversification:
(i) With all alternative *rabi* crops requiring considerably less water application than rice, irrigation water savings can be considerable, providing better winter habitat for the fishery.
(ii) Alternative *rabi* crops are also typically harvested several weeks prior to *boro.* The risk of early flooding damaging the crop would be proportionally reduced.
(iii) Earlier harvest of the *rabi* crop also implies that the pressure on sluice managers to keep gates closed during the early flood season would be reduced.
(iv) Where diversification in *rabi* is accompanied by deepwater rice in *kharif*, wet season fisheries habitat can also be expected to be improved. More vegetation cover would be available, and the fishing area would be reduced.

Implementing *rabi* diversification

There is a catalogue of constraints to diversification in the *rabi* season. The more profitable *rabi* alternatives such as spices and vegetables also usually carry correspondingly higher price risk. Input costs are usually as high or even higher than in the case of *boro* rice. Successful marketing of these commodities would also depend on access to urban markets. Subsistence pressures tend to favour the choice of rice as the *rabi* crop. Often, significant co-ordination between farmers is required in alternative *rabi* crop systems. For instance, onion crops cannot tolerate waterlogging, and hence blocks of contiguous farmers need to take up the crop, ensuring that water from *boro* irrigation in neighbouring plots does not saturate the onion crop.

Implementing a programme of *rabi* diversification would thus necessitate several forms of technical, financial and logistical assistance. Given the provision of appropriate assistance, however, the system benefits can be substantial.

Sluice Gate Management

Early Flood season sluice management

As discussed before, sluice gates are typically kept closed at the beginning of the flood season in May and June. The operation of gates is typically intended to benefit agricultural interests. Remnant unharvested low-lying boro plots must be protected from flooding at this stage, and the fledgling *aman* crops must be similarly protected from inundation. Consequently, sluice gates are likely to be kept closed in these months for the most part, and openings are likely to be only occasional and only for a few days at a time.

There are two potential effects on fish production: (i) a 'habitat' effect, where the reduction in water level caused by sluice closures in this period negatively impacts the fishery, and (ii) the 'migration' effect, where the blockage of in-migration of whitefish (migratory species) and their fry reduces fish productivity. Our simulation results show that closure of the sluice gates provides only marginal agricultural gains in May. This is consistent with the view that sluices are kept closed at this time only at the behest of powerful landowners operating small numbers of very low lying *boro* plots. On the other hand, our simulations also show that the 'habitat' effect on the fishery is not very high either – *i.e.*, the reduced water levels from closure in May do not greatly reduce fish productivity. This is consistent with Halls' (1998) finding that *potential* fish production is as great inside floodplain areas protected by sluice closure as outside. However, the 'migration effect' is likely to tip the balance in favour of keeping sluice gates open as much as possible in May. There is now substantial evidence (Halls, 1998; De Graaf, *et. al.*, 1999) that in-migration of adult fish as well as fry is likely to be significantly reduced by closed sluices.

In accordance with these findings, the recommendation is to keep sluice gates open as much as possible in May and June. If *boro* production on low elevation plots were to be reduced, as discussed before, the success of this strategy would be more assured. If deepwater *aman* were the predominant *kharif* crop in low land, more sluice openings in the early flood season would be even more justifiable. The deepwater crop is more tolerant of flooding than the transplanted one, and sluice gate closure can be restricted to negate only cases of extreme flooding, and situations where there is a continuous surge of water over several days.

Research in the Compartmentalization Pilot Project (Marttin and DeGraaf, 2000) has also shown that the 'overshot' mode of sluice gate operation is more conducive to fish productivity than the 'undershot' mode. Promotion of this mode of operation, in addition to the recommendation of keeping the gates open as much as possible in the early flood season, could significantly benefit the fishery while imposing few sacrifices on the agricultural sector.

Implementation of early flood season sluice openings:
Sluices gate operation is typically under the overall control of an appointed Bangladesh Water Development Board official, with inputs provided by local sluice committees. An important first step would be to include representation of fishing interests on such committees. Currently, the practice of keeping sluices predominantly closed during the early flood season probably reflects a precautionary mode of operation – gate closure provides insurance against destructive flooding, which may or may not happen. Our recommendation of more flexible operation would doubtless involve more micro-management of the gates on a day-to-day basis.

Dry season sluice management

Research by Halls (1998) and Halls *et. al.* (2001) has shown that fish yield losses incurred by water level reductions in the flood season, caused for example by flood control embankments, can be counterbalanced by retaining more water on the floodplain in the dry season. In fact, that research demonstrated that the importance of dry season water levels for the fishery increases sharply as flood season water levels increase. Beyond an average flood season water height (FSWH) of about 9 metres at the sluice gates, fish production is determined almost exclusively by the dry season water level. This indicates that even in regions where flood control has diminished fish productivity, concerted efforts to maintain more water in the dry season can scale back losses. The trend is however in the opposite direction. For the dry season, the priority is usually to allow the water to drain quickly off the floodplain land beginning with the drawdown in October and November, so that *boro* rice may be planted to as large an extent as possible. Setting sluice gates to maximise drainage after drawdown, and actual drainage of large areas of residual water by mechanical means frees up even low-lying *beel* and floodplain land for cultivation.

Our recommendation for dry season sluice gate management involves restricting drainage so that average dry season water heights at the sluice gates are somewhat higher than under the common practice of maximising drainage. In the site we have studied, the baseline average water height during the dry season was 4.5 metres, and increased water height maintenance of 0.25 metres on average over this baseline was sufficient to produce a 9% increase in fishing productivity. What is being proposed is therefore not a substantial change in current practice, in return for a significant improvement. Of course, greater water height maintenance at the sluice gates would imply higher water levels in the deeper sections of the *beels* and secondary rivers. Correspondingly, a certain amount in the deeper areas of the dry season waterbodies would be lost to dry season rice cultivation. However, our simulations indicate that this sacrifice need not be very great. For the 0.25 metre average increase in water height we considered, only 8 hectares (out of 6775 total) were predicted to be lost to rice production. However, blocked drainage is likely to also result in inundation of more land adjacent to the drainage channels and sluice gates, the extent of which we have not been able to estimate.

Land retirement/Increased water cover

A natural outcome of the dry season sluice gate management strategy outlined above is the ‘retirement’ of some previously *boro*-cropped land from cultivation. As discussed above, this needs only be a small fraction of the total cultivable land, in the deeper areas of waterbodies, and adjacent to drainage channels. There may also be value in strategic retirement of occasional parcels of further land – for instance, plots vulnerable to early flooding[44], for the protection of which landowners petition sluice gate controllers to keep gates closed in the early flood season. Critically for the feasibility of this strategy, our estimation is that these retirements need only constitute a small fraction of overall cultivable land in individual floodplain hydrological units. Since these are relatively small amounts of land, action research groups may well consider direct monetary compensation (leasing/buying) to enable such retirement.

Effort control

Our simulations predict substantially improved fish productivity in response to effort control regimes, both in the form of closed seasons and closed areas. Early flood season closures are always likely to be produce some increases in yield-per-recruit, since most floodplain species experience rapid growth in the early flood season.

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[44] Although, these may be the same very low plots that are inundated by increased dry season water retention.

However such closures are not attractive on equity grounds unless the fishery is a closed one. In open fisheries, access to all, including the landless poor, is available at this time, and the absence of agricultural opportunities implies that fishery closures at this time would impose excessive hardship. The poorest are similarly dependent on the fishery during peak floods as well as drawdown, and although labour demand picks up with the drawdown and the commencement of preparation for the *boro* crop, fishing is often complementary to agricultural labour during this period.

In the early dry season, access to fishing areas becomes largely restricted, and there is declining dependence on the fishery for landless labourers. Professional fishers continue to operate leased sections of deeper beel and rivers, but the major change is in the increased proportion of catch going to landowners draining *kuas*. There is some merit to controlling effort in this period. However, *kua* draining is also for irrigation purposes, and there continues to be some dependence on the fishery for the range of household types, even if it is declining for many categories. If the *kua* catch in this period could be restricted instead of a complete closure, it would bolster the spawning stock, which could be protected with a late dry-season closed season involving relatively low sacrifices.

Closed seasons towards the end of the dry season/beginning of the flood season would protect spawning fish and provide significant benefits with relatively low sacrifices. It is the professional fishers that predominantly operate in this period, and this would be the group that would have to make the sacrifices. Some amount of (unauthorised) fishing by non-lessees may take place at this time, but this is not likely to constitute a significant proportion of this period's catch. For all categories apart from professional fishers, dependence on the fishery tends to be minimal. This also helps in terms of the management of the effort control regime, since organisation of a very heterogeneous group is not necessitated.

Although longer closures provide higher returns, our simulations indicate that these increases taper off with the length of the closure. Additionally, longer closures are more difficult to enforce, as participant enthusiasm drops off in inverse proportion to the length of the closure. In accordance with these facts, a two to three month closure, late in the dry season (April to June), is recommended. In some areas, catches may already be close to zero in the last part of this key period, while in others, significant catches may continue to be taken right until the end of the dry season. Local closures will thus have to be tailored according to the specific pattern of catches.

Closed areas are an alternative way of instituting an effort control regime, with the advantage of being more easily visible and understandable, and therefore enforcible. Year-round reserves may not serve much of a purpose in Bangladesh since there is a need to allow the fishery to be exploited as much as possible in the interest of fishing-dependent livelihoods, and also because most floodplain species are adapted to survive very high levels of mortality. A previous study (Hoggarth and Halls, 1998) had suggested small dry-season reserves every 5 km or so based on the limited mobility of the fish, and the interceptory nature of the fishery. Optimal closure size is a key unknown, and our simulations indicate that most benefits peter out after about 25% reservation of area, attaining a maximum with a closure between 30 and 40%. Even an area closure amounting to10 to 15% of deeper beel and river section areas would provide significant benefits within two to three years of reserve establishment. Apart from the professional fishers who would lease such areas, reserves would also imply restrictions on the drainage of plots by farmers to free up more land for *Boro*. Retirement of land to provide additional water cover, discussed previously, could add to the potential area that can be set aside as reserves.

Indeed, the optimal effort control regimes suggested by our simulations are not dissimilar to the action research already being undertaken in Bangladesh by projects such as CBFM and MACH. Given that these projects have also experimented with institutional aspects to implementation, future action research work incorporating an element of effort control could usefully adopt blueprints from these projects.

Additional considerations

Our findings have indicated that early flood risk to the Boro crop applies primarily to very low elevation plots, and less frequently, to low elevation plots. Our proposal of ‘retiring’ some very low land to water cover would, of course, make this risk redundant for those plots. Also, the promotion of diversified cropping may eliminate the problem by substituting *boro* with crops that are harvested earlier. These cannot be the only solutions to the early flood risk solution problem, however, since the extent of very low land may be very considerable in some sites, and only a fraction may be feasibly retired or included in the diversification programme. In the very low and low plots that remain under *boro* production, examination of varietal composition may prove insightful. Evidence we have examined indicates that plots most exposed to early flood risk are inevitably very low plots continuing to use the older generation of relatively long duration varieties such as IR8 and BR11. Shorter duration varieties such as BR 26 and BR 28 are available that can reduced the field duration by two weeks and provide comparable yields. A two week reduction in duration would be sufficient to eliminate damage from the most common early flood events. The early flood risk problem is thus simply one of available technology failing to reach farmers adequately.