Bio-economic Development of Floodplains: Farming versus Fishing in Bangladesh [†]

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Abstract

This paper explores the linkages of environment and economic development in the floodplain of large rivers. There is considerable evidence that even the most vital floodplains in the world are not being managed efficiently and both economic and ecological factors need to be considered for effective management. Floodplain management policies in Bangladesh emphasize structural changes to enhance agricultural production. However, these structural changes reduce fisheries production, where the fishery is an important natural resource sector and a source of subsistence for the rural poor. We develop a model where net returns to agriculture and fisheries are jointly maximized taking into account the effect of flooding depth and timing on production. Results for a region in Bangladesh show that optimal production in a natural floodplain yields higher net returns compared to a floodplain modified by flood control structures. This finding has important implications for management policies -- neglecting the bio-economic relationship between fisheries and land use may significantly affect the long-run economic role of a river floodplain, particularly in a poor country.

JEL classification: Q2, O13, Q22

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I. Introduction

Traditional development planning has focused primarily on commercial uses of natural resources, such as agriculture, and has failed to take into account the broader environmental effects of policies, particularly those affecting non-commercial resources, such as subsistence floodplain fisheries. Rural communities in developing countries depend heavily on natural resources, both for commercial production and subsistence consumption. Agriculture, forestry, fisheries, and many other economic activities often depend simultaneously on both the exploitation and conservation of natural resources. These competing needs have to be balanced in order to maximize returns from development in the long run. For low-income countries that depend heavily on primary production, such as, agriculture, fisheries and forestry, it is particularly important to understand the economic importance of the environmental resource base that supports such production. Degradation of the environmental resource base affects the quantity and quality of services that are produced by ecosystems, as well as the resilience of these systems (Dasgupta and Mäler, 1997). These effects can, over time, significantly diminish the economic value of productive activities dependant on the natural system.

In this paper, we explore the linkages of environment and economic development in an important natural system, the floodplain of large rivers. Large river floodplains around the world support large population settlements, where development goals most often include improved navigation, enhanced agricultural production and flood protection. Floodplain development policies, such as building levees, appear to offer these desired benefits. However, by altering the annual hydrologic regime, many development programs also have undesirable effects on the ecosystem. There is now considerable evidence that even the most vital floodplains in the world are not being managed efficiently and both economic and ecological factors need to be considered for more effective management (Rogers *et al*., 1989; Interagency Floodplain Management Review Committee, 1994; Naiman *et al*., 1995; Sparks, 1995).

Our focus is on Bangladesh, where eighty percent of the country is the floodplains of the Ganges, Brahmaputra, Meghna and other rivers (Clarke, 2003). Floodplain fisheries are an important natural resource sector in the country, where both commercial and subsistence fishing are important (Tsai and Ali, 1997). Seventy-five percent of rural households engage in part-time fishing from floodplains, rivers and *beels*[1] (FAP 16, 1995; UNDP, 1995). Fish also constitute an important source of nutrition for the rural poor; it is estimated to provide up to eighty percent of animal protein consumed by rural households (UNDP, 1995). Despite the importance of floodplain fisheries, the value of this sector is not adequately accounted for in traditional development planning because much of it takes place in the informal economy.

This paper studies agriculture and fisheries production in an integrated bio-economic framework in order to understand the tradeoffs between these sectors and to quantify the economic impacts of structural changes in the floodplain. The policy challenge is to manage the floodplain such that the value of both agriculture and fisheries are taken into account. This work is distinct in that we explicitly account for productivity linkages between agriculture and fisheries and apply econometric tools to characterize the hydrology that drives both systems. We develop a floodplain land use model where land is allocated to either agriculture or fisheries based on the highest net returns to land. This is an optimization model where the objective is to maximize joint returns from agriculture and fisheries production subject to a set of production and flooding constraints. We model the trade-offs between agriculture and fisheries production in different land types where land types are classified based on the exposure to flooding. Agriculture and fisheries production are then

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[1] *Beels* are permanent backwater lakes in the floodplain, which support fish year-round.

modeled to vary with the area of land in each flood exposure class or flood land type. The model is used to study the effect of alternate management policies. Management policies include levees which affect the hydrology of the floodplain and thus change the distribution of areas in each flood land type. By changing the distribution of areas in each land type, we can study the economic effect of alternate floodplain management policies.

II. Floodplain Systems

Floodplains are wetland ecosystems and are defined as areas that are periodically inundated by the lateral overflow of rivers and lakes (Junk, Bayley, and Sparks, 1989). In their natural state, floodplains support diverse wildlife habitats, fisheries and forests, whose productivity depend critically on the annual flood cycle. The pulsing of the river flow or the flood pulse is considered to be the principal driving force responsible for the existence, productivity, and interaction of the major biota in river-floodplain systems (Junk, Bayley and Sparks, 1989). Economic development in river floodplains often imposes external losses on renewable resource production, such as fisheries, by altering the natural hydrologic regime of the floodplain (Sparks, 1995; Welcomme, 1985).

Economic development is pursued in floodplains around the world primarily through the installation of dams, embankments or levees[2], and through river channelization. In Bangladesh, the trend has been to construct large-scale Flood Control, Drainage and Irrigation (FCDI) projects--systems of embankments. FCD/I[3] projects are designed to reduce flooding and enhance agriculture production. These projects change the intensity, timing and duration of flooding. The area flooded and depth of routine flooding are reduced so as to make more land available for agriculture and to increase agricultural productivity. Floodplain management policies in Bangladesh target the agriculture sector, with the goal of increasing productivity and achieving self-sufficiency in rice

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[2] The terms embankments and levees are used interchangeably here.

[3] The notation FCD/I is used to imply either a FCD or a FCDI project. FCD projects are Flood Control and Drainage projects with no irrigation component.

production. While floodplain rice production has boomed, however, some areas have noted declines in fish population and species diversity. As floodplain lands are reduced by FCD/I projects, so is the potential for floodplain fish production (World Bank, 1991). Changes in the hydrological cycle caused by FCD/I projects affect floodplain fisheries in several ways. First, a decrease in flooded area during the monsoon results in a loss of fisheries habitat and reduced spawning grounds. Second, the influx of riverine fish and hatchlings at the beginning of the flood season is diminished due to the blockage of lateral migratory paths. Finally, dry season habitat is reduced as *beels* are drained to provide irrigation water and/or to create open more land for agriculture. All of these factors result in a decline in floodplain fish production both in the wet and dry seasons (FAP 20, 1994; Halls, 1998).

Hydrologic Cycle and Tradeoffs between Agriculture and Fisheries Production

The annual flood season in Bangladesh is from July to October, with early flooding possible in May and June. Water recedes from the plains in October and November. The dry season covers December through June.

Agricultural productivity, the choice of crops grown, and the cropping pattern in the floodplain are largely determined by hydrologic conditions (MPO, 1987). Most important of these are the depth, timing and duration of flooding, the rainfall pattern, and the availability of dry season drainage and irrigation. Depending on the water regime, from one to three crops are grown in the floodplain each year. Rice is the dominant crop and several varieties may be grown in a given year. Other crops include wheat, jute, mustard, and pulses. There are three main seasons for the floodplain crops, the pre-monsoon season (March-June), the monsoon season (July to October) and the winter dry season (November to March).

The life cycle of fish is also based on the annual hydrologic cycle. Spawning takes place during the pre-monsoon and early monsoon seasons. Some species breed in the rivers while others breed in the floodplains. Lateral migration to the floodplains occurs with the early floods as the water level in the rivers rise. Adult fish are carried into the floodplains with the water in July. They spawn during the early monsoon months and the fingerlings grow rapidly in the floodplain during the monsoon flood season. As the floods recede, some fish move back to the rivers, while others remain in the floodplain *beels*.

The physical trade-offs between agriculture and fisheries production occur in some flood land types, based on land elevation. In a natural floodplain, crop production is feasible in higher elevation lands with shallow to medium seasonal flooding, while it is not feasible in lowlands and in *beels* where flooding is deeper and longer-lived. Fish production is feasible in medium to deeply flooded lands and in *beels*. High-yield crop varieties are produced in shallow to medium flooded lands and farmers attempt to keep flood waters out of areas where these crops are planted. The loss of flood coverage reduces fish production for reasons discussed earlier.

During the flood season, the floodplain fishery is an open-access resource. The rural poor and the landless harvest fish for household consumption (Ali, 1997) as well as for sale in local markets. This is also the time of the year where the tradeoff with agriculture production occurs in the floodplain. Since landowners make cropping decisions, the fisheries sector is generally ignored in their land-use decisions. A primary source of conflict between farmers and fishers is over the controlled timing of flooding, particularly during the pre-monsoon season in May and June. Fishers often cut embankments (or open sluice gates, where present) to allow pre-monsoon floodwaters (and accompanying fish) to enter the floodplain. Farmers resist this, particularly if their rice crop is yet to be harvested. The property rights structure in the floodplain is such that farmers benefit directly from the flood control structures, even though they do not have to bear any costs associated with these structures. The open access approach to the fishery in this case reduces potential gains from the fishing sector. It gives individual subsistence fishers little bargaining power with the landowners.

In the dry season, farmers often drain *beels* to grow a winter rice crop. This results in a reduction of water area and fish productivity, causing conflict with fishers. Most professional fishers in the region are landless. During the dry season, they work as wage laborers or shareworkers for fisheries leaseholders to fish in the beels. Lost fish production in the beels directly cuts into their primary source of income, causing conflict with the farmers.

III. Floodplain Management Model

A floodplain land-use model permits systematic analysis of the economic tradeoffs between agriculture and fisheries production. In our model, land is allocated either to crop production or to maintain fish habitat based on the highest return to land. The social objective is to determine the floodplain management plan and the land allocation that maximizes net returns from both agriculture and fisheries production in the floodplain, given expected flooding conditions. Management plans here include any measures that directly affect the total area of land exposed to flooding and the area of land in each flood land type. We study four management options: a natural (unmodified) floodplain and three types of structural changes in the form of low, medium, and high embankments. The planner observes a range of economic and hydrologic factors that affect the use of floodplain land for agriculture or fish production. These factors include prices and production costs, crop yields, fish productivity and the suitability of land for agriculture or fish production. The planner determines the management plan such that net returns from agriculture and fisheries are maximized given an optimal allocation of land between agriculture and fishing activities. A prime factor affecting the suitability of floodplain land for agriculture or fisheries and the productivity in each sector is the timing, duration and depth of flooding. The land use model here incorporates the differences in productivity based on flood land type, as categorized by the average depth of flooding in each month. The flood land types are as defined in Table 1.

The theoretical foundation for the analysis is derived from theories of natural resource development and renewable resource exploitation (Clark and Munro, 1975; Dasgupta and Mäler, 1997; Swallow, 1994). It also draws from the body of literature that stresses the value and optimal use of environmental resources as inputs into production (Barbier, 1998; Dasgupta, 1990; Mäler, 1991; Serafy, 1993). This approach allows us to determine the best use of resources, such as land and water, in recognition of their economic value through their support of natural production as well as of agriculture. In our case, floodplain area can be thought of as a stock of environmental resource that can be used as a direct input in agriculture or to support fisheries. There are indirect uses of the floodplain resource also, such as, providing breeding grounds and nurseries for river fisheries or for sediment and nutrient retention, which ultimately enhances the productivity of the resource.

Our floodplain management model (FMM) is designed to maximize net returns from agriculture and fisheries by solving for the optimal allocation of land between agriculture and fishing activities for any given management plan. The FMM builds on comparable models focusing on the tradeoff between land development and preservation (Barbier and Strand, 1998; Parks and Bonifaz, 1994; Shahabuddin, 1987; Stavins and Jaffe, 1990; Swallow, 1990 and 1994). The area of land allocated to crop i in flood land type l at time t is A_{ilt}, the area maintained for the fishery is A_{flt}, and the total land available in each flood land type is A_{lt}. Fish stock is given by S_{lt}, fish catch by Q_{lt} and the fishing effort expended is given by E_{lt}. Crop yield is given by y_{ilt}. Prices and costs are given by p_f; c_f and p_i, c_i for fish and crops respectively.

Fisheries Model

An important component of the FMM is the empirical fisheries model. 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 evidence that fish production is dependent upon floodplain for habitat and nurseries (Welcomme and Hagborg, 1977; FAP 20, 1994), we model explicitly the effect of flooded area on fish production. We do not model fish stock dynamics explicitly here. To the extent that fish growth and stock dynamics may affect fishing seasons and seasonal production outcomes, our model will fail to capture that. Thus, the model is useful only for studying annual optimal production levels, which was our primary goal. This approach is appropriate for the study context in Bangladesh, where recruitment occurs predominately from stocks outside the floodplain in the form of seasonal migrations of fish (Halls, 1998). Fishing practices in Bangladesh do not leave much of the floodplain fish stock for the following year. Thus, an annual fishery can be modeled with an initial stock dependent on available floodplain land and its flooding condition.

We start with the Schaefer specification, which is commonly used in the fisheries literature (Clark, 1976; Barbier and Strand, 1998). The fish harvest or catch function is given by:

$$Q_t = aS_t E_t \qquad (1)$$

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:

$$Q_t = aS_t^{\phi} E_t^{\delta} \tag{2}$$

where, $a > 0$, $0 < \phi < 1$ and $0 < \delta < 1$. That is, catch Q is increasing in both stock and effort but 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:

$$q_t = bS_t^{\phi} \tag{3}$$

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 (Halls, 1998; Welcomme, 1979). Using the area of land in each flood land type captures the effects of both the intensity and the duration of flooding. Evidence from other floodplains suggests that stock is an increasing function of the area flooded but stock per unit area is a decreasing function of the area flooded (FAP 20, 1994; Welcomme and Hagborg, 1977). Thus we have the general form stock function:

$$S_t = F(A_{ft}) \tag{4}$$

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

$$S_t = cA_{ft}^{\theta} \tag{5}$$

where, $c > 0$ and $\theta < 1$. Combining equations (3) and (5), we get:

$$q_t = \alpha A_{ft}^{\beta} \tag{6}$$

where, $\alpha > 0$ and $\beta < 1$.

Next, 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 simply by specifying equation (6) for each of the flood land types, l. Since for different intensity floods we have not only different flooded areas, but also different distributions of l, this would lead to different fish outputs in the various flood land types. So accounting for l leads to:

$$q_{lt} = \alpha A_{flt}^{\beta} \tag{7}$$

where $\beta < 1$ for floodplain lands l_1 to l_4 and $\beta = 1$ for *beels*, i.e., flood land type l_5. Fishing is not feasible in land type l_0, since that is dry land. Equation (7) is the fish production function, which is modeled here explicitly as a function of floodplain area maintained for the fishery. Fish output increases at a decreasing rate with an increase in flooded area. Output for floodplain lakes or *beels* is assumed to exhibit constant returns to scale (land type l_5). This is because flood depth in *beels* is close to constant across the *beel* area and thus output per unit area is assumed to be constant over the area.

Next, we add a parameter, μ, which measures 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 overall fish productivity. This reflects the partial inaccessibility of the floodplains inside the embankment by migratory fish species. Halls' study area is the Pabna Irrigation and Rural Development Project (PIRDP), which is an FCDI project. Halls' results suggest that floodplain fish productivity is reduced by as much as 50 percent due to the embankments.

Finally, a variable, θ, is added to reflect the portion of fish catch which is valued at the market price. When θ is equal to one, all fish harvested are valued at market price. That is, we assume that even subsistence fish consumption is valued at market prices. The analysis here does not attempt to estimate the value that households place on fish for subsistence consumption but rather attempts to measure the total value of all fish produced in the floodplain, whether for the market or for household consumption. In this case, using the market price of fish, as a shadow value for domestic use, is the best measure we have for the use value. When θ is less than one, only the marketed portion of fish catch is valued at market price. The rest of the fish catch, which is used for subsistence consumption, is valued at an alternate nutritional value. This alternate value is measured by computing the price of an equivalent protein supply from another source, pulses, in the region.

Agriculture and the Full Empirical Model

For computational ease, the agriculture sector is modeled using simple production technologies. These are characterized by linear input-output coefficients that 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. These include wheat, jute, pulses, mustard and seven varieties of rice: High Yielding Variety (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 that there are constant returns to scale in agriculture. We also assume that irrigation water is available as needed during the dry season. This is reasonable since groundwater irrigation is common in the study area and water is usually not scarce. However, individual farmers might face other constraints in determining crop choice, such as credit, capital costs, labor, etc., which are not explicitly modeled here. This abstraction might lead certain crops, particularly the high-cost 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 model scenarios.

The full empirical floodplain management model is:

$$\underset{A_{ilt},A_{flt}}{Max}\sum_{i,l,t}(p_i y_{ilt}-c_i)A_{ilt}+\sum_{f,l,t}(p_f\theta\mu q_{flt}+p'_f(1-\theta)\mu q_{flt}-c_f A_{flt}) \tag{8}$$

subject to,

$$\sum_i A_{ilt}+\sum_f A_{flt}\le A_{lt}\quad for\ all\ l\ and\ t \tag{9}$$

$$q_{flt}=\alpha A_{flt}^{\beta}\quad for\ l_0,\ldots,l_4 \tag{10}$$

$$q_{flt}=kA_{flt}\quad for\ l_5 \tag{11}$$

The objective is to maximize the sum of net returns from agriculture and fisheries (equation (8)). The first term 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. Revenues are reduced to the extent the parameters μ and θ take on values less than one. The total cost is given by the cost per hectare of fishing multiplied by the total area allocated to fishing.

Equation (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. Equations (10) and (11) are the fish production functions for the floodplain and *beels,* respectively, as explained earlier. Several other conditions are specified for the empirical model such as production parameters 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. All input cost and price data and results are in 1995 Taka.[4] For analytical convenience, an annual model is used with discrete monthly time increments, t. For agriculture, cropping decisions are made on a seasonal basis, whereas, fish catch can vary daily. A monthly time increment was chosen as a reasonable middle-ground. An annual model is used for both of these sectors. Crop choice and cropping pattern are based on the expected 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.

IV. Model Calibration

The study area is in the Tangail region of North-Central Bangladesh. An area of 143,640 hectares (ha) was selected in the Bangshi-Dhaleswari floodplain, which is part of the larger Brahmaputra River floodplain. Detailed data on agriculture and fisheries in the study area were available from several other ongoing research studies in the area. These data include fish catch, fishing effort, cropping pattern, growing season, water tolerance, crop yields, as well as costs and prices. Islam

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[4] 1 US$ equals 57.95 Bangladeshi Taka in April 2003.

(2001) provides further details. The data on fish catch were not detailed enough for econometric estimation of equation (10); instead, we numerically estimated the parameters of the fish production function, α and β, using data from a fish catch survey conducted by the Center for Natural Resource Studies in Dhaka (CNRS, 1997). Catch data and approximate floodplain area data were used to estimate the parameters by setting one parameter value and solving for the other. With fish production exhibiting only slightly decreasing returns to scale (Welcomme, 1985), we expected β to be close to 1. So, we started by setting the value for β and solving for α, and repeated the process until there was convergence.

Hydrology Simulation

As mentioned earlier, flood season hydrology is an important input into the floodplain management model. We use properties of historical water level data to simulate a series of water levels, which are then inputs to the optimization model. Figure 1 shows sample historical hydrographs. Historical water level data were provided by the Surface Water Modelling Centre in Bangladesh (SWMC, 1997). A novel approach based on a branch of time-series econometrics called Fourier (harmonic) analysis is developed here to simulate flood levels. Fourier analysis decomposes periodic data into a sum of sinusoidal components (Bloomfield, 1976). The procedure describes or measures the fluctuations in a time series by comparing them with sinusoids. This approach provides a realistic series of simulated hydrographs by accounting for both the fluctuations and the random component in annual floods. There are several steps to this analysis. First, econometric analysis is used to fit the best curve to the historical data. Next, residuals from the fitted model are tested for heteroscedasticity and autoregressive processes. Finally, the fitted values are combined with fitted residuals in order to randomly generate a new water level series. For our purposes, one hundred years of daily water level series were simulated (Islam, 2001).

The simulated hydrographs were then used to generate monthly average water levels and to calculate the associated areas in each flood land type. The area-types are inputs into the floodplain management model. The annual distribution of areas in each flood land type is calculated by combining the simulated hydrographs with area-elevation data from a digital elevation model (DEM) of the study area (Environment and GIS Support Project for Water Sector Planning, 1997a). The area-elevation data is first fitted to a generalized logistic function. Then this fitted function together with the simulated water level is used to calculate the area in each flood land type, based on the depth of flooding. This provides a stochastic distribution of flood land types, an input into the FMM.

Figure 2 presents a schematic of how the different model components come together. The figure reflects the sequencing of the empirical model. Outputs from the DEM and the hydrology components from the simulation model 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, producing a distribution of optimal net returns for each specified model scenario.

V. Results

This section presents results from the four management scenarios. The optimization model is solved for each of the scenarios using non-linear programming techniques.

The base model is for the natural (unmodified) floodplain. It is run with parameter values of α=20, β=0.8, θ=1, and μ=1 (see Appendix A for sensitivity of model results to changes in these parameter values). Results show that crops are grown in land types L0, L1, and L2 with no crops grown in L3, where the optimal land use is for fisheries. Table 2 shows the cropping pattern for a typical year of the model run – it shows the percentage of total floodplain land devoted to each crop in each month and in each land type. Different varieties of rice are found to be optimal in each season. This cropping pattern is comparable to what we find in the floodplain. Rice is the dominant crop in the region where the traditional rice crops of Aus, Aman and Boro are grown in the *Kharif*-I (pre-monsoon), *Kharif*-II (monsoon) and *Rabi* (winter) seasons respectively (EGIS, 1997b; FAP 20, 1992). Our results reflect this, although local varieties of rice are not always found to be optimal since HYV crops yield higher returns. The absence of credit constraints may account for the over-representation of HYV crops that require more costly inputs. Another factor is that the different varieties of rice taste different and there may be some preference for traditional local varieties over HYVs, although the trend has been toward planting more HYV crops (FAP 20, 1992). Jute is also grown in the region, but is not reflected in our optimal cropping pattern. The acreage of jute has been decreasing due to low market prices (FAP 20, 1992).

Since the base model results correspond well to current practice in most respects, the slight differences in cropping pattern are not of serious concern. These results indicate the highest possible returns given the production constraints in the floodplain and are consistent across the different scenarios. This suggests that the model is appropriate for making counterfactual predictions and we can apply it to this end.

The optimal fishing pattern in the base model includes some fishing in all feasible land types, L1 to L5. Table 3 shows the optimal fishing pattern for a typical year of the model run – it shows the percentage of total floodplain land devoted to fisheries in each month and in each land type. Land types L4 (low-lying land) and L5 (floodplain *beels*) are not suited to agriculture. As expected, the model allocates all of L4 and L5 areas are allocated to fisheries. What is interesting is that there is some land in L1, L2 and L3 allocated to fisheries, thus indicating that returns from fisheries are higher compared to agriculture for some of these areas. This is in contrast to traditional planning models that fully allocate these land types to crop production. Optimal floodplain fish catch per unit area (CPUA) in the base model ranges from 83 kg/ha/year to 128 kg/ha/year, with an average of 104 kg/ha/year. Data on actual floodplain CPUA is sparse and variable in time and place. A study in the PIRDP floodplain found CPUA to be 104 kg/ha/yr in 1995 and 130 kg/ha/yr in 1996 (MRAG, 1997). A survey in the Tangail region found CPUA of90 kg/ha/year in 1992/93 to 403 kg/ha/year in 1993/94, including *beel* catch (FAP 20, 1994). The official national Fish Catch Statistics report 130 kg/ha/year for the 1994-1995 water year (DOF, 1995). Thus, the optimal CPUA from our FMM is at the low end of observed conditions. This is true for all of the counterfactuals studied, and therefore does not affect the comparison between them. But, it does mean that fisheries are disadvantaged relative to agriculture in all scenarios.

Comparison of Alternate Management Scenarios

The three alternative management scenarios involve the installation, respectively, of low, medium and high embankments. These scenarios offer increasing levels of flood protection to land behind the embankments but decreasing access of fish to the floodplain. In all three cases, the optimal cropping patterns are very similar to the base model. For the models with low and medium embankments, the cropping patterns are identical to the base model. The shift in flood land types brought about by these embankments was not sufficient to change the optimal cropping pattern. For the model with high embankments, more land of type L0 is allocated to agriculture compared to the base model. This is what we would expect since there would be more L0 land with high embankments management scenario and all of that land would be devoted to cropping since it is not feasible for fisheries.

The fishing patterns for the low and medium embankment models are also close to the base model (note that μ is equal to one here). For the first year, they are identical. There are slight variations in other years. For the high embankment model, less land is optimal for fisheries as compared to the base model. This is particularly true in land types L1 and L2 where the tradeoff between agriculture and fisheries is greatest. This is expected given that there is typically less land in L1 and L2 and more land in L0 for the high embankment scenario.

Next, net returns under the alternate management plans are lower than in the base model for all years. We calculate net returns by subtracting annualized capital and O&M costs of each management scenario from the total returns (Islam, 2001 provides further details). For the base model, net returns are equal to the total returns since there are no structural changes for which costs have to be taken into account. Table 4 presents summary statistics of agriculture, fisheries, and net returns from the different models based on the 100 years of model runs. Figure 3 plots the net returns for all 100 years of model results. Net returns from the high embankment are almost always higher compared to the other two scenarios of structural change. This implies that even though the cost of the high embankment management plan is the highest, the benefits of reduced flooding under this plan are higher than the other management plans. However, the higher costs are not justified when compared to the base model. This is clearer when we compare the two components of returns, one agriculture and the other fisheries. We expect returns from agriculture to be greater and fisheries returns to be less under the alternate management plans as compared to the base model. Results from model runs bear this out for the most part. Agriculture returns increase with the medium and high embankment models, but change little with the low embankment scenario (see Table 4). Fisheries returns decrease under each management plan, with the largest decline of 5.5 percent under the high embankment model. It is important to note that fisheries productivity is assumed not to change under these management plans; that is, the parameter, μ, is equal to 1. Fish production changes only to the extent that areas flooded change with the different structural changes. In reality, we would expect productivity to change beyond this since structural changes block migration routes of fish and delay the timing of flooding. This is addressed below in Appendix A.

The decrease in fisheries returns is not made up by an increase in agricultural returns under the low and medium embankment plans. Thus, total returns are lower than the base model, without accounting for the cost of the management plan. In the case of high embankment, the increase in agriculture returns offsets the decrease in fisheries returns. This shows a slight increase in operating returns of about one percent when compared to the base model. However, when the capital cost is taken into account, the net return is 10.6 percent lower than in the base model (see Table 4).

Next, we examined the sensitivity of model outputs to the key input parameters, α, β, θ and μ. We find that model results are not sensitive to realistic ranges of the parameters, α and β, the parameters of the fish production function. Results are very sensitive to the parameters θ and μ, as expected. Appendix A presents details of our sensitivity analysis.

Finally, we carried out a stochastic dominance analysis which confirms that the base model dominates over other the models by first-degree stochastic dominance. Appendix B presents details of the stochastic dominance analysis.

VI. Policy Implications and Conclusions

Our results provide two important conclusions. First, we find that the optimal resource use in the base case (that of a natural floodplain) allocates less land to agriculture than is currently observed in the floodplain and allocates some additional land to fisheries in several flood land types. Second, we find that net returns from the base scenario are higher than the other management scenarios and that the base model dominates the other models by first-order stochastic dominance.

An important assumption of our conceptual model is that producers make optimal land-use decisions given the policy choice made by the planner, while the planner in turn chooses the optimal floodplain management policy assuming optimal land-use decisions are made by floodplain producers. Thus, to the extent our results from the base scenario diverge from actual observed conditions in the floodplain, we can conclude that floodplain producers currently do not make socially optimal land-use decisions in the study area. This finding, that more than optimal areas of land are currently being allocated to agriculture, is not surprising. Fisheries production is not adequately valued by agricultural land-owners since much of the floodplain fish production is used for subsistence consumption by the landless.

The second key result shows that the base model, solved for a natural floodplain, dominates the other management scenarios of low, medium, and high embankment.[5] This is true even under different values of key parameters. The finding that the base model always yields higher net returns than the three structural management scenarios is rather surprising, given the dominance of these structural changes in traditional development planning. Our results give tentative support to the hypothesis that structural changes in the floodplain, as represented by these scenarios, would not always provide higher returns if the economic value of fisheries production were accounted for, along with agriculture. In fact, our results may even be conservative in that the fisheries sector may be undervalued. Our results depend critically on the value placed on fish production. To the extent that the market price of fish we use does not fully reflect the true social value of fish, this would be true. The market price may be too low because much of the fishery is open access and fish harvest may be too high in the flood season. In this case we would want to use a shadow price of floodplain fish that takes into account the scarcity value of the fish and reflects the future loss of the resource due to changes in the management regime. Another issue is how we value the non-marketed portion of fish production. We use a value associated with an alternate protein source, which does not fully value fish as an important food source. A better measure would be to value the fish at its full replacement cost for nutritional intake. That is, find a complete bundle of foods that will provide an equivalent nutritional supplement and estimate the market value of that bundle. This

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[5] This key result also holds when structural changes with sluice gates were studied. That study was part of a project commissioned by UK's Department for International Development and is not reported here.

would be the nutritional replacement value for any fish lost. We believe these adjustments would further strengthen our results.

These results suggest that traditional development policies that emphasize structural changes in the floodplain and target agricultural growth have been misdirected in their oversight of the fisheries sector. The floodplain fisheries sector is not taken into account since it is not a commercially important sector. However, recent emphasis on the fisheries sector in Bangladesh, brought about by concerns over reduction in fish stocks and the subsequent effect on rural poor who depend on fish for subsistence consumption, will hopefully stimulate further research in this area and inform future planning. For the rural poor, environmental resources, such as fisheries, can supplement income and consumption especially in times of economic stress. Degradation of the environmental resource base can make certain communities destitute even while the economy on average is growing (Dasgupta and Mäler, 1997).

This paper is one of the first attempts at quantifying the effects of floodplain economic development policies in Bangladesh on two key sectors, agriculture and fisheries, in an integrated bio-economic framework. The primary contribution is the empirical floodplain management model developed here to study both agriculture and fisheries sectors in one framework. This allows us to quantify floodplain production tradeoffs in a way that was not possible before. Although similar land use models exist in the literature, what is unique here is the integration with hydrology and physical characteristics of the floodplain. Our work is distinct in that we take explicit account of the productivity linkages between agriculture and fisheries production for different flooding conditions. The model we develop here is flexible enough that we can study the effects of different policy options for different input conditions. Both the floodplain land use model and the simulation methodology developed here can be used in other studies of wetland management.

In modeling the effects of floodplain management policies, we have not attempted to include all possible effects of these policies. Further research needs to take into account several factors that we have not incorporated. First, we have not made any attempt to measure the reduction in flood damages brought about by structural changes in the floodplain, such as embankments. In normal flood years, the primary functions of embankments are to reduce flooding and delay the start of the flood, which greatly benefits agricultural production. There is very little damage to property in normal flood years since most rural roads and homes are built on naturally or artificially elevated lands. Also, life in rural Bangladesh is well adapted to normal annual floods, and thus the benefits of these structural changes beyond agriculture are small. Severe damages to property do occur during years of high floods. This is when flood control structures are most useful, but only to an extent. These structures are typically breached or topped during particularly high floods and their failure may exacerbate the resulting damages. Thus, it is important not to over-value the flood control benefits of these structures.[6]

The FMM also does not take into account externalities that occur over time and space. Externalities over space include changes in river channel structure and the effect on downstream flooding. For fisheries, the effect of flood control structures over time would be to reduce overall populations of river fish and thus further decrease productivity of the fisheries, both in the floodplain and in the river. This is because flood control structures erode the floodplain nursery and feeding habitats of river fish, although the extent of this effect is not well understood. Fewer recruits would remain from one year to the next to repopulate fished-out areas. For agriculture, flood control structures may reduce productivity over time for two reasons. First, flood control structures reduce nutrient-rich sediment deposition on floodplains. Second, the flood pulse is important for groundwater recharge and this may be reduced with flood control structures, thus

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[6] Note that our analysis focuses on rural floodplains only. Reducing flood damages is an important consideration for urban areas, which we do not address here.

reducing irrigation water available for agriculture (Clarke, 2003). Both effects could potentially reduce agriculture productivity over time, although the extents of these effects are not well understood. A more detailed model, one that incorporates these various externalities of flood control projects, could provide results that further support ours.

Our results suggest that flood control projects may not be the best development option for many floodplains and it will thus be important to better account for the different effects of these projects, rather than focus only on the agriculture sector. These results cannot be ignored as natural river floodplains are important wetland ecosystems with extraordinary biological potential. Seasonal flood cycles are the principal driving force responsible for the existence, productivity, and interaction of the major biota in these systems (Junk, Bayley and Sparks, 1989). Our analysis shows that the advantages of a free-flowing river connected to its floodplain are not only biological, but also economic.

Better management of river floodplains, where fisheries are considered alongside agricultural development, will be essential for realizing the long-term economic benefits of these ecosystems, particularly in low-income countries like Bangladesh. Better integrated management will also require specific understanding of the interactions between land, water and the people dependant on the floodplains. Of particular importance is the institutional structure in place, including an understanding of current property rights structures and the key winners and losers of floodplain development. Without such integrated management, the true goals of development will not be reached.

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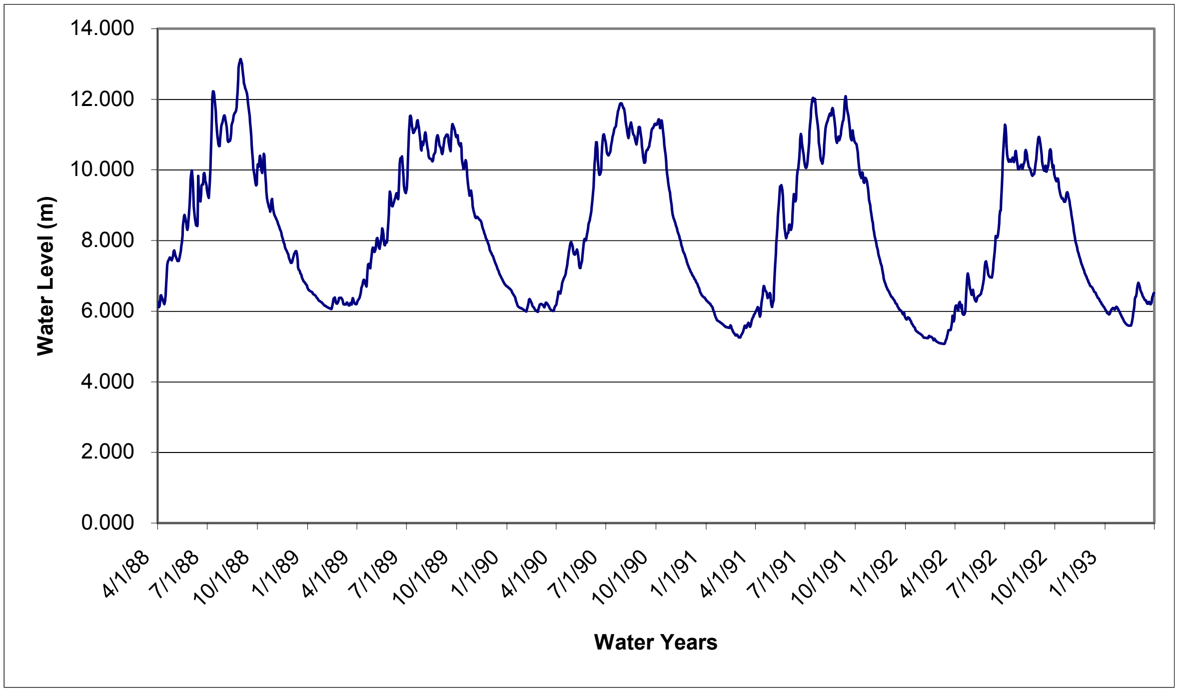
Table 1: Flood Land Types Defined on the Basis of Flood Depth

Flood Land Type	Flood Depth	Flooding Condition	Note: Type of crop grown in wet season
L_0	0-30 cm	Intermittent	High Yield Variety (HYV) rice
L_1	30-90 cm	Seasonal	Local and HYV rice
L_2	90-180 cm	Seasonal	Local varieties of rice
L_3	180-300 cm	Seasonal	Local varieties of rice
L_4	Greater than 300 cm	Seasonal deepwater body	No crops grown in the wet season.
L_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.

Note: This is based on the land classification, F0-F4, used in Bangladesh. For our purposes we have separated out *beels* from F4 and classified it separately as L_5.

Source: MPO, 1987.

Figure 1: Annual Hydrographs showing Daily Water Levels for 1988-1992 Water Years



Source: SWMC, 1997.

Figure 2: Floodplain Management Model Schematic - Systems and Linkages

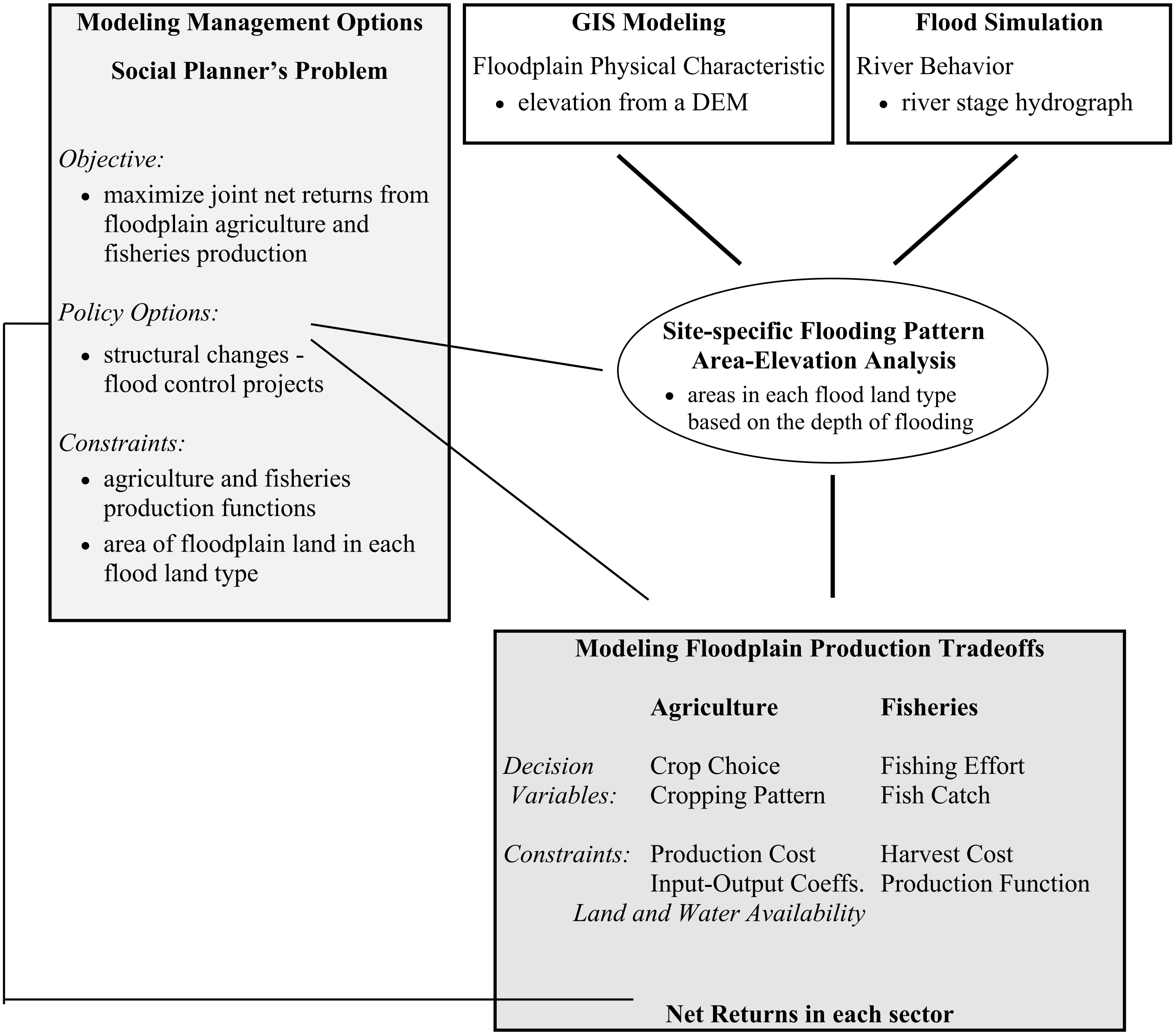


Table 2: Optimal Cropping Pattern in the Base Model (no embankment)

		Optimal land use by crop and by land type (percent of total floodplain area)			
Month	Crop	L0	L1	L2	L3
December	Pulses	67.35			
January	HYV Boro rice	29.65			
January	Pulses	67.35			
February	HYV Boro rice	29.65			
February	Pulses	67.35			
March	HYV Boro rice	29.65			
March	Pulses	67.35			
April	HYV Aus rice	55.23			
April	HYV Boro rice	29.65			
May	HYV Aus rice	55.23			
May	HYV Boro rice	29.65			
June	HYV Aus rice	55.23			
July	HYV T. Aman rice	9.30	7.52		
July	DW T. Aman rice			15.90	
August	HYV T. Aman rice	9.30	7.52		
August	DW T. Aman rice			15.90	
September	HYV T. Aman rice	9.30	7.52		
September	DW T. Aman rice			15.90	
October	HYV T. Aman rice	9.30	7.52		
October	DW T. Aman rice			15.90	

Model Parameter Values: Alpha=20, Beta=0.8, Theta=1, Yield=1.
Results for one sample year, Y1.

Table 3: Optimal Fishing Pattern in the Base Model (no embankment)

	Optimal land use for fisheries by land type (percent of total floodplain area)				
Month	L1	L2	L3	L4	L5
April					8.60
May					8.60
June	12.98	14.58	8.60		8.60
July		0.98	27.72	29.97	8.60
August	0.34	1.46	27.68	28.46	8.60
September	2.87	4.18	25.96	18.62	8.60
October	6.55	2.11	15.97		8.60
November	3.91				8.60
December	5.25				8.60
January					3.00
February					0.55
March					0.40

Model Parameter Values: Alpha=20, Beta=0.8, Theta=1, Yield=1.
Results for one sample year, Y1.

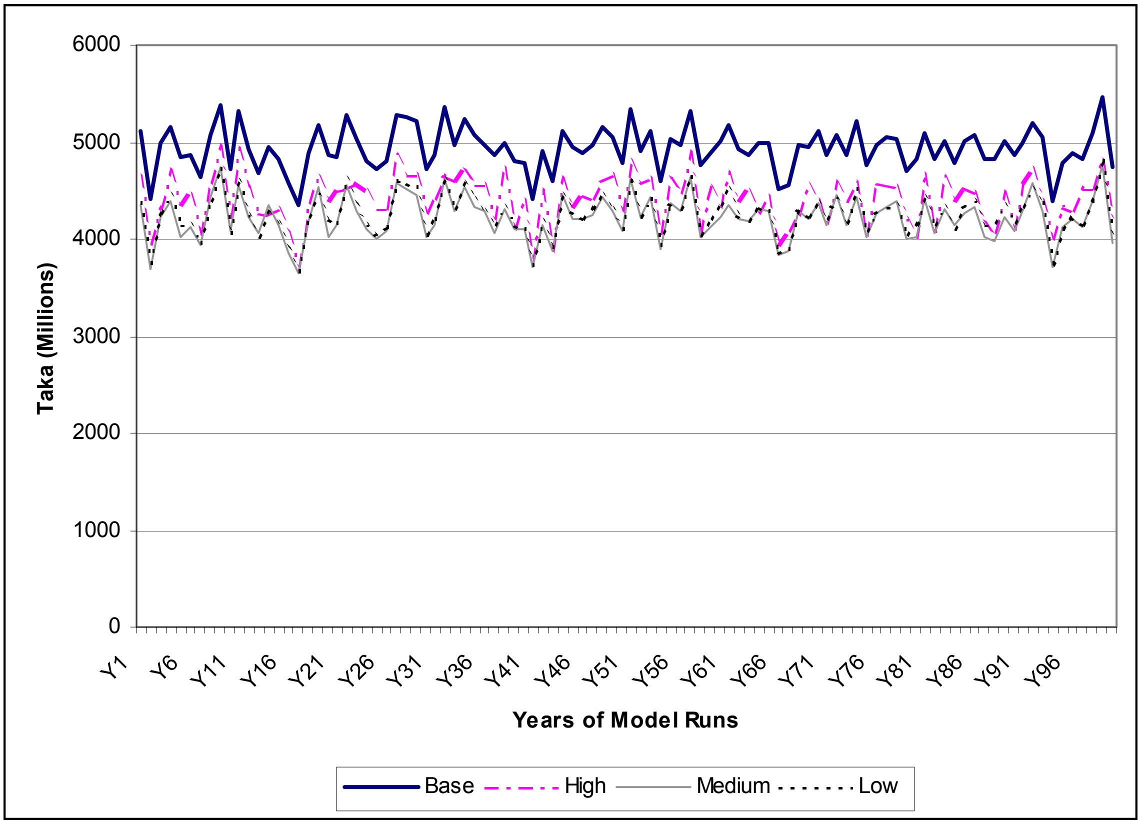
Table 4: Returns under Alternate Management Scenarios: Summary Statistics from 100 Years of Model Runs

	Returns (Million Taka)				Percent Change from Base Model
	Max	Min	Mean	Std. Dev	Mean Returns
Base Model (No Embankment)					
Agricultural Returns	3,863	2,676	3,258	252	
Fisheries Returns	2,005	1,130	1,677	138	
Total Returns	5,464	4,357	4,935	221	
Net Returns	5,464	4,357	4,935	221	
Low Embankment					
Agricultural Returns	3,871	2,678	3,257	254	-0.04%
Fisheries Returns	1,989	1,120	1,654	135	-1.37%
Total Returns	5,462	4,337	4,911	217	-0.49%
Net Returns	4,804	3,679	4,253	217	-13.82%
Medium Embankment					
Agricultural Returns	3,907	2,677	3,266	266	0.24%
Fisheries Returns	1,983	1,152	1,623	129	-3.25%
Total Returns	5,422	4,309	4,889	226	-0.95%
Net Returns	4,754	3,641	4,220	226	-14.49%
High Embankment					
Agricultural Returns	4,004	2,683	3,405	291	4.49%
Fisheries Returns	1,955	1,102	1,585	132	-5.47%
Total Returns	5,522	4,299	4,990	253	1.11%
Net Returns	4,945	3,722	4,413	253	-10.58%

Model Parameter Values: Alpha=20, Beta=0.8, Theta=1, Yield=1.

*All returns are in 1995 Taka.

Figure 3: Net Returns under Alternate Management Plans



Model Parameter Values: Alpha=20, Beta=0.8, Theta=1, Yield=1.
All returns are in 1995 Taka.

Appendix A

This appendix presents further details of the sensitivity analysis mentioned in Section V. Table A1 reports the parameter values for which the sensitivity analysis is carried out. We find the floodplain management model to be relatively insensitive to different values of α and β (the two parameters of the fisheries production function) within realistic ranges. Tables A2 and A3 show the model runs with different values of these parameters for all the management scenarios. For the two values of α that were used, 15 and 25, fisheries returns changed by less than 10 percent as compared to the initial model with an α of 20. The change in net returns is even smaller, about 2 percent in either direction. This is because fisheries returns make up a smaller share of the total returns than agriculture. We used a twenty-five percent change from the initial case in the parameter value of α (15 and 25 compared to 20) since smaller changes made very little difference in fisheries returns. For the parameter, β, we compared values of 0.9, 0.85 and 0.75 to 0.8 in the base case. Two values higher than 0.8 were chosen, compared to one lesser value, because we believe that fisheries production exhibits only slight decreasing returns with respect to increased floodplain area. Results show that fisheries returns change by about two percent or less, although the change is bigger for lower values of β. We would expect this since a lower β indicates more pronounced decreasing returns, thus increasing the trade-off with agricultural production. Nevertheless, the models are not very sensitive to this parameter. Net returns in all the scenarios change by less than one percent for the alternate parameter values of β (see Table A3).

Table A4 presents model results from sensitivity analysis on the parameter, θ, which is the share of fisheries production that is valued at market price. A θ of 1.0

implies all of the fish catch is valued at market price, regardless of how much of the fish caught is for subsistence consumption and how much is actually sold in the market. A θ less than 1 implies that θ x 100 percent of the catch is valued at market price while the (1-θ) x 100 percent of fish caught for subsistence consumption are valued at less than the market price. The alternate value is based on the price of pulses with comparable protein content (see Islam 2001 for details of the calculation.) The model results are very sensitive to this parameter for all the management scenarios. Fisheries returns decrease by about 30 percent for θ = 0.7 as compared to θ = 1, for all the scenarios. Net returns decrease by about 11 percent for the three flood control scenarios and by 10 percent for the base scenarios (see Table A4). This shows the importance of adequately valuing the fish production.

Table A5 presents model results from sensitivity analysis on μ for all the management scenarios. The parameter, μ, represents how much fish productivity or yield is decreased due to structural change in the floodplain, above and beyond the effect of reduced flooded areas (that is, reflecting additional productivity loss due to the structures blocking key migratory paths). A value of 1 indicates that productivity is 100 percent and any change in fish production is due only to the fact that less area is flooded under a given flood control structure. On the other hand, a value of 0.5 indicates that 50 percent of fisheries productivity is lost due to structural changes alone. In this case, any reduction in total production will reflect both this loss in productivity as well as the fact that less area is flooded for a given structural change. The model is very sensitive to μ. For a parameter value of 0.9, indicating a 10 percent reduction in productivity, fisheries returns decrease by about 15 percent and net returns are 5 percent less compared to a μ of

1. Compared to the base model, fisheries returns decrease by about 17 percent in the low embankment scenario to about 19 percent in the high embankment scenario (see Table A5). For a parameter value of 0.5, indicating a 50 percent reduction in productivity, fisheries returns decrease by about 70 percent, while net returns decrease by about 35 percent, for all the model scenarios. It is clear from these results that we need a better understanding of how fisheries productivity is affected by alternate management plans, above and beyond the simple effect of reduced flooded areas.

Table A1: Parameter Values Used in the Floodplain Management Model

Parameter	Base Value	Sensitivity Tests
α	20	15, 25
β	0.8	0.9, 0.85, 0.75
θ	1	0.9, 0.8, 0.7
μ	1	0.9-0.5

Table A2: Mean Returns under Different Parameter Values – Alpha (α)

		Mean Returns (Million Taka*)			Percent Change from Alpha=20		
		Agriculture	Fisheries	Net Returns	Agriculture	Fisheries	Net Returns
Base Model (No Embankment)							
Alpha	15	3310	1529	4839	1.59%	-8.82%	-1.95%
	20	3258	1677	4935	0.00%	0.00%	0.00%
	25	3231	1814	5045	-0.85%	8.18%	2.22%
Low Embankment							
Alpha	15	3309	1507	4158	1.58%	-8.90%	-2.25%
	20	3257	1654	4253			
	25	3230	1791	4362	-0.84%	8.26%	2.56%
Medium Embankment							
Alpha	15	3312	1482	4125	1.40%	-8.68%	-2.25%
	20	3266	1623	4220			
	25	3240	1756	4328	-0.80%	8.21%	2.54%
High Embankment							
Alpha	15	3412	1483	4318	0.22%	-6.47%	-2.16%
	20	3405	1585	4413			
	25	3392	1696	4511	-0.38%	6.98%	2.22%

Model Parameter Values: Beta=0.8, Theta=1, Yield=1.

*All returns are in 1995 Taka.

Table A3: Mean Returns under Different Parameter Values – Beta (β)

		Mean Returns (Million Taka*)			Percent Change from Beta=0.8		
		Agriculture	Fisheries	Net Returns	Agriculture	Fisheries	Net Returns
Base Model (No Embankment)							
Beta	0.9	3256	1715	4971	-0.07%	2.26%	0.72%
	0.85	3255	1697	4953	-0.09%	1.21%	0.35%
	0.8	3258	1677	4935			
	0.75	3282	1640	4921	0.72%	-2.24%	-0.28%
Low Embankment							
Beta	0.9	3255	1692	4289	-0.07%	2.29%	0.84%
	0.85	3254	1674	4271	-0.09%	1.23%	0.40%
	0.8	3257	1654	4253			
	0.75	3281	1617	4239	0.72%	-2.27%	-0.33%
Medium Embankment							
Beta	0.9	3264	1660	4256	-0.06%	2.32%	0.85%
	0.85	3264	1642	4238	-0.08%	1.23%	0.41%
	0.8	3266	1623	4220			
	0.75	3287	1588	4206	0.63%	-2.15%	-0.34%
High Embankment							
Beta	0.9	3405	1620	4449	0.02%	2.21%	0.81%
	0.85	3405	1602	4430	0.01%	1.07%	0.39%
	0.8	3405	1585	4413			
	0.75	3407	1567	4397	0.07%	-1.16%	-0.36%

Model Parameter Values: Beta=0.8, Theta=1, Yield=1.

*All returns are in 1995 Taka.

Table A4: Mean Returns under Different Parameter Values – Theta (θ)

		Mean Returns (Million Taka*)			Percent Change from Theta=1		
		Agriculture	Fisheries	Net Returns	Agriculture	Fisheries	Net Returns
Base Model (No Embankment)							
Theta	1	3258	1677	4935			
	0.9	3280	1488	4768	0.66%	-11.27%	-3.39%
	0.8	3298	1304	4603	1.23%	-22.23%	-6.74%
	0.7	3308	1131	4438	1.52%	-32.58%	-10.07%
Low Embankment							
Theta	1	3257	1654	4253			
	0.9	3279	1467	4088	0.66%	-11.28%	-3.88%
	0.8	3297	1286	3925	1.22%	-22.26%	-7.72%
	0.7	3306	1115	3763	1.51%	-32.61%	-11.52%
Medium Embankment							
Theta	1	3266	1623	4220			
	0.9	3285	1441	4058	0.58%	-11.17%	-3.84%
	0.8	3302	1265	3898	1.08%	-22.07%	-7.64%
	0.7	3310	1097	3739	1.34%	-32.39%	-11.42%
High Embankment							
Theta	1	3405	1585	4413			
	0.9	3408	1423	4253	0.09%	-10.27%	-3.62%
	0.8	3411	1260	4094	0.17%	-20.51%	-7.23%
	0.7	3412	1100	3935	0.21%	-30.63%	-10.84%

Model Parameter Values: Alpha=20, Beta=0.8, Yield=1.

*All returns are in 1995 Taka.

Table A5: Mean Returns under Different Parameter Values – Yield (μ)

		Mean Returns (Million Taka*)			Percent Change from Base Model		
		Agriculture	Fisheries	Net Returns	Agriculture	Fisheries	Net Returns
Base Model (No Embankment)							
Yield	1.0	3258	1677	4935			
Low Embankment							
Yield	1.0	3257	1654	4253	-0.04%	-1.37%	-13.82%
	0.9	3287	1395	4024	0.88%	-16.83%	-18.47%
	0.8	3305	1151	3798	1.43%	-31.39%	-23.05%
	0.5	3312	471	3125	1.64%	-71.91%	-36.68%
Medium Embankment							
Yield	1.0	3266	1623	4220	0.24%	-3.25%	-14.49%
	0.9	3293	1371	3995	1.05%	-18.26%	-19.05%
	0.8	3309	1132	3773	1.54%	-32.49%	-23.56%
	0.5	3315	464	3110	1.73%	-72.35%	-36.98%
High Embankment							
Yield	1.0	3405	1585	4413	4.49%	-5.47%	-10.58%
	0.9	3409	1359	4191	4.63%	-18.99%	-15.09%
	0.8	3412	1134	3969	4.71%	-32.38%	-19.59%
	0.5	3413	468	3304	4.73%	-72.08%	-33.06%

Model Parameter Values: Alpha=20, Beta=0.8, Theta=1.

*All returns are in 1995 Taka.

Appendix B

This appendix reports on the results of our stochastic dominance analysis. Stochastic dominance analysis allows us to identify scenarios that dominate or rank over others on economic grounds. As presented earlier, the floodplain management model is run one hundred times for each management scenario, based on one hundred years of simulated flood hydrographs. The resulting net returns and standard deviations provide the basis for stochastic dominance analysis. Stochastic dominance analysis involves pair-wise comparisons of cumulative probability distribution functions (CDF). In our case, we would compare the CDFs of net returns for the different management strategies. First-degree stochastic dominance (FSD) is the simplest and most widely applicable efficiency criterion (Johnson and Cramb, 1996). The basic assumption for FSD is that marginal utility is always positive, that is, the decision-maker always prefers more to less. For FSD, the CDF of the dominant strategy lies entirely to the right of all other alternatives. In cases where the CDFs are completely separated, choosing the dominant strategy using FSD is simple. If we allow for decreasing marginal utility, then the second-order stochastic dominance (SSD) rule must be applied. An SSD strategy discriminates only when the CDFs of the relevant strategies cross each other. Thus, SSD rules often fail to order distributions.

With the results presents earlier, we derived the CDFs of net returns for the alternate management scenarios. The CDF of net returns from the base FMM lies clearly to the right of the CDFs of the other models. Thus the base model dominates over the other models by the FSD rule. The CDFs of the low, medium, and high embankment models do not cross but are tangent to each other at different points. Thus, we cannot conclusively use the SSD rule to rank the three flood control strategies. The mean and standard deviation of net returns and the degree of stochastic dominance of each management strategy are presented in Table B1.

Table B1: Returns under Alternate Management Scenarios

Management Scenario	Net Returns (Million Taka*)		Degree of Stochastic Dominance
	Mean	Std. Dev	
Floodplain Management Model			
Base - No Embankment	4935.40	221.36	FSD over all other scenarios
Low Embankment	4253.34	217.33	FSD over Medium Embankment; FSD by Base Model
Medium Embankment	4220.48	225.80	FSD by Base Model
High Embankment	4413.02	252.50	FSD by Base Model
Traditional Planning Model			
Base - No Embankment	3313.31	236.15	FSD over 'other scenarios
Low Embankment	2654.09	238.18	FSD over Medium Embankment; FSD by Base Model
Medium Embankment	2646.49	249.64	FSD by Base Model
High Embankment	2835.52	284.01	FSD by Base Model

Model Parameter Values: Alpha=20, Beta=0.8, Theta=1, Yield=1.

*All returns are in 1995 Taka.