AN INTEGRATED APPROACH FOR THE IMPROVEMENT OF FLOOD CONTROL AND DRAINAGE SCHEMES IN THE COASTAL BELT OF BANGLADESH

An Integrated Approach for the Improvement of Flood Control and Drainage Schemes in the Coastal Belt of Bangladesh

DISSERTATION
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SUMMARY

General

Bangladesh is a country of limited resources. The present population is 130 million, having an area of 147,570 km^2. The current population density of 849 people per km^2 is already the highest of any nation other than the tiny city-states. The country is basically a delta formed by the alluvial deposits of three mighty rivers: the Ganges, the Brahmaputra and the Meghna, it has a complex river network of about 230 rivers occupying about 6% of the area. An important feature of the rivers is that 57 are cross boundary, coming from India and Myanmar. These river systems drain a catchment of about 1.72 million km^2, out of which only 7% is located in Bangladesh. Rests 93% of the catchment situated outside in China, India, Nepal, Bhutan and Myanmar. Bangladesh has been suffering from the twin problem of 'floods and droughts' for centuries.

Initially the Zamindars constructed low dikes and wooden box sluices and maintained them for protection against saline water intrusion and floods. Unofficially the Zamindars have continued this maintenance job even though they were relieved from that duty when the British ruler abolished the Zamindary system. In absence of Zamindar's initiative, the local farmers often started to make bunds themselves, which were technically poor and insufficient. After taking over the works by the Government more attention was given to the construction of polders. Lack of technical know how and financial constraints hampered the polderisation. Polder construction has increased the scale of production and introduced hopes for further development.

Large-scale land and water development schemes began in the early 1950s. At that time, after several years of studies, a team of United Nations (UN) experts proposed the Ganges-Kobadak Project lying in the greater districts of Kushtia, Jessore and Khulna. After the country had suffered from unprecedented floods in 1954 and 1955, a flood commission was constituted by the Government to look into the problems and to advise on remedial measures. Subsequently, they obtained the services of a UN Technical Assistance Mission in 1956, a team of experts on water resources management, known as the Krug Mission. This Mission submitted the 'Krug Mission report' in 1957 after a detailed review of the gigantic problems associated with the flooding. Based on the recommendations of the Krug Mission, the East Pakistan Water and Power Development Authority (EPWAPDA) was created in 1959 for the unified and co-ordinated development of the water and power resources in the present Bangladesh. This authority, with the help of the International Engineering Company Inc. (IECO), prepared a Master Plan for water resources development in 1964. This plan marked the beginning towards the formulation of an integrated plan for flood control and development of the water resources of the country. In the Master Plan the limited available hydrological data were presented and recommended actions were emphasising on systematic and scientific hydrological data collection and processing.

The Master Plan included a portfolio of 58 land and water development projects including 3 barrages on major rivers for implementation spread over 20 years, beginning in 1965. These projects envisaged flood protection for 5.8 million ha of land. Not all the identified projects were taken up for implementation due to lack of

funds. Irrigation within the flood-protected areas was foreseen, but emphasis was on flood control through a system of dykes and polders as in those days higher flood control through major water control schemes was seen as the key to increase agricultural production. Three alternative options were proposed:
- flood embankments with gravity drainage;
- flood embankments with tidal sluice drainage;
- flood embankments with pump drainage.

The Coastal Embankment Project was conceived and initiated by the then East Pakistan Water and Power Development Authority in the early sixties. Subsequently, it was proposed in 1967 that the Coastal Embankment Project be divided into two phases and that the first be expedited as part of the Grow More Food programme. Thus, the first phase was approved in April 1968. This phase consisted of 92 polders with about 4,022 km of embankments and 780 drainage sluices. The gross polder area to be protected under phase-I was estimated to be slightly more than one million ha. Phase-I was completed in June 1971. Polders under phase-II were classified as deferred in the revised programme and final project evaluation study. Phase-II included three categories of land areas such as:
- relatively non-saline areas;
- off-shore islands which were so far unsuitable due to erosion and sediment deposition;
- partially reclaimed and unreclaimed areas resulting from the construction of the Meghna Cross-Dam.

After the independence of Bangladesh in December 1971, the East Pakistan Water and Power Development Authority was bifurcated into two separate bodies, leading to the creation of the Bangladesh Water Development Board (BWDB) and the Bangladesh Power Development Board (BPDB). This was done with a view to undertake expanded water and power development programmes and speed up the execution of projects.

The emphasis on large scale works for high level flood control was dropped following the World Bank's Land and Water Resources Sector Study of 1972. Instead, the development of minor irrigation through low lift pumps (LLP) and tube wells, to some extent supported by complementary low cost Flood Control and Drainage (FCD) projects, was advocated.

In 1974 Bangladesh experienced a devastating flood. Considering the damage of that flood the Government realized the need for quick implementable FCD projects. FCD schemes are located in the floodplains of the rivers, or they are coastal polders. Embankments along the periphery provide protection against river, or sea floods, or against salt-water intrusion. Where necessary, hydraulic structures are placed in the embankments to drain khals (natural channels which connect the low-lying areas and the rivers). Many inland FCD schemes have field depressions that contain water during most, or all of the year, called beels. They are often connected to rivers through a network of khals or man-made canals and can only be drained when river levels permit. In most FCD schemes there are nowadays three distinct cropping seasons, namely: Kharif-I, Kharif-II and Rabi. From an agricultural perspective the FCD schemes are designed to:
- protect standing Aus against early river floods;

- expand the area under Aman by excluding flood waters from the schemes;
- retain water in the scheme during the post-monsoon period.

By taking into account the various characteristics of FCD schemes - such as the types of infrastructure, the topography, the main water management challenges and the typical conflicts - the water management schemes can be classified in:
- Hoar schemes;
- Chittagong polders;
- Khulna polders;
- Beel schemes;
- Floodplain schemes.

The multitude of water management options in FCD schemes makes water management in these schemes quite complex. Internationally, much has been written on improving water management in irrigation systems. This has resulted in the development of appropriate management models for irrigation systems. For FCD schemes this has not been the case and water management in FCD schemes remains much behind the management of irrigation systems.

During the past decades huge investments have been made in flood protection, drainage and irrigation systems to reclaim and develop many polder areas. In these areas a careful water management is required to get optimal results from the investments in the physical infrastructure and enable the farmers to have a reasonable living. However, in many instances the actual water management in the FCD schemes has been below expectation, resulting in lower yields than were envisaged during the feasibility, design and construction stages.

Past experiences in the water sector development showed the necessity of a good water policy in Bangladesh. After detailed discussions the Government of Bangladesh finalised the National Water Policy in 1999.

Flood protection schemes bring about overall improvements, through the reduction of flood depth to ensure secure environments for living as well as for agriculture. However, they can also bring about drastic changes in the natural water regime, which may result in an imbalance in aquatic environments and ecosystems. For example, structural interventions disrupt the free flowing environment of the floodplains. Moreover, continued congestion or stagnation can prevent natural flushing and lead to the spreading of water-borne diseases that may threaten public health. Total elimination of floodwater can also severely impact groundwater recharge. FCD schemes generally cause negative impacts on capture fisheries which results from reduction of regularly inundated floodplains and beels and the blockage of past fish migration routes into the scheme area. In addition pesticides used in Rice lands may destroy fish species. Many fishermen have lost their livelihood or were diverted to river fisheries, leading to over-fishing in those areas, which are also adversely affected by the change in the fish migration potential. Flood control of FCD schemes has also provided opportunities for culture fisheries.

The land elevation within a polder is not all over the same. That is why conflicts arise on water management. The stakeholders in a polder do not have the same interests. So, conflicts are found in almost all FCD schemes. The operation and maintenance of the FCD schemes is not upto the mark. A lot of effort is still needed to improve this situation.

Set up of the Study

This study describes the historical background of the development of water management in Bangladesh and the present status of the FCD schemes. The present land use situation and hydrological conditions with respect to the FCD schemes is presented. A review of coastal lowland development in South East Asia is given. A performance analysis of the different FCD schemes and the water sector in Bangladesh has been executed, which has been used as a basis to formulate a suitable approach for the improvement of the FCD schemes in the coastal belt of Bangladesh.

Most of the schemes that were implemented to increase the agricultural production are not performing as was expected. Injudicious planning of roads, canals and other infrastructure blocking the natural drainage ways cause many of the drainage problems, especially in low lying irrigation and drainage schemes. There is considerable scope for preventing and alleviating drainage problems by more integrated planning and water management. Many of the FCD schemes have been built quite a long time ago, consequently there is a need for improvement of the water management practices and to a certain extent modernisation to meet the requirements of integrated water management. The situation and hydrological conditions of the implemented schemes have changed with time. The user's demands are changing due to changed situations. The performance of the schemes is also reducing. The operation and maintenance of the schemes has been neglected substantially by the Government and the users. Involvement of the farmers and their opinion were not taken as an important aspect in project planning. New development possibilities in the water sector are reducing but not yet finished. In future project planning should also take into account the related aspects of water development and try to minimise possible negative environmental consequences.

In light of the above there was an urgent need to develop an appropriate approach for the improvement of the performance of FCD schemes, among others, by involving local people, especially in operation and maintenance, as well as in the preparation of improvement of schemes. It was also necessary to investigate whether these FCD schemes are operated and maintained as designed and improvements in the designs can be made.

Thus, the general objective of the research was to develop an approach for sustainable development and water management of FCD schemes in Bangladesh. Based on this, effective techniques, tools and institutional arrangements were developed to support the implementation of the concept.

Water Management Considerations

Soil conditions and water management practices, based on the relationship between hydrology and topography, mainly determine the agricultural development possibilities in the coastal area. This relationship is referred to as hydro-topography. Hydro-topography can be defined as the field elevation in relation to high or low river water levels at the intake point and in the field. Hydro-topography is expressed by the irrigation possibilities during the dry season and drainage possibilities during the wet season. During high tides, water can flow into the polders, and during low tides water can be drained to the rivers. The actual hydro-topographical conditions of a polder depend on tidal river water levels, gradually changing field levels and topography. The hydro-topography is not uniform and constant in time and space. For example, it varies with micro-level variations of the topography. However, the hydro-topographical conditions define the range of agricultural and water management practices available to the farmers. The following hydro-topographical categories were defined by Suryadi for the tidal lowlands in Indonesia:

A: tidal irrigated areas, in both the wet and the dry season;
B: tidal irrigated areas, only in the wet season;
C: areas just above ($\leq$ 0.50 m) the average high water level in the wet season;
D: high areas, water levels independent from tidal influence.

The researcher introduced these hydro-topographical categories based on the prevailing conditions in polder 43/2A.

Water management needs are different for each type of land use and require different interventions. Rice crops call for inundated fields while Rabi crops need certain soil moisture in the land. The canals require such a water level that adequate conditions for irrigation and drainage are created and where applicable proper conditions for fisheries and domestic use of water. The focus of water management in the polder areas must therefore be on water level control and on preventing stagnant water conditions. In coastal lands there are two options that are drainage and flushing to improve adverse water management conditions. In order to achieve this hydraulic structures will have to be operated to store water inside the polder when it is required due to dry conditions, which means that gates will be open during high tide and remain closed during low tide, or to discharge water from the polder when this is required due to wet conditions, which means that gates will be closed during high tide and open during low tide.

The drainage condition plays an important role in defining agricultural and water management practices available to the farmers. The excess wet season rains are normally drained through the hydraulic structures of the FCD schemes. Lowering of the water level by drainage should be realized in such a way that fish culture and environmental issues are also properly taken into account. The drainage criteria of the FCD schemes should be developed on the basis of the inundation depth that may occur during heavy rains in the wet season. A water depth greater than 0.3 m for three days or more is not suitable for any Rice crop. So lowering of the water level by operating the hydraulic structures must depend on achieving the 0.3 m depth within three days.

An effective and sustainable water management scheme requires an institutional framework, which can ensure the democratic representation of the various water users and their interests. The set-up of the framework should be such that it can accommodate various interests of the different users. Efforts should be made to create opportunities for various users to participate in different stages of the scheme cycle. To achieve this a two tier institutional set up was developed. Suggested planning steps developed in this study for the improvement of water management in FCD areas are:

Step 1: Investigation of the stakeholders interest for improvement and willingness to contribute to the improvement and the resulting operation and maintenance;

Step 2: Assessment of the existing water management situation;
Step 3: Posting of a skilled guidance team in the scheme area;
Step 4: Intensive meetings with the stakeholders and interest groups regarding alternative water management options and their related benefits and problems;
Step 5: Establishment of a water management association and water management groups of the stakeholders;
Step 6: Development of a preliminary operation and maintenance plan. Provisional agreement with the concerned parties on the water management strategy, the required operation and maintenance and the role and contribution of each party;
Step 7: Identification of the required repairs and the share of each party in the repair;
Step 8: Repair of hydraulic structures (gates) and embankment;
Step 9: Start of operation and maintenance as per provisionally agreed water management strategy and based on the agreed roles, responsibilities and shares;
Step 10: Operation of the hydraulic structures and maintenance of the system at least for one wet season and one dry season. Discussion on the positive and negative consequences of the operation with the stakeholders and revision of it where agreed to be required;
Step 11: Finalization operation and maintenance plan by the water management association and water management groups;
Step 12: Transfer of the operation and maintenance responsibility and the ownership of the agreed parts of the system from Agency to the Association.
Step 13: Operation and maintenance by the Water Management Association and Water Management Groups.

With the changing requirements of the people flushing for irrigation becomes one of the major demands. The people in this area are still in favour of the flushing condition (gravity flow) they had before the schemes were constructed. But after the reclamation flushing possibilities have been reduced due to less openings (hydraulic structures) compared to the no scheme situation. The flushing option involves improvement of freshwater supply into the area. Flushing through hydraulic structures in the lower areas and low lift pumping, or traditional lifting, or inlet of water for irrigation in the higher areas. Flushing is mainly required in the month of April (pre wet season) for land preparation and transplantation of T. Aus. Hydraulic structure operation needs proper attention during flushing regarding inland fisheries in the area. Fish normally enters into the floodplain in this period and remains until it is grown enough. Flushing is also required in the dry season, subject to the tidal level fluctuation in the main river. If there is a dry spell in the wet season, flushing sometimes is important too. For basin irrigation for Rice small bunds are required in the field to hold water upto a certain depth. But no field bunds are practiced in this region of Bangladesh. Water from rain and irrigation cannot be stored in the field and may cause problems in the low-lying areas of the schemes.

The Pilot Area Polder 43/2A

Polder 43/2A was chosen for the case study of the researcher. The polder is located under Patuakhali sadar thana in Patuakhali district. The gross area is 5,100 ha and the net cultivable area 3,500 ha. The polder is surrounded by the Payra (Bighai) river

West to North and the Gulisa Khali river on East and South. The area consists of 19 administrative wards in three unions namely Bora Bighai, Chota Bighai and Matherbunia. The area lies in moderately flat land with a ground elevation varying from 1.10 to 2.10 m+PWD (Public Works Department datum). The land area surrounding the periphery is relatively high and the middle is relatively low forming a saucer shape.

Before reclamation tidal water entered into the area through the khals. During the wet season, heavy rainfall together with tidal flows created severe flooding and drainage congestion in the area. This flooding and drainage congestion caused recurring damage to the crops, homestead and property resulting in huge losses to the people. To overcome the situation of continuous flooding and drainage congestion, the area was included under the proposal of the Coastal Embankment Project phase II (as 43/2). Due to the huge money requirement and non-interest of the donors the said project did not start in time. Later the polder (43/2) has been sub-divided into seven small polders, 43/2A is one of them. It was completed in 1988. The original objective of the reclamation was to increase food production by protection against floods, preventing of salinity intrusion and improving drainage. The whole area is surrounded by 40 km of peripheral embankment. Six drainage and surface drainage sluices (DS/SDS) at six connecting khals, out of sixteen, have been constructed. The other khals were closed completely by the peripheral embankment and closures.

The people of the area in general admit that their livelihoods have changed significantly since the completion of the polder. The general feeling is that the overall impact of the interventions has been positive. Some negative impacts on the livelihoods of the people are also present.

Both rainfed and irrigated agriculture are practised in the area. Some critical moments for Rice cultivation that were identified by the researcher are:

- for T. Aus (LV/HYV):
  - seedbed preparation and transplantation are not possible if insufficient rainfall occurs in April and May;
  - yields reduce when there is insufficient rainfall during the vegetative growth stage in the months of May and June;
  - sometimes the crops are severely damaged in the matured or ripening stage when there is excessive rainfall in the months of July and August;
- for T. Aman (LV/HYV):
  - it can not be cultivated in time in some years due to drainage congestion caused by excessive rainfall in the months of July and August;
  - it is sometimes damaged in the matured, or flowering stages when there is no, or limited rainfall in the month of October.

After analysing the overall water management situation in Bangladesh and examining the pilot polder 43/2A (model simulation) an approach has been developed to improve the water management in the FCD schemes. In developing this approach the needs of agriculture, fisheries, navigation and environment have been considered in an integrated way.

Modeling and Simulation

The polder area is crisscrossed by a large number of canals, few of them are very big and the rest is smaller in size (length and width). Considering the environmental issues, it was preferred that the canals within the area would remain almost full. While hydraulic gradients in the polder are marginal, for the hydrodynamic network schematization the polder area has been simplified to a reservoir type. The cross-sections of the arbitrary sections were taken from the contourwise area, which was determined with the Geographic Information System IDRISI Area module.

Two situations namely flushing and drainage have been developed for the hydrodynamic simulation. The flushing situation refers to the storing of water inside the polder area, which is used for irrigation. The drainage or flood situation has been investigated to determine the preferred water levels during the wet season and the drainage capacity to remove surplus water from heavy rain. The latter is required to determine the damage under the present cropping pattern and to develop a possible strategy for improvement. For both cases only the existing hydraulic structures and the embankment have been considered in the simulations.

Based on the rainfall depth duration frequency curves for the Patuakhali station the 3-day consecutive rainfall was determined and 1:5 or 1:10 year return period values were chosen for the water balance simulation with the hydrodynamic model DUFLOW to test the existing drainage capacity of the hydraulic structures.

The storing possibilities in the dry season (April-May) completely depend upon the tidal water levels in the river. Data of the station Mirjagonj show that water in the dry season can be stored only during spring tide. Normally two spring tide situations will be available in a month. Based on the collected data a sinusoidal curve was developed as a boundary condition. As per requirement of the farmers and considering the existing problems, the simulation was done month wise to find out the maximum possible water level that can be attained in the dry season, especially in April. During the wet season the simulation was done for the month of August while this is the critical month from the drainage point of view. The highest spring tidal values occur in this month. So results for this month will be more representative than for other months. Also the drainage capacity of the hydraulic structures could be verified.

The simulations show the benefits of gate operation in the present condition. The result also shows the present drainage congestion level inside the polder area if there is no proper gate operation. The results for two probable conditions (1:5 and 1:10 year return period), are on the safe side compared to the normal situation. The maximum dry season (April) water level could be attained after 14 days of operation. For storing there will be a gap of 7 to 8 days in the gate operation due to the available (spring) tidal water levels in the river.

Identification of hydro-topographical categories is the first step in delineating land suitability zones. In order to answer the question what kind of agricultural development would be feasible in different parts of the area, several factors must be taken into account i.e. the salinity intrusion, soil properties, the tidal range, tidal irrigation depth and level and the drainage level. From agricultural point of view the salinity level in this area was found safe for most of the cases. In order to develop an appropriate water management strategy, land suitability zoning should be investigated which requires a systematic and comprehensive analysis.

From the hydro-topographical map a flushing (irrigation) and drainage depth map has been produced. Based on the developed criteria and water management strategy a land suitability analysis has been performed. This analysis was done for the present and potential conditions. Finally a land suitability zoning map was produced showing the suitability for different cultivation, as well as where improvement is needed in the present situation. Based on the land suitability zoning map future planning can be carried out. The change in area of different land suitability could be calculated.

Water Management Strategy

As per requirement in the field and considering the results of the hydrodynamic simulations, a new water management strategy has been developed for the whole year as shown in Figure I. The strategy has been prepared to match the normal practice of the farmers, to support the present cropping pattern and also to maintain the best environment. To develop the strategy several meetings and discussions were held with the farmers of the area and different professional groups.

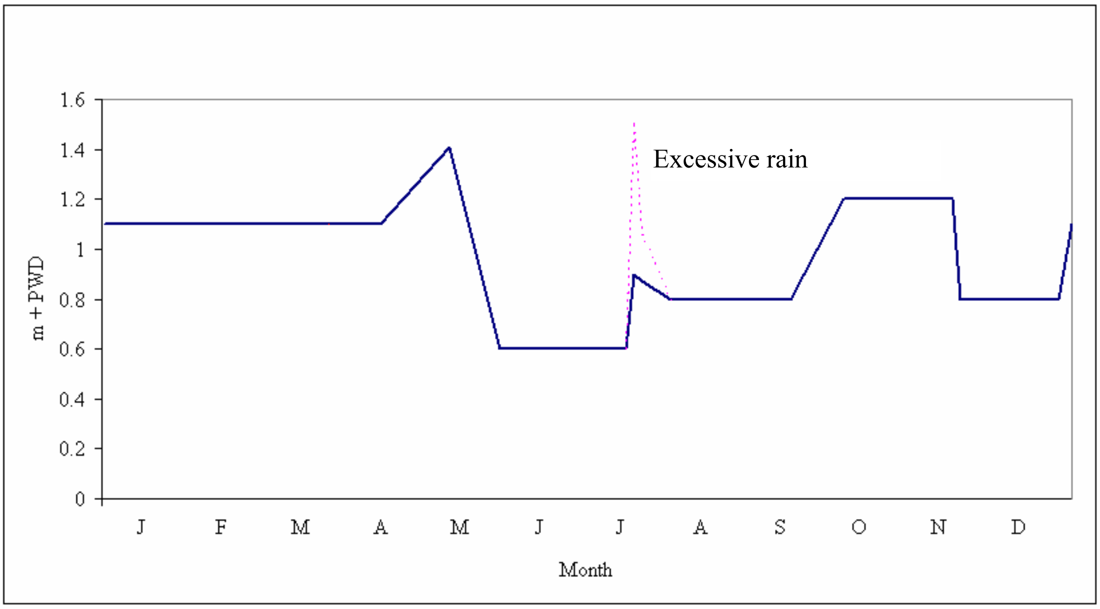

Figure I Preferred water level for polder 43/2A

The water management strategy is based on the following considerations. At the beginning of the year there will be a continuous water level of 1.10 m+PWD. This level has to be maintained until middle of the April. This level will be appropriate for sufficient soil moisture and water level in the polder for Rabi and Boro crops. This level is also chosen because of domestic uses of water within the area and fish culture. If the outside water level permits the stored water can be cleaned once during this period for quality reasons. During the period from mid April – until mid May water will be stored to the maximum level (1.40 m+PWD) within 14 days according to the outside river level for Aus transplantation. By considering the field requirements that level could be lowered within 3 - 7 days as per convenience of the farmers and transplanting time of the next crop. This lowered level would have to be maintained, based on internal navigation and fish culture considerations. After that Aus can be grown in rainfed conditions. Thereafter the farmers can be ready to operate the hydraulic structure further to reduce the water level during heavy rains in the polder area when river water levels remain relatively high during low tide. Aman crops need flood protection, which they already have by the embankment. Sometimes Aman needs supplementary irrigation which is also possible by this strategy. At maturity stage of Aman the water level inside the polder can be raised again to provide sufficient soil moisture in the land where the farmers will grow Rabi crops. During the harvesting time of Aman the water level can be lowered again for a safe harvesting.

The water levels within the polder area and surrounding rivers were measured at different times during the study. The researcher took initiative to repair all the gates of the hydraulic structures for better water management practices and to show the consequences to the farmers, but due to lack of money this was not possible. Therefore he chose two hydraulic structures, which needed minor repairs. The researcher repaired the hydraulic structure gates and the connecting canal network was re-excavated by the Union Parishad. The measurements were carried out in the selected part of the polder for the year 2001. Several temporary gauges were installed for that purpose. The drainage and flushing conditions of the polder area were measured for a particular year. The field measurements were carried out in the dry and wet seasons of the year 1998 - 1999. During the fieldwork of the researcher, an experiment was carried out to verify the possible water storing capacity of one hydraulic structure. For that purpose the sluice in Kazirhat (3 vents) was selected. From the measurements it could be observed that sufficient flushing capacity could be realised to prevent water shortage during the dry season.

Several meetings and discussions were held with the users of the area regarding the measured water levels and results of the hydrodynamic simulations and geographical analysis. The newly developed water management strategy was also presented. All possible consequences of the strategy have been presented to the users along with their role in the water management. To verify the model results and realise the changes in water management practices for the area another set of temporary gauges was installed by the researcher in a selected part of the polder.

Not all the observed water levels for 2001 are representative, while the spring tide was extremely high. With this high situation the hydraulic structure operation showed much better results following the operation as described in the new approach. The results might be even better under normal conditions. Water levels could be lower, exactly as the model results show. The simulation results for drainage and flushing were quite representative for the water levels compared to the measured values.

Evaluation

The scope for new land and water development schemes is decreasing day by day all over the world mainly because of financial constraints and environmental considerations. The situation in Bangladesh is the same. Over the period of time huge investments have already been made in this sector. But the returns from the schemes were not satisfactory. So the Government is now trying very hard to improve the present performance of existing schemes, but is still lacking far behind to find suitable approaches addressing the relevant aspects of water management. There were no operational arrangements and at the same time no preferred water levels to achieve maximum benefits from the schemes. Realising that necessity, the researcher has developed a water management strategy to achieve preferred water levels in a polder area by considering the physical possibilities of the schemes, the present practices of the farmers, the interests of the different users, and environmental impacts.

FCD schemes and irrigation systems have to be treated differently. Stakeholders' demand and management requirements are completely different in FCD schemes compared to irrigation systems. A different management strategy is needed for the FCD schemes. Some good examples from the irrigation systems might be taken but not as a whole like was done earlier.

The FCD schemes would preferably be improved, modified and rehabilitated if required, only when the stakeholders agree to take over the responsibility and share the cost of operation and maintenance. The stakeholders will have to be involved right from the beginning of the modernization exercise in planning, design and implementation (if any) of the improvement measures and have to commit themselves for their future share in the operation and maintenance activities. Involvement of the people in operation and maintenance of the FCD schemes, the crucial requirement for progress in this context also requires a strong political will of the Government. After showing the results of the approach as developed in this study, the schemes can be handed over to stakeholders for operation and maintenance.

It should be realized that the hydro-topographical (drainability and tidal flushing) conditions of areas are dynamic and change due to the natural phenomena or man made measures (sea level rise, land subsidence, obstruction in the drainage and flushing network). Land suitability zoning shows the possibility of future development for present and potential conditions. This analysis might be applied to other FCD areas to resolve water management conflicts of people from different land classification and profession. The potential conditions might need new interventions.

The proposed water management strategy is expected to have a positive impact on the life and living of the people. This strategy is designed to achieve the maintaining of preferred water levels during the year which will give new benefits that were not thought of earlier. The proposed preferred water levels will have to be explained to the farmers at the beginning of the cropping season. Only water management in the FCD schemes will not assure equal distribution of benefits to the categories of people in the area, there are other socio-economic parameters which would have to be considered for that purpose.

The water management strategy is not a fixed one, it can be modified or changed as per requirement of the farmers in the polder area. The preferred water levels as developed in this study are based on a statistical analysis. Users might find little deviation while following the strategy. For sure the water levels would be within allowable limits. For adapting this newly developed preferred water levels time has to be allowed, because integrated water management involving local people needs time to cope.

As the polder is aimed at integrated water management, the present land utilisation will most probably increase resulting in an incremental Rice crop production, which is estimated at 6,200 ton/year. This will increase the number of farm families who will get farm benefits from the polder. The employment opportunities, especially the farm labour utilisation, may increase to 260,000 man-days by an intensive programme for agriculture. The proposed strategy is expected to further improve the fish production by 140 ton/year and to increase the fish consumption of the people.

1 INTRODUCTION

1.1 GENERAL

Agriculture is the largest sector of the Bangladesh economy, the largest source of employment and the largest water user. Water management in Bangladesh involves a wide range of interventions in the country's land and water regime. But the two main categories that can be distinguished are irrigation and flood control and drainage (FCD) during dry and wet seasons. Within each category there are differences in scale, ownership, and the nature and quality of service.

During the past decades huge investments have been made in flood protection, drainage and irrigation schemes to reclaim and develop many polder areas. In these areas a careful water management is required to get optimal results from the investments in the physical infrastructure and enable the farmers to have a reasonable living. However, in many instances the actual water management in the FCD schemes of coastal polders has been below expectation, resulting in lower yields than were envisaged during the feasibility, design and construction stages.

Water management in FCD schemes is complex and fundamentally different from traditional water management in irrigation systems. A distinct characteristic of water management in FCD schemes is that there are many different stakeholders, each with different, often-conflicting water management demands. The stakeholders occupation or the location of the land owns determine his level of interest in water control. So, participation of stakeholders in the context of FCD schemes in Bangladesh is crucial for the planning and design of sustainable water management schemes.

Polder areas are either water logged, or temporarily or permanently covered with a water layer. In this study, the domain will be limited to the areas where the incoming water originates from rainfall and or the tidal zone of rivers. Polders, which are close to the sea and influenced by the vertical tides, rank amongst the world's best agricultural resources. Development of lowlands is actively pursued in many countries all over the world as a way of relieving land pressure (Suryadi, 1996). The potential of any tidal coastal land for development should be analyzed carefully. This is not an easy task because it covers various disciplines, such as: water management, agronomy, engineering, ecology, economy and sociology. For the future development, Segeren (1983) and Verhoeven (1983) stated that one of the possible options is development in sparsely populated areas within densely populated regions. Most of the coastal land areas in the South East Asian region belong to this category. In the future, polder development will likely be taken up again due to the increase of the world population and the increase of food requirement (Volker, 1982).

In this study an integrated approach to land, water quality (salinity) and water quantity (drainage and flushing) has been developed, which can improve the conditions for agriculture and fisheries in the polder areas of Bangladesh. Here, water management includes planning, design, operation and maintenance of FCD schemes and covers technical and non-technical aspects (socio-economy and institutional) which are relevant for the development of the reclaimed areas.

In order to formulate suitable water management strategies for this type of areas research has been conducted in a pilot polder area, the polder 43/2A. In the framework of this research water management strategies and practices have been developed in consultation with the farmers. This has also resulted in recommendations for land suitability zoning, linked to topography, soil and water management conditions. The effects of this management on crop yield and fish production have been assessed.

1.2 OBJECTIVES OF THE STUDY

In light of the above there was an urgent need to develop an appropriate methodology for the improvement of the performance of FCD schemes, among others, by involving local people, especially in operation and maintenance, as well as in the preparation of improvement measures. It was also necessary to investigate whether these FCD schemes are operated as designed and whether improvements in the design concept can be made.

Thus, the general objective of the research was to develop an approach for sustainable development and management of FCD schemes in Bangladesh. Based on this, effective techniques, tools and institutional arrangements were developed to support the implementation of the concept.

To realize the general objectives some specific objective came into consideration which were:

- to develop a methodology, based on a participatory approach for water management in the FCD schemes in Bangladesh, that contributes to sustainability (focus on all stages of the schemes);
- to perform impact assessments for different aspects of the FCD schemes;
- to develop a computer model to create a better insight in the flushing, flooding and drainage conditions of a certain area as well as their interaction and to attain a uniform approach;
- to evaluate the consequences of the present situation of completed FCD schemes under the changed geomorphological situation of the rivers and the floodplain for water management in the polder areas.

1.3 STRUCTURE OF THE THESIS

This thesis starts with a general introduction on the FCD schemes in Bangladesh and a description of the objectives of the study. In Chapter 2, the historical background of the development of water management in Bangladesh will be described. A few relevant FCD schemes will be described in this Chapter too. In Chapter 3, the present land use situation and hydrological conditions of Bangladesh with respect to the FCD schemes will be given. A review of coastal lowland development scenarios in South East Asia will be presented in Chapter 4. A performance analysis of the different FCD schemes in Bangladesh will be given in Chapter 5. In Chapter 6 and 7, the present problems and practices of polder 43/2A along with an overview and evaluation will be given in order formulate a suitable approach for the improvement of the water management in the polder. An approach and methodology will be formulated in

Chapter 8 with the support of the one dimensional hydrodynamic model (DUFLOW) and GIS (IDRISI) simulations and considering the relevant aspects of water management: sociology, agronomy, environment, agriculture, economy and fisheries. The model development and application to the polder area and formulation of a suitable water management strategy will be given in Chapter 9. The field measurements and verification of the model results will also be shown in this Chapter. In Chapter 10, the possible agricultural, social and environmental impacts of the proposed strategy will be described. The evaluation of this study will be described in Chapter 11.

2 HISTORICAL BACKGROUND

The history of irrigation, canal networks, pond digging and water management in Bengal can be divided in four periods, being the Ancient Period, the Medieval Period, the Colonial Period and the Modern Period. A summary of the historical development of the water development in Bangladesh is presented in Table 2.1, and will described in more detail in the next section. The description is mainly based on the water management related part of the history.

Table 2.1 Summary of historical development activities

<table>
<tr><th colspan="2">Name of the Periods</th><th>Duration</th><th>Main activities</th></tr>
<tr><td colspan="2">Ancient Period</td><td>Upto 1200</td><td>Overflow irrigation</td></tr>
<tr><td rowspan="3">Medieval Period</td><td>Sultani Period</td><td rowspan="3">1200 - 1757</td><td>Construction of embankments, roads, tanks</td></tr>
<tr><td>Turkish Period</td><td>Construction of embankments, roads, tanks</td></tr>
<tr><td>Mughals Period</td><td>Construction of planned canals and embankments, river dredging, development of road link and river network</td></tr>
<tr><td colspan="2">Colonial Period</td><td>1757 - 1947</td><td>Embankment, reservoirs and tanks gradually declined due to lack of maintenance</td></tr>
<tr><td colspan="2">Modern Period</td><td>1947 to date</td><td>Formation of East Pakistan Water and Power Development Authority in 1959
Master plan for the country in 1964
Large scale Coastal Embankment Project in 1968
Creation of Bangladesh Water Development Board in 1972 and starting of small scale FCD schemes
Projects and programme related to this study:
- Early Implementation Project in 1975
- Delta Development Project in 1976
- Land Reclamation Project in 1977
- Beginning of National Water Plan preparation in 1980
- Dhaka City Protection Project in 1989
- System Rehabilitation Project in 1990
- Flood Action Plan in 1990
- Dhaka Integrated Flood Protection Project in 1991
- Beginning of National Water Management Plan preparation in 1998
- Finalization of National Water Policy in 1999</td></tr>
</table>

2.1 ANCIENT PERIOD

Irrigation in Bengal in the early stages was better than in other parts of the world. About 3,000 years ago the rulers of Bengal had introduced a system called ‘overflow irrigation’. This system was practised till 1200. For the purpose of the study of irrigation this period may be termed as the Ancient Period (Willcocks, 1930). The distinguishing features of overflow irrigation were:

- canals were broad and shallow carrying the crest waters of the rivers floods, rich in clay and free from coarse sand;
- canals were long and continuous, fairly parallel to each other, and at the right spacing for the purpose of irrigation;
- irrigation was performed by cuts in the banks of the canals, which were closed when the flood was over.

The ancient ruler's representative, after cutting the bank of the canal in a planned way, used to hand over the responsibility of distribution of the water to the local boards. The boards working through the peasantry used to ensure that the water reached every field. The management of overflow irrigation was very systematic and planned. Figure 2.1 illustrates the management of irrigation during the Ancient Period.

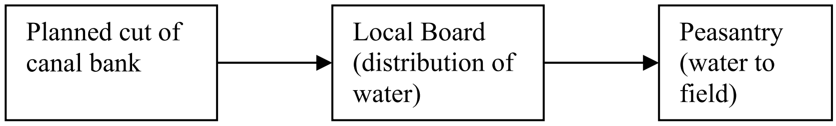

Figure 2.1 Management of overflow irrigation during the Ancient Period (after Bangladesh National Committee of the International Commission on Irrigation and Drainage (ICID), 1992)

2.2 MEDIEVAL PERIOD

The Medieval Period (1200 – 1757) may be distinguished into three sub-periods: Sultani Period, Turkish Period and Mughals Period. During this period the irrigation practice improved from overflow to tank irrigation. Flood control through the construction of embankments and improvement of drainage facilities began during that time. The road communication was also developed substantially. This continued till the end of the Mughal Empire in 1757 (Bangladesh National Committee of the International Commission on Irrigation and Drainage, 1992).

Sultani and Turkish rulers considered tank construction and their maintenance as the most suitable method for managing flood and irrigation. Tanks were filled with water during the rainy season and supplied water for irrigation during the dry season. In addition the banks of the tanks were used for village settlement above flood level. The Mughal rulers maintained the systems that were made by the previous rulers. They added the concept of construction of additional canals along the river channels (for better irrigation, drainage and navigation) and embankments besides the rivers. The Mughals also added river-dredging works.

The Mughals maintained an independent department for looking after embankments, roads, bridges, river dredging, etc. It was called Pulbandi Dafter. The functions of the Pulbandi Dafter were delegated to the local Zamindars (local level rulers) who received the budgetary allocation from the Government in the form of a deduction from land revenue collected by them from the paraganas (2nd units of a province) under their possession. Thus the Zamindars had to take action to protect their crop fields against flooding during the rainy season. New interventions, including maintenance works, were the prime responsibility of the Zamindars. The day and night workers at the field level were called astapahari. They worked under the supervision of village officials called gramsaranjami. The gramsaranjami worked under the direction of the village panchayet. All works of flood and irrigation management within the limits of a mouza (unit under a village) were looked after by the village panchayet. Similarly, all works of the same nature within a Zamindari were looked after by the concerned Zamindars. The process ascended upto the supreme Government. The major works were managed by the Pulbandhi Dafter. The hierarchy of flood control, drainage and irrigation management during the Medieval Period is presented in Figure 2.2.

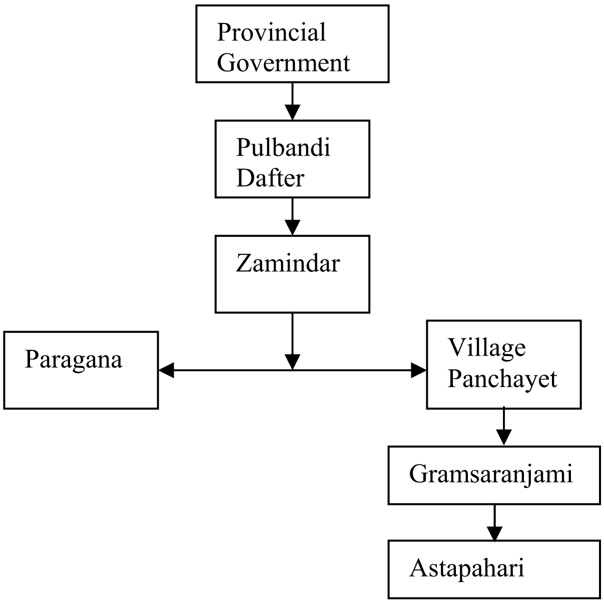

Figure 2.2 Hierarchy of flood control, drainage and irrigation management during the Medieval Period (Bangladesh National Committee of the International Commission on Irrigation and Drainage, 1992)

2.3 COLONIAL PERIOD

The entire period from 1757 to 1947 of the British regime is called the Colonial Period (Bangladesh National Committee of the International Commission on Irrigation and Drainage, 1992). The early Englishmen, who were traders and sailors, had no interest in flood control, drainage and irrigation. Their activities mainly concentrated on the navigation for trade. The development and maintenance of flood control, drainage and road communication networks was suddenly stopped and attention was given to navigation instead of to irrigation.

During the Colonial Period the British ruler abolished the Pulbandi Dafter. Zamindars were relieved of their traditional duties. The state support to the village panchayet was withdrawn. The gramsaranjami was dissolved. As a result the Zamindars and tenants of Central Bengal neglected the clearing of the canals and the repairing of the banks.

Unofficially the local Zamindars continued their maintenance job for a long time even though they were relieved from that duty. When the British ruler abolished the Zamindary system, that unofficial management practice by the Zamindars was officially stopped.

2.4 MODERN PERIOD

The Modern Period started in 1947, the year of independence of Pakistan. Negligence in water management for a long time (200 years) had led to a number of serious problems. The conditions of the embankments, reservoirs and tanks had gradually declined due to lack of maintenance. The depth of rivers was reduced due to siltation and the fact that dredging of chars (sandbars) had not been done properly. The cumulative results were frequent flooding and subsequent crop damage.

2.4.1 Flood Control and Drainage

Bangladesh has suffered from the twin problem of 'floods and droughts' for centuries. Large-scale land and water development schemes began in the early 1950s. At that time after several years of studies, a team of United Nations (UN) experts proposed the Ganges-Kobadak Project, lying in the greater districts of Kushtia, Jessore and Khulna. After the country had suffered from unprecedented floods in two consecutive years 1954 and 1955, a flood commission was constituted in December 1955 by the Government to look into the problems and to advise on remedial measures (East Pakistan Water and Power Development Authority, 1964). Subsequently, the service of a UN Technical Assistance Mission was obtained in 1956, a team of experts on water resources management, known as the Krug Mission. This Mission submitted the 'Krug Mission report' in 1957 after a detailed review of the gigantic problems associated with the floodings (United Nations, 1957). Based on the recommendations of the Krug Mission, the East Pakistan Water and Power Development Authority (EPWAPDA) was created in 1959 for the unified and co-ordinated development of the water and power resources in the present Bangladesh.

In the context of the increased need for agriculture development, in 1961, the East Pakistan Agricultural Development Corporation (EPADC), presently the Bangladesh Agricultural Development Corporation (BADC) was created to supply seed, fertilisers, pumps and other production inputs to farmers.

The East Pakistan Water and Power Development Authority, with the help of the International Engineering Company Inc. (IECO), prepared a Master Plan for water resources development in 1964 (East Pakistan Water and Power Development Authority, 1964). This plan marked the beginning of the formulation of an integrated plan for flood control and development of water resources of the country. The Master Plan organized the limited available hydrological data and recommended emphasis on systematic and scientific hydrological data collection and processing. The Master Plan included a portfolio of 58 land and water development projects including 3 barrages on major rivers for implementation spread over 20 years, beginning in 1965. These projects envisaged flood protection for 5.8 million ha of land. Not all the identified projects were taken up for implementation due to lack of funds. Irrigation within the flood-protected areas was foreseen, but emphasis was on flood control through a system of dykes and polders as in those days higher flood control through major water control schemes was seen as the key to increase agricultural production. Three alternative options were proposed:
- flood embankments with gravity drainage;
- flood embankments with tidal sluice drainage;
- flood embankments with pump drainage.

Polders can be found all over the world, where waterlogged lands or even lakes and estuaries have been reclaimed, mainly for agricultural purposes. Several definitions of polders exist. The most widely used ones are:

- A tract of lowland reclaimed from the sea, or other body of water, by dykes, etc. In the polder, the runoff is controlled by sluicing or pumping and the water table is independent of the water table in the adjacent areas (International Commission on Irrigation and Drainage, 1996);
- A polder is a reclaimed level area, with an originally high groundwater table, that has been isolated from the surrounding hydrological regime and where the water levels (surface and ground water) can be controlled (Volker, 1982);
- A polder is a level area, in its original state subject to high water levels (permanently or seasonally, originating from either ground water or surface water), but which through impoldering is separated from its surrounding hydrological regime in such a way that a certain level of independent control of its water table can be realized (Segeren, 1983).

The term polder has been extensively used in Bangladesh since the sixties to designate the reclaimed bodies of land in the coastal regions. The primary purpose of polderisation was to increase agricultural production and productivity and reduce flood damages by protecting the land from the Bay of Bengal by constructing embankments and drainage sluices. The Coastal Embankment Project was conceived and initiated by the then East Pakistan Water and Power Development Authority in the early sixties (Figure 2.3). Subsequently, it was proposed in 1967 that the Coastal Embankment Project be divided into two phases and that the first phase be expedited as part of the Grow More Food programme. Thus, the first phase was approved in April 1968. This phase consisted of 92 polders with about 4,022 km of embankments and 780 drainage sluices (Talukder, 1991). The main features of phase-I of the Coastal Embankment Project are presented in Table 2.2. The gross polder area to be protected under phase-I was estimated to be 1.01 million ha. Phase-I was completed in June 1971 (Talukder, 1991).

After the independence of Bangladesh in December 1971, the East Pakistan Water and Power Development Authority was bifurcated into two separate bodies, leading to the creation of the Bangladesh Water Development Board (BWDB) and the Bangladesh Power Development Board (BPDB). This was done with a view to undertake expanded water and power development programmes and speed up the execution of projects.

Sea dikes were constructed at locations facing the Bay of Bengal, along the banks of the major or wide rivers, and at other places where high waves could be expected. Interior dikes were provided at more protected locations along major streams or along exposed sections of secondary streams or interior channels. Marginal dikes are located along interior channels where current and wave action is mild. The return period for the design water level was about 20 years. Typical dimensions of three standard types of embankment are given in Table 2.3 and cross sections are given in Appendix A.

Polders under phase-II were classified as deferred in the revised programme and final project evaluation study (East Pakistan Water and Power Development Authority, 1968). Phase-II included three categories of land areas, such as:
- relatively non-saline areas;
- off-shore islands which were so far unsuitable due to erosion and sediment deposition;

- partially reclaimed and unreclaimed areas of new land resulting from the construction of the Meghna Cross-Dam.

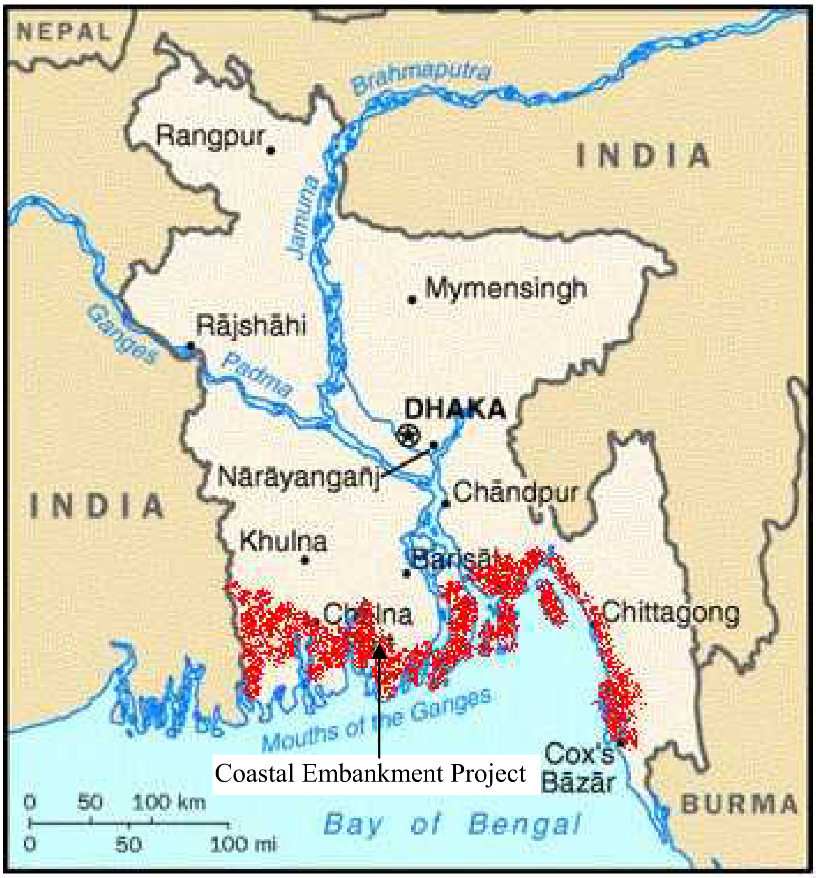

Figure 2.3 Coastal Embankment Project area, Bangladesh

Table 2.2 Main features of phase-I of the Coastal Embankment Project (after Uddin, et al., 1982)

Embanked area in million ha	1.01
Number of polders	92
Variation in area of each polder in ha	846 to 73,170
Total length of embankments in km	4,022
Sea dikes in km	860
Marginal dikes in km	542
Interior dikes in km	2,620
Total number of sluices	780
Size of sluices from 1 - 21 vents (openings)	Vents 1.50 m wide and 1.80 m high

Table 2.3 Typical dimensions of three standard types of embankment

Type of embankment	Side slope		Crest width in m	Minimum free-board in m	Minimum set back from bank in m	Return period in years
	Country side	River side				
Sea	1:2	1:7	4.2	1.5	76	20
Interior	1:2	1:3	4.2	0.9	53	20
Marginal	1:2	1:2	2.4	0.9	38	20

The emphasis on large scale works for high level flood control was dropped following the World Bank's Land and Resources Sector Study in 1972. Instead, the development of minor irrigation through low lift pumps (LLP) and tube wells, to some extent supported by complementary low cost FCD schemes, was advocated.

In 1974 Bangladesh experienced a devastating flood. Considering the damage of that flood the Government realized the need for quick implementable flood control and drainage improvement projects.

2.4.2 Development of Flood Control and Drainage Schemes

The areas for the development of the FCD Schemes are the lowlands of Bangladesh. The floodplain areas are complex and diverse sub-systems of the main rivers that enable the temporary storage of excess water during floods. They increase enormously the fish productivity of the river systems. Two types of floodplain can be distinguished in Bangladesh, namely the internal floodplains and deltaic floodplains. Before any Government intervention, flood control and drainage practices existed on the unprotected floodplains (Figure 2.4) (Bangladesh Water Development Board, 1998), people took initiatives to control water through the construction of small embankments, cross dams and drainage canals.

The internal floodplains, located mainly in the central and North-eastern part of the country are subject to seasonal flooding during the wet season. These floods are fairly predictable and the cropping patterns are adapted to them, although they result in low cropping intensities and yields. More damaging are the unpredictable flash floods, mainly in the Chittagong and Sylhet regions during the wet season. The situation in the deltaic plains along the coastal belt is not much different. The area suffers from flooding during spring tide and from salt intrusion during the dry season. Consequently yields are low.

In order to increase crop security in the floodplains, initial Government interventions invariably related to controlling floods from the river or from the sea. The intervention opted for was the construction of embankments (Figure 2.5) (Bangladesh Water Development Board, 1998). However embankments solve the problem of flooding, but create others. They obstruct the drainage of rainwater from within the protected area. In some cases run-off from the hills also accumulates behind the embankments. The engineering solution to this problem is the construction of sluices (in the main channel only) in the embankment equipped with flap gates on the riverside (Figure 2.6) (Bangladesh Water Development Board, 1998). However, the area is definitely not flooding free, because the first round of interventions also creates new problems, in particular drainage problems during the post wet season. Prior to the construction of an embankment, the area would drain off almost as fast as river water levels fell, as water could drain from the area along the whole periphery. After completion of the flood control intervention, drainage was confined to the main arteries equipped with sluices, as smaller khals were often closed. Moreover, in many locations water got trapped in local low pockets behind the embankments. To evacuate the water trapped in low pockets, people have often cut the embankments (Figure 2.7) (Bangladesh Water Development Board, 1998). In this phase, surface drainage outlets were constructed to evacuate accumulated water from low pockets behind the embankments. Often some re-excavation work to improve the conveyance capacity of the drainage channels (khals) was carried out (Figure 2.8) (Bangladesh Water Development Board, 1998). This, however, was not the end of the development of the FCD schemes. As a result of the improved control over water farmers saw new possibilities of high yielding varieties and changed cropping patterns and intensities. This lead to higher demands for water during the dry season. To meet this increasing demand for water, means were devised to retain water within the scheme at the end of the rainy season. During this phase, FCD schemes were remodeled to enable retention of water. The sluices, until then equipped only with flap gates, were modified by adding vertical lift gates on the countryside of the sluices. As water needed to be stored in the scheme for future use khals were deepened and widened to increase the storage capacity. With the possibility to retain water in the scheme, the need for devices to lift the water from the channels onto the land developed. Many traditional lifting devises were used, but this was also the moment when the low lift pumps (LLP) made their entry (Figure 2.9) (Bangladesh Water Development Board, 1998).

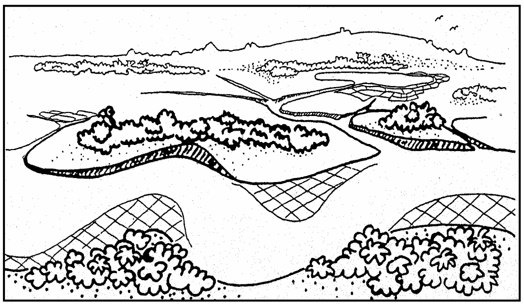

Figure 2.4 FCD Schemes before any intervention

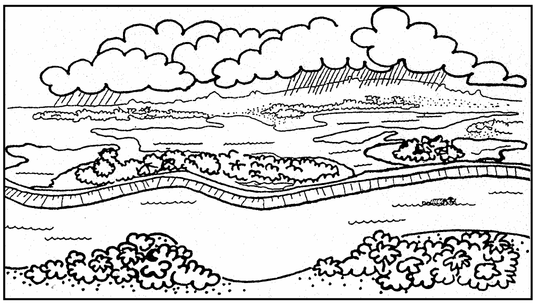

Figure 2.5 Initial intervention: flood protection

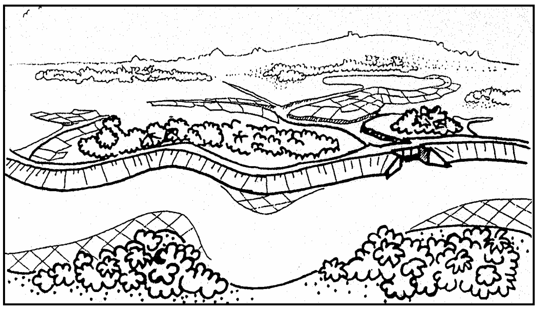

Figure 2.6 Including main sluices for drainage

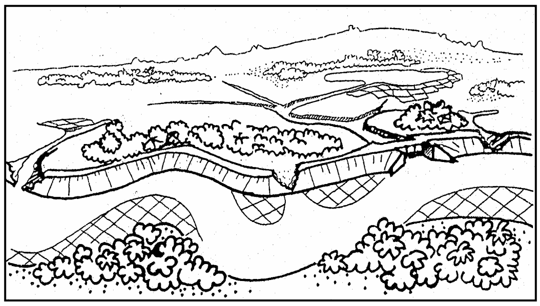

Figure 2.7 Actions to alleviate local drainage congestion

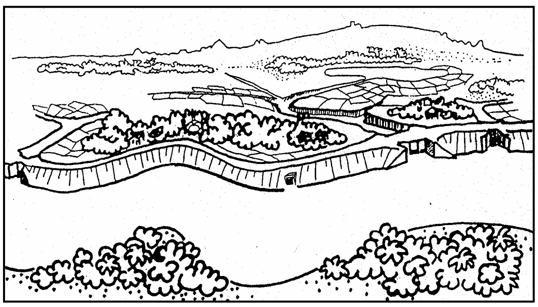

Figure 2.8 Installation of minor sluices

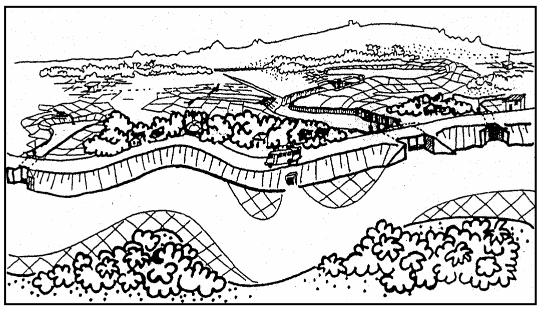

Figure 2.9 Optimized water control

Parallel to this, but quite independently, another development occurred, namely installation and use of shallow and deep tube wells (STW and DTW) for irrigation during the dry season.

Since sluices were initially designed to facilitate the outflow of water only, further modifications were required, in particular with regard to protective works on the countryside of the sluice. Besides modifying the existing infrastructure to facilitate entry of water, special sluices with the sole purpose to let water in, such as flushing sluices, irrigation inlets and salt and shrimp inlets, were sometimes constructed in the peripheral embankment to serve a small area.

Under the supervision of the Bangladesh Water Development Board several projects of various type have been implemented over the period of time. Some of the important projects relevant to this study are described in the next section.

2.4.3 Early Implementation Project

In 1975 a cooperation programme started between the Government of Bangladesh and the Government of The Netherlands. The initial contribution of The Netherlands Government was to support relatively small labour-intensive, quick-yielding water sector projects through the Bangladesh Water Development Board. The project had mainly a rehabilitation and relief character. They needed comparatively limited technical preparation and could therefore, in theory, start early: Early Implementation Project (EIP) (Figure 2.10).

Gradually, the project changed its scope and objective. In this way the project went through five distinct phases. During the process, the Early Implementation Project drew the attention of other donors. In 1981 the Government of Sweden became a new partner in Early Implementation Project, and continued its support till 1992.

Over the years, the Early Implementation Project has implemented 88 schemes in various regions of Bangladesh, covering an area of 463,250 ha (Figure 2.10). The implemented schemes consisted of the development of haors (dish shaped depressions within a perimeter consisting of river levees) and polders, i.e., the excavation of canals, construction of sluices, closures, and embankments.

Evaluating the benefits of the Early Implementation Project, some other donors were also supporting the construction of small-scale FCD schemes in different places of Bangladesh. The Local Government Engineering Department is involved in the implementation of minor water sector projects. At present, it is implementing 400 small-scale (very small in size compared to the Bangladesh Water Development Board’s projects) water sector projects spreading over the Northwest and Southwest regions of Bangladesh.

2.4.4 Delta Development Project

The problems and constraints affecting the polder development activities in Bangladesh enhanced the need for an overall development programme for the implemented polders, which is called the Delta Development Project (DDP). The project was originally proposed in 1976 and consisted of three basic components (Bangladesh Water Development Board, 1981):

- impoldering projects;
- pilot areas;
- delta development studies.

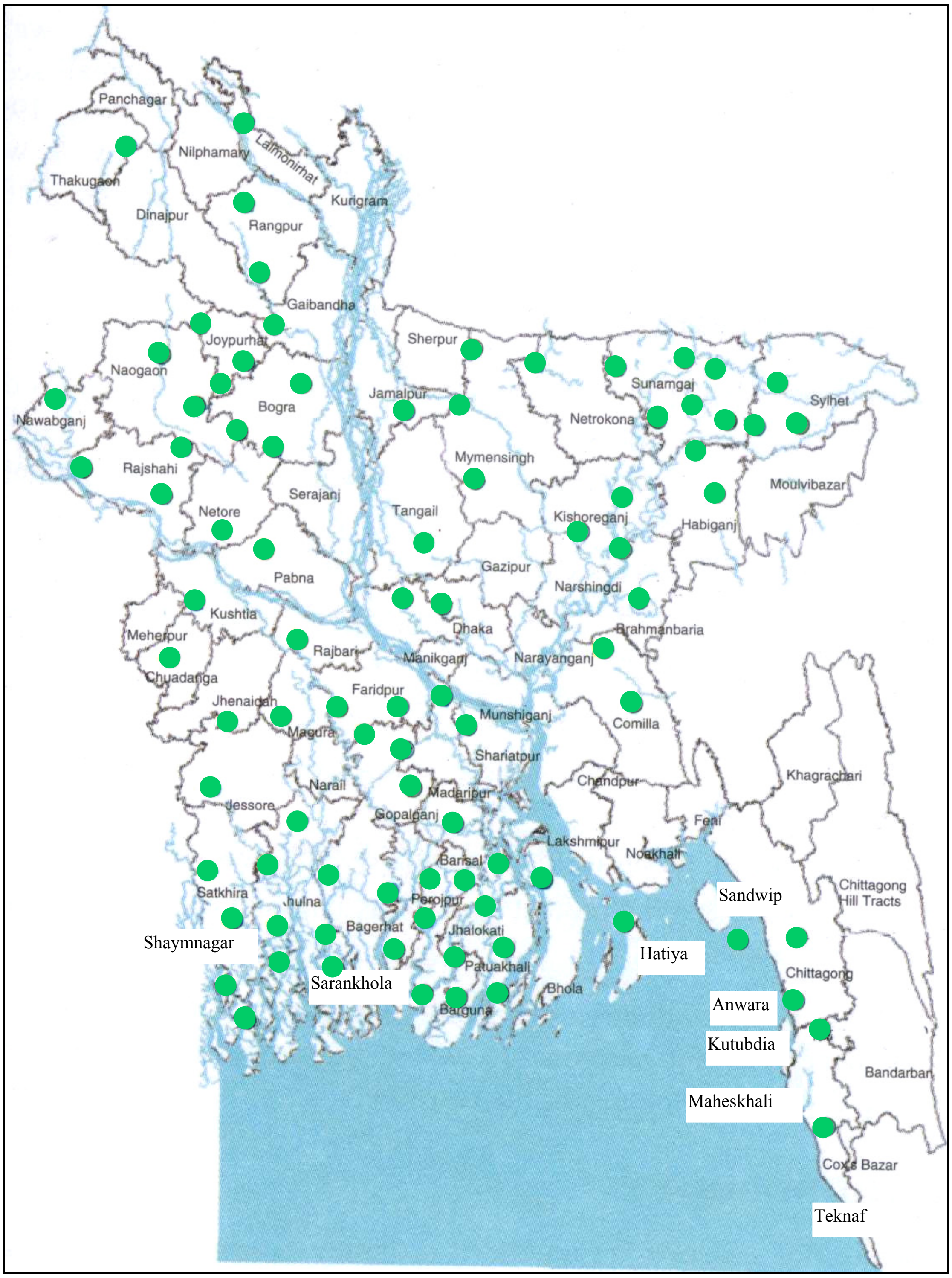

Figure 2.10 Location of the Early Implementation Project (Datta, 1999)

The original proposal was to establish three impoldering projects of a representative nature for different water zones: the saline water zone, the fresh water zone, and the transition zone. Their problems and consequently the development strategies are different. The development programme of the project also included technical and socio-economic elements. The objective was to reach the full development of these three polders. Experience gained in this process could then be the base for the development activities of the entire South-western region in a later stage. An area of 40 to 80 ha, in each polder project, would be selected as pilot area to test and develop appropriate farming methods, crop diversification and intensification. The experience gained would be gradually disseminated to the entire polder (Quaseem, 1982).

It was proposed that technical studies and overall comprehensive and proper long term planning for the entire deltaic region would be undertaken under the delta development studies. There was a proposal to include mathematical modelling to support the technical study. This study would also include experimental closures of tidal channels which would integrate the local method with more advanced scientific and technological innovations.

Due to the financial constraints, the project was taken up only in phases at a very reduced scale. In phase I, one polder project, instead of three, was taken up for implementation. That was polder 22 about 45 km South-west of Khulna, lying in the saline water zone. The delta development studies, one of the basic components of this project were left out.

2.4.5 Land Reclamation Project

Bangladeshi rivers carry heavy amounts of fine sediment from the upstream catchment. Due to favourable conditions these sediments cause accretion of new lands, which initially may come up with about one meter per year (Koch, 1986). The most favourable conditions for siltation occur at the salt-fresh water interface, the place where seawater and river water meet. During the wet period when sediment concentrations are highest, the water in the estuary is completely fresh. The interface is located in the deep sea where the sediments are carried away by ocean currents.

The construction of two cross-dams over branches of the river Meghna on the coast of the Noakhali district during 1957 and 1963 showed very positive results which introduced the prospect of land accretion in Bangladesh. During 1976, encouraged by the tremendous accretion, the Government of Bangladesh requested the Netherlands Government for technical assistance in land reclamation. Based on the Identification Mission Report, the Land Reclamation Project (LRP) began to function in late 1977. The Bangladesh Water Development Board was in charge of the implementation. The objectives of the projects were:

- to set up an organization within the Bangladesh Water Development Board to carry out surveys and studies in order to develop a long term policy for land accretion works in the South-eastern delta of Bangladesh;
- to try out various methods to accelerate the accretion of land in order to define those methods that are possible;
- to implement experimental schemes with the purpose of promoting a quicker and more effective use of newly gained lands, so that food production can be increased and conditions made viable for poor farmers.

The Land Reclamation Project is situated in the most active delta region, which lies between the Tentulia estuary in the West and the Chittagong coast in the East. In this region, lands are surfacing naturally and have a potential for reclamation of new land. To expedite the natural process of accretion and to find out a suitable approach for the new land gained, or to be gained an attempt was needed. Therefore, a pilot polder scheme was developed at Char Baggardona. To carry out a consistent research programme and to find the best methods for optimising land development, a research plot within the pilot polder area was established in 1980 (Chowdhury, 1982). Other aspects of the project besides the polder development were also investigated to achieve the project objectives like:

- hydrographic survey for future planning and policy making;
- accretion trials on Daria Nadi;
- sedimentation field to reduce estuary erosion.

A feasibility study on the construction of a 23 km long dam connecting Sandwip island with the mainland was also executed within the framework of the Land Reclamation Project. The study showed that dam construction could accrete 25,000 ha new land by blocking strong tidal currents. But the dam construction scheme was dropped.

2.4.6 National Water Plan

Realising the need for a long-term water resources development plan the Master Planning Organization (MPO) was established in 1980. Phase-I of the National Water Plan was completed in 1986 focusing on the assessment of water resources and future demand by different users. Phase-II, which started in 1988, was completed in 1991. One of the objectives of phase-II was to develop a planning methodology, guidelines for selection of priority projects and to prepare a comprehensive list of water projects and assess their economic viability and priorities.

The National Water Plan assembled a substantial amount of information, developed a range of planning models, analytical tools, and recommended strategies and programmes. The Master Planning Organization was renamed in Water Resources Planning Organization (WARPO) in 1991. Its objectives are to upgrade the National Water Plan and to evolve national policies and strategies for utilisation and conservation of water resources.

2.4.7 System Rehabilitation Project

A pre-feasibility assessment study on the completed schemes of the Bangladesh Water Development Board was done by the United Nations Development Programme (UNDP). Based on this pre-feasibility assessment a complete feasibility assessment of the 21 completed schemes was done and published in 1989. The study clearly pointed out the need for rehabilitation. At the beginning of the System Rehabilitation Project (SRP) formation stage emphasis was given on the physical rehabilitation, but the subsequent development project proposal included the improved operation and maintenance procedures and practices in the Bangladesh Water Development Board and to encourage farmer’s participation through on farm development works.

The Bangladesh Water Development Board finally undertook the Systems Rehabilitation Project in 1990 with a seven years programme. This was a project supported by four donors: the World Bank, the European Union, the Government of The Netherlands and the World Food Programme. The objective of the project was to rehabilitate 80 FCD and Flood Control, Drainage and Irrigation (FCDI) schemes which were constructed by the Bangladesh Water Development Board, to promote on farm development, to improve operation and maintenance, to improve the capabilities of the Bangladesh Water Development Board and to develop the participatory activities. At the beginning of the project, the concept of participatory approach did not get much attention. Later on, much stress was given to this aspect.

2.4.8 Flood Action Plan

The disastrous floods that struck Bangladesh in 1987 and 1988 attracted worldwide attention and resulted in a concentrated international effort to find a long-term solution to the persisting flooding problem. As a result the Flood Action Plan (FAP) was initiated in 1989, which was coordinated by The World Bank. A proposal of 26 studies and 3 pilot projects was endorsed at a meeting convened by The World Bank in London in December 1989. The Government of Bangladesh set up the Flood Plan Coordination Organization (FPCO) in 1990 to supervise, coordinate and monitor the Flood Action Plan activities. A panel of experts and specialists was appointed.

The Flood Action Plan aims at the identification, planning and possible construction of technically, economically, environmentally and socially feasible high priority projects. The Flood Action Plan follows a staged approach through which regional and supporting studies will provide input to the planning and design of the main components of the plan. A systematic approach is applied to investigate the feasibility of embankments on both sides of the major rivers, river training, channel improvement and protective infrastructure for the major towns. The plan has developed improved systems for flood forecasting and warning and studies on the issues of catchment management, coastal afforestation and sustainable development of agriculture and fisheries.

The Flood Action Plan studies culminated in the Bangladesh Water and Flood Management Strategy (BWFMS) report (Flood Plan Coordination Organization, 1995). The report noted the limitations of earlier master plans, which had focused too heavily on agriculture development without adequate consideration of the needs of the other sectors. A widespread criticism of earlier plans was that the social and environmental impacts of land and water development were not being addressed. Responding to this, the Bangladesh Water and Flood Management Strategy recommended that the Government should formulate a national policy that addressed these issues and that a comprehensive National Water Management Plan (NMWP) should be prepared within this framework. Consequently the Flood Plan Coordination Organization was incorporated in the Water Resources Planning Organization (former Master Planning Organization).

2.4.9 Dhaka Integrated Flood Protection Project

With the assistance of the Government of Japan a feasibility study, called Greater Dhaka Protection Project was executed by Japan International Co-operation Agency

(JICA) in 1992, which covered the area of greater Dhaka, Tonghi, Savar, Karanigonj and Narayangonj (Japan International Co-operation Agency, 1992). In 1991 the Asian Development Bank (ADB) funded another feasibility study for flood protection and drainage improvement of Dhaka Metropolitan City (260 km^2), which was called Dhaka Integrated Flood Protection Project (Louis Berger International, Inc., 1991). But due to fund constraints and the huge volume of work only the Western part of Dhaka City (136 km^2), which was comparatively densely populated was taken for implementation.

During the feasibility studies the Government of Bangladesh started a project called Dhaka City Protection Project to protect Dhaka City from the impacts of flooding after the devastating effects of the 1988 flood, which was implemented in the period January 1989 to June 1991. As per progress report of the Bangladesh Water Development Board the components that were constructed during that period are shown in Table 2.4.

Table 2.4 Components of the Dhaka City Protection Project

Item of works	Quantity	Implementing Agency
Embankment in km	10.0 6.0 14.0	Bangladesh Water Development Board Dhaka City Corporation Bangladesh Armed Forces
Floodwall in km	31.2 4.8	Roads and Highways Dhaka City Corporation
Number of pipe sluices	6.0	Bangladesh Water Development Board
Heightening of existing roads in km	6.0 2.9	Roads and Highways Dhaka Improvement Trust
Rehabilitation of drainage channels in km	13.0	Dhaka Water and Sewerage Authority

Due to improper site selection and undue pressure for quick implementation without a proper feasibility study, the project was not working properly. Some adverse effects were identified. Finally an agreement was signed between the Government of Bangladesh and the Asian Development Bank in 1992 for some new work to overcome the difficulties of the project in line with the recommendations of the feasibility study. The objective of the project was protection against floods, secure the living environment, and to improve the urban areas and environmental conditions (particularly for the urban poor) in Dhaka City. It consisted of:

- flood control and drainage works;
- environmental improvement programme, including low cost water supply, sanitation, slum and squatter area development.

It involved mainly the completion of the flood protection and drainage programme initiated by the Government following the 1988 floods and was completed in 2001.

2.4.10 National Water Policy

Past experiences in the water sector development showed the necessity of a good water policy in Bangladesh. After detailed discussions the Government of Bangladesh finalised the National Water Policy in 1999 (Ministry of Water Resources, 1999). In this policy it was noted, among others, that there was no interagency coordination among the various organizations (Government and Non Government Organizations).

The water policies of Bangladesh laid down the broad principles of development of water resources and their rational utilisation with some constraints. The policy was intended to guide both public and private actions in the future for ensuring optimal development and management of water that benefits both individuals and the society at large. As water is essential for human survival, socio-economic development of the country and preservation of its natural environment, it is the policy of the Government that all necessary means and measures will be taken to manage the water resources of the country in a comprehensive, integrated and equitable manner. The National Water Policy will be reviewed periodically and revised as necessary. Objectives of the National Water Policy are broadly:

- to address issues related to the harnessing and development of all forms of surface water and ground water and management of these resources in an efficient and equitable manner;
- to ensure the availability of water to all elements of the society, including the poor and the underprivileged, and to take into account the particular needs of women and children;
- to accelerate the development of sustainable public and private water delivery systems with appropriate legal and financial measures and incentives, including delineation of water rights and water pricing;
- to bring institutional changes that will help decentralise the management of water resources and enhance the role of women in water management;
- to develop a legal and regulatory environment that will help the process of decentralisation, sound environmental management, and improve the investment climate for the private sector in water development and management;
- to develop a state of knowledge and capability that will enable the country to design future water resources management plans by itself with economic efficiency, gender equity, social justice and environmental awareness to facilitate achievement of the water management objectives through broad public participation.

The National Water Policy also addresses:

- river basin management;
- planning and management of water resources;
- water rights and allocation;
- public and private involvement;
- institutional policy for the various public departments and their future working environment;
- public water investment;
- water supply and sanitation;
- water and agriculture;
- water and industry;
- water and fisheries and wildlife;
- water and navigation;
- water for hydropower and recreation;
- water for the environment;
- water for preservation of haors, baors and beels;
- economic and financial management;
- research and management;
- stakeholder participation.

2.4.11 National Water Management Plan

One of the main proposals of the Bangladesh Water and Flood Management Strategy was the preparation of a broad-based National Water Management Plan (multi-sectoral). The emphasis is on year round water management, social and environmental considerations, full participation of stakeholders, particularly affected people, in the planning process and institutional development. The Water Resources Planning Organization started the preparation of the plan in March 1998. They have already published the development strategy for the plan. Now the plan is in the final stage.

The preparation of the National Water Management Plan comprises four main components:

- a consensus document consolidating the policy and strategy framework set by the Government within which water sector plans are to be developed;
- a long-term water management programme to 2025, and within this a priority programme to 2005, identifying structural and non-structural measures to be implemented at national and regional level, and their expected impacts;
- an investment portfolio of national, regional and sub-regional projects, prepared by sector Agencies and screened by the Water Resources Planning Organization;
- a special report on the Ganges dependent area including recommendations on alternatives for the augmentation of dry season flow, including the Ganges Barrage.

3 WATER RESOURCES AND LAND USE PATTERN IN BANGLADESH

3.1 ECONOMY AND LAND USE OF BANGLADESH

Bangladesh is a country of limited resources (economic). The present population is 130 million, having an area of 147,570 km^2. The current population density of 880 people per km^2 is already the highest of any nation other than the tiny city-states. Progression of a few key social development indicators over a 23-year period, as presented in Table 3.1, gives some idea about the social development status of the country.

Table 3.1 Key social development indicators (Bangladesh Bureau of Statistics, 2000)

Indicator	1975	1998
GDP per capita in US$	180	357
Population in million	80.1	126.2
Population density in persons per km^2	543	855
Population growth rate in %	2.6	1.5
Infant mortality rate per 1,000 live births	140	57
Life expectancy	46	61
Access to safe water in % of population	56	96

Bangladesh is predominantly an agricultural country. Its economy is still heavily dependent on its agriculture. During the decades between 1984/1985 and 1994/1995, the share of agriculture to the Gross Domestic Product (GDP) declined from 41.8% to 32.8%, while the manufacturing and services sectors went up (Huda, 1998). Despite this, agriculture continues to be the largest provider of jobs. Projection of employment up to 2020 shows that until that time agriculture will continue as the major source of employment by absorbing over 40% of the labour force (World Bank and Bangladesh Centre for Advanced Studies, 1998).

Land and water are the two most important resources for the overall development of Bangladesh. For Bangladesh having such a high population density land is a very scarce resource. By 2020, even with a steady decline in fertility, the estimated population of the country will reach 170 million and density will increase to 1,150 persons per km^2.

There is no approved land use policy in the country. Being an agricultural country and land becoming scarcer with every passing year, there was a need for a scientific land classification on the basis of its productivity. In the absence of such policy, prime agricultural land in Bangladesh is in many cases used for non-agricultural purposes.

From 24 million people in 1996, the urban population reached 30 million at the end of the 20th century. It is expected to reach about 50 million by 2010 and nearly 80 million in 2020. The probable loss of cultivable land to land uses as housing and infrastructure is likely to be enormous (World Bank and Bangladesh Centre for Advanced Studies, 1998). In Table 3.2 some characteristic land use statistics of Bangladesh are presented.

Table 3.2 Land use in Bangladesh (1974 – 1996) (Khalil and Bangladesh Bureau of Statistics, 1998)

Nature of land use	Area in 1,000 ha			Percentage of total		
	1974	1990	1996	1974	1990	1996
Cultivated cropland	8,489	8,837	7,802	59	58	53
Currently fallow	627	288	392	4	2	3
Cultivable idle land	272	267	531	2	2	4
Forests	2,229	1,858	2,151	16	12	13
Cultivation not available	2,661	3,934	3,961	19	26	27
Total	14,278	15,184	14,837	100	100	100

3.2 COASTAL CONDITION OF BANGLADESH

The coastal area of Bangladesh has a vast potential for agriculture, land reclamation, fish culture, salt culture and other economic activities, like recreation and production of seafood. The coastal zone, where land and sea meet, is composed of a variety of complex environments. The zone includes bays, estuaries, deltas, marshes, dunes and beaches. Since ancient times river deltas and coastal areas have been the location for economic and commercial activities and were of fundamental importance to civilisation. Bangladesh has a vast coastal area full of resources in the South where the land meets the Bay of Bengal. The coastal region of the country spreads over the old Districts of Chittagong, Noakhali, Barisal and Khulna. The coastal morphology is mainly characterised by (Talukder, 1991):

- a vast network of rivers;
- an enormous discharge of river water heavily laden with sediments, both suspended and bed load;
- a funnel shaped and shallow Northern Bay of Bengal at the North of which the coastal area is located;
- strong tidal and wind actions;
- tropical cyclones and associated storm surges.

The coastal deltaic area (14,000 km^2) where polders are being developed, is cut into numerous separate landmasses by the intricate tidal river systems. Most areas have saucer-like shapes with ground elevations from below mean sea level to above 6 m+PWD. The average coastal tidal land lies only a metre above mean sea level (Bangladesh National Committee of the International Commission on Irrigation and Drainage, 1995). Sediments, deposited by the Ganges-Brahmaputra-Meghna river system have formed the polder areas. Most of the soils in the area, predominantly silty clay loam, are recent alluvial, mineral in character. Soils in general are fertile and respond well to chemical as well as natural fertilisers.

The area is subject to semi-diurnal tidal effects with a period of 12 hours and 24 minutes. The tides that affect the coastal zone originate in the Indian Ocean, travel past the deep parts of the Bay of Bengal and reach the depth of 18.3 m contour line at Hiron Point and Cox's Bazar at about the same time. There is a pronounced variation between the heights of two consecutive high tides. The tidal range varies from 0.60 m to nearly 6.00 m (Uddin and Islam, 1982). Tidal channels carry saline water from the seas into the interior. The sea and fresh water fronts divide the area into three distinct zones, year round saline zone, year round fresh water zone and a transition zone, consequently having different salinity problems. In Figure 3.1 a typical example of tidal fluctuation (spring tide) for the station Mirjagonj in April, 1995 is shown.

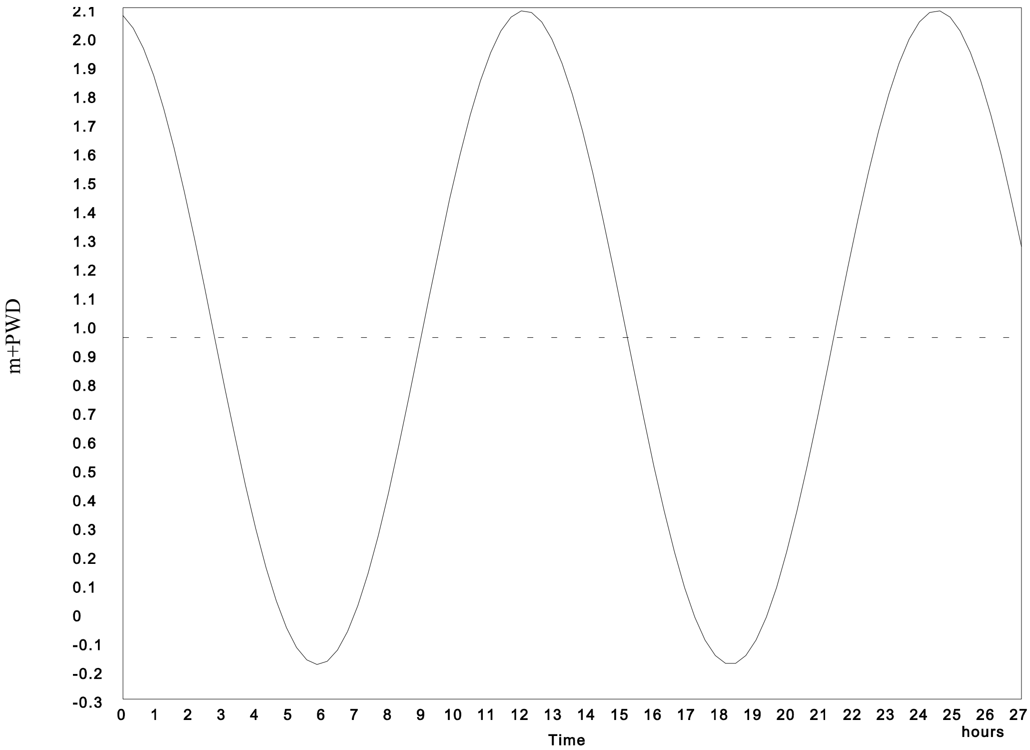

Figure 3.1 Tidal fluctuation for the station Mirjagonj

3.2.1 Land and Water Use

Rice (Aman, Aus, Boro), Betelnut, Jute, Fruit, Vegetable, Pulses, Sugarcane, Oil seeds, and Tobacco are grown in the coastal region. Dry season crops like Pulses, Vegetables and Sesame cover only 4.5% of the total cultivated land. Aus (early wet season rice) is grown as a single crop or sometimes mixed with Aman. Boro is grown in the dry season in those parts where fresh water for irrigation is available. Agriculture practices are restricted by soil salinity as well as by lack of irrigation water during the cropping seasons, particularly the dry season. Salinity of water restricts the scope for adequate irrigation in most parts of the area. Supplementary irrigation for Aman is possible and practised.

3.2.2 Needs of the Coastal Polders

Before the construction of the polders, complete or almost complete crop failures due to saline inundation or wet season flooding were reported in most coastal areas on average once in every three years. Crops near the riverbanks were also damaged by the heavier silts carried with the floodwater. On average yields were very low, depending on the extent of salinity and flooding conditions. In addition to the agricultural damage, loss of property and life was a common phenomenon in these areas due to cyclonic storms and tidal seawater surges.

Polder construction has increased the scale of production and introduced hopes for further development. Crops are saved from salinity intrusion and their yield has increased significantly. Assurance of save harvesting and protection of homestead from tidal flooding was achieved. Road communication and marketing facilities have increased. The living standard of the people has been improved and more job opportunities for agricultural labour were created. The cultivable area has been increased due to impoldering.

3.3 HYDROLOGY

3.3.1 Climate and Rainfall

Generally Bangladesh is blessed with a sub-tropical monsoon climate. There are three prominent seasons in a year namely winter, summer (pre-monsoon) and monsoon. Winter, which is quite pleasant, begins in November and ends in February. Usually in winter there is not much fluctuation in temperature. The normal winter temperature ranges from a minimum of 7 ^{0}C to a maximum of 31 ^{0}C. The winter season receives a negligible amount of rainfall and is characterised by low temperature, low humidity and high solar radiation. The summer begins from March through May, with a mean temperature of about 30 ^{0}C and occasionally a rise above 40 ^{0}C. The hot summer (pre-monsoon) season receives some rainfall in occasional heavy thunderstorms and hailstorms. The summer is characterised by its highest temperature and evaporation rates. The monsoon (rainy) season begins in June and continues up to October with maximum temperature usually around 30 ^{0}C with high humidity and low solar radiation. Mean annual temperature throughout the country is about 26 ^{0}C but extreme temperatures range from about 5 ^{0}C to about 43 ^{0}C (Bangladesh National Committee of the International Commission on Irrigation and Drainage, 1995).

Due to the presence of the lofty mountains of the Himalayan range in the North, the lower elevation hills in the East and the influence of the South-west monsoon of maritime origin, Bangladesh receives an average annual rainfall from 1,200 mm in the extreme West to 5,800 mm in North-east. The average overall annual rainfall is about 2,300 mm. About 81% of the rainfall in Bangladesh occurs in the wet monsoon period (May - October) (Bangladesh National Committee of the International Commission on Irrigation and Drainage, 1995). Runoff from adjacent riparian countries is generated by rainfall, which averages 5,000 mm/year over the Himalayas, and exceeds 10,000 mm/year over the Meghalaya plateau of Sylhet.

The mean monthly evaporation varies from a minimum of 51 mm in winter to a maximum of 183 mm in summer. The rate of evaporation in the Eastern part is generally lower than in the Western and North-western parts.

3.3.2 River Systems in Bangladesh

Bangladesh is a delta formed by the alluvial deposites of three mighty rivers: the Ganges, the Brahmaputra and the Meghna. Bangladesh has a complex river network of about 230 rivers occupying about 6% of the area of the country (Hoque, 1997). An important feature of the river systems is that 57 are cross boundary rivers, coming from India and Myanmar. These river systems drain a catchment of about 1.72 million km^2, out of which only 7% is located in Bangladesh. Rests 93% of the catchment situated outside in China, India, Nepal, Bhutan and Myanmar. The historical development of the main river system of Bangladesh is presented in Figure 3.2.

The Brahmaputra river originates in the Himalayan range and collects snowmelt and rainfall from the huge catchment lying in China, Bhutan, India and Bangladesh. After rising in Tibet the river flows in an Easterly direction parallel to the main range of the Himalayas. It receives the flows of two branches (the Dibang and the Luhit) and the combined stream takes the name of Brahmaputra, flows through the Assam valley and enters Bangladesh round the Garo hills near Majihali in Kurigram District. Within Bangladesh it takes the name of Brahmaputra and Jamuna. The river flows further in Southerly direction and joins with the Ganges near Aricha. In Bangladesh, the river receives the discharge of Dudhkumar, Dharla, Teesta, Karatoa and Atrai rivers. There are only two main spill (discharge) channels, which are the old Brahmaputra and the Dhaleswari.

The Ganges rises from the Gangotri glacier in the Himalayas at an elevation of about 7,010 m near the Indo-Chinese border. From Hardwar to Allahabad, the river flows generally in a South-easterly direction and in the lower reaches it flows Eastward and enters into Bangladesh near Rajshahi. The river flows Southwards and then meets the Brahmaputra near Aricha and flows further under the name Padma. Three major tributaries of the Ganges - the Karnali, the Gandaki and the Kosi rise in China and flow through Nepal to join the Ganges in India. In Bangladesh the Ganges receives discharge of only one river, the Mohananda, meeting the Ganges near Godagari. There are a number of spill (discharge) channels of which Baral, Mathabhanga, Gorai and Arialkhan are prominent.

The Meghna emerges from the hills of Manipur in India. At the head stream, the river is known as the Barak. After descending from the hills, the river flows in a meandering course till it enters into Bangladesh. Near the Indo-Bangladesh border (Amalshid), the Barak bifurcates into two rivers named the Surma and the Kushiyara. The Surma and the Kushiyara again join together at Ajmiriganj in Bangladesh. The combined flow of the Surma and the Kushiyara takes the name of Meghna. It then flows in a South-westerly direction to meet the Padma at Chandpur. Below Chandpur the combined river is known as the lower Meghna.

The combined average annual discharge of these rivers is about 40,000 m^3/s and the combined peak discharge in the order of 200,000 m^3/s (Hoque, 1997). The total annual runoff of the surface water passing through Bangladesh is in the range of 1,200 to 1,500 billion m^3. The sediment discharge is in the range of 1.2 to 1.7 billion tons, which is coming from outside the country. The yearly maximum sediment flows of the three rivers are 737 (Brahmaputra), 479 (Ganges) and 12 (Meghna) million tons respectively. The main features of the three systems are presented in Table 3.3.

The hilly rivers of the Chittagong region, including the Karnafuli, the Sangu, the Matamuhuri, and the Naaf, remain to be considered. They are swifter than those in other parts of Bangladesh and are mountain streams for most of their course. A large number of hill torrents can increase their flow suddenly after a heavy thunderstorm, which often leads to flash floods.

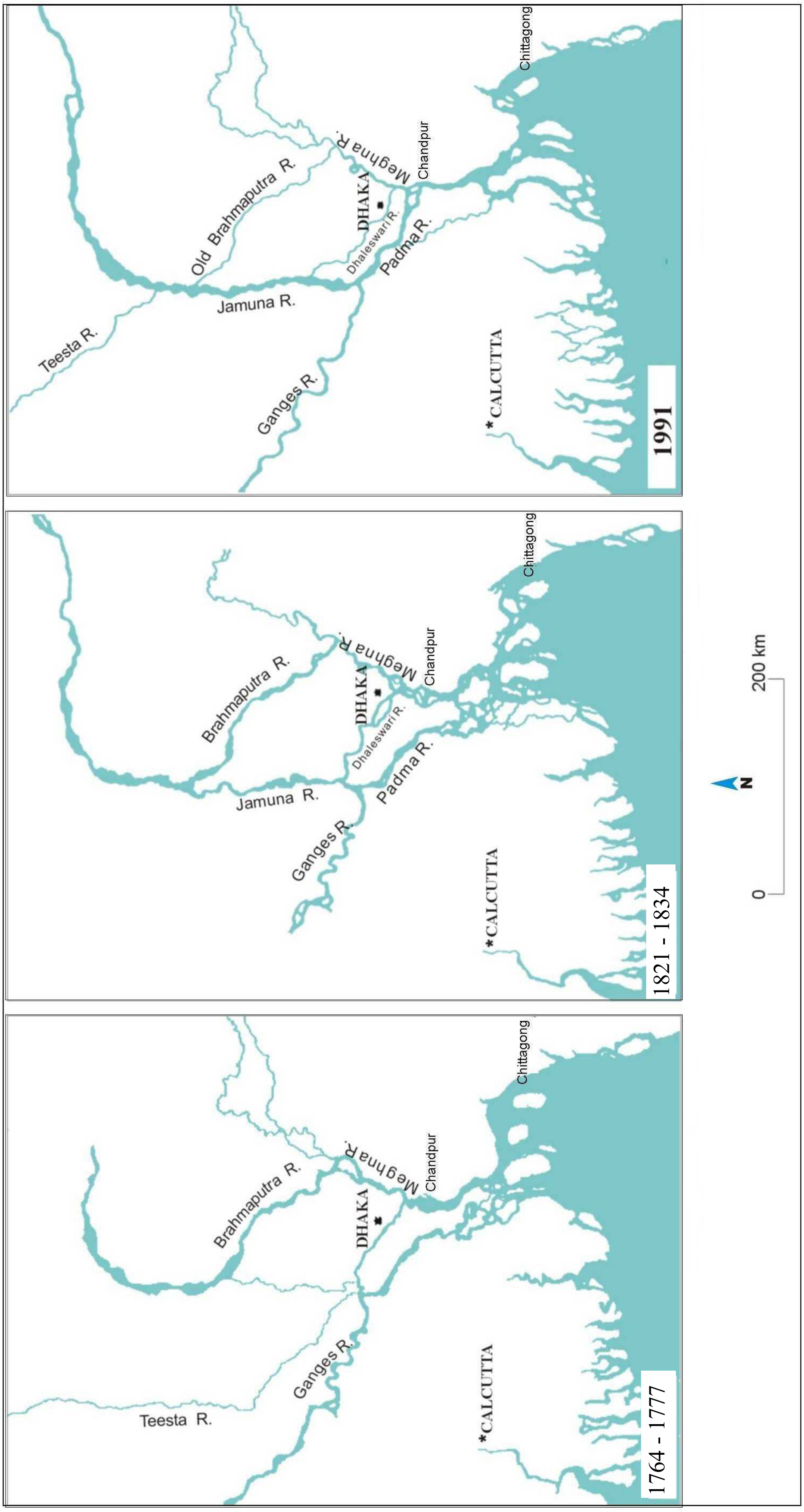

Figure 3.2 Historic maps of the river systems of Bangladesh (Rennel, 1794, Wilcok, 1840 and National Oceanographic and Atmospheric Administration, 1991)

Table 3.3 Main features of the major river systems of Bangladesh (Hoque, 1997 and Bangladesh National Committee of the International Commission on Irrigation and Drainage, 1995)

Name of the river	Total length in km	Length in Bangladesh in km	Total catchment in km^2	Catchment in Bangladesh in km^2	Maximum discharge in m^3/s	Minimum discharge in m^3/s	Annual average flow in m^3/s
Brahma-putra	2,900	260	552,000	39,100	98,300	2,860	19,500
Ganges	2,550	157	1,087,300	46,300	76,000	261	11,500
Meghna	902	403	83,000	35,000	19,800	Tidal in dry season	7,500

Recorded highest water levels for some of the major floods in Bangladesh for the years 1974 to 1999 for nine stations are presented in Table 3.4.

Table 3.4 Highest water levels in m+PWD of major flooding years for different stations (Bangladesh Water Development Board, 1998 and 1999)

Name of the river	Name of the station	Year						
		1974	1987	1988	1993	1996	1998	1999
Brahmaputra	Bahadurabad	20.25	19.68	20.62	19.90	19.99	20.37	19.82
Brahmaputra	Serajganj	14.23	14.57	15.12	13.78	14.01	14.76	14.10
Ganges	Goalando	9.60	9.52	9.83	8.72	9.13	10.21	9.25
Ganges	Rajshahi	18.54	19.46	19.00	17.97	18.86	19.68	19.18
Ganges	Hardinge Bridge	14.38	14.80	14.87	13.74	14.50	15.19	14.45
Meghna	Bhairab Bazar	7.62	6.91	7.66	6.93	6.49	7.33	6.43
Meghna	Chandpur	5.21	4.70	5.33			5.62	
Buriganga	Dhaka	6.62	6.64	7.58		5.80	7.24	5.81
Lakhya	Narayanganj	6.23	6.04	6.71		5.75	6.93	5.96

PWD = Public Works Department Datum

3.3.3 Cyclones and Storm Surges

Storm surges associated with tropical cyclones have the most damaging effect on loss of human lives, livestock and properties in the coastal area of Bangladesh. Cyclonic storms with winds of more than 120 km/hr occur with the advent of the monsoon season. These are particularly severe just before and after the monsoon. Winds of over 160 km/hr, heavy downpours and tidal surges of over 6 m above the normal level have brought devastation to life and property. The predicted surge heights at the coast corresponding to return periods of 20, 50 and 100 years for five coastal regions are presented in Table 3.5.

The average frequency of tropical cyclones over the Bay of Bengal is about six per year, but not all of them strike Bangladesh. The country is also periodically affected by cyclonic storms in the coastal districts. The country has over 700 km of coastline on the mainland and several offshore islands in the Bay of Bengal. During the last 125 years, over 42 cyclones have hit the coastal belt; 14 occurred during the last 25 years. Cyclones often take a heavy toll in human life, livestock, crops, properties and physical infrastructure (World Bank, 1995).

Table 3.5 Surge heights at the seacoast and 90% confidence limits (Bangladesh National Committee of the International Commission on Irrigation and Drainage, 1995)

Region	Surge height in m+PWD on the sea beach along with the 90% confidence limits		
	20 years return period	50 years return period	100 years return period
Teknaf to Cox's bazar	2.7 ± 0.7	3.7 ± 0.8	4.5 ± 1.3
Chakaria to Anwara and Maheshkhali to Kutubdia Islands	4.3 ± 0.9	5.8 ± 1.3	7.0 ± 1.6
Chittagong to Noakhali	4.8 ± 1.0	6.5 ± 1.4	7.8 ± 1.8
Sandwip, Hatiya and all islands in this region	4.8 ± 1.0	6.5 ± 1.4	7.8 ± 1.8
Bhola to Barguna	3.8 ± 0.8	5.1 ± 1.1	6.2 ± 1.5
Sarankhola to Shaymnagar	3.1 ± 0.7	4.3 ± 1.0	5.2 ± 1.2

3.4 WATER MANAGEMENT SCHEMES IN BANGLADESH

Wet season floods and water scarcity during the dry season are major challenges for water resources development and water management in Bangladesh. Cropping patterns and crop yields in the floodplains are strongly affected by floods, as are fisheries and transportation. In coastal areas, salinity and cyclones are additional factors influencing farming systems. According to the Government of Bangladesh the primary objective of water management schemes is to increase agricultural production through the provision of one, or a combination, of the following measures: flood control, drainage, reduction of salt intrusion, and irrigation.

FCD schemes are located in the floodplains of the rivers of Bangladesh, or they are coastal polders. Embankments along the periphery provide protection against river, or sea floods, or against salt intrusion. Where necessary, sluices are placed in the embankments to drain natural khals (natural channels which connect the low-lying area and the rivers). Many inland FCD schemes have field depressions that contain water during most or all of the year, called beels, in their interior. They are often connected to rivers through a network of khals or man-made canals and can only be drained when river levels permit.

In Bangladesh, the term FCD is confusing, as it suggests that a certain type of water control infrastructure be only used for flood control and drainage. FCD schemes are also operated with additional objectives like controlled flooding and retention of water. Moreover, irrigation is often practiced in FCD schemes through low lift pumps (LLP), tube-wells or traditional irrigation practices and devices. Hence, from a water management perspective there is no clear distinction between FCD and Flood Control, Drainage and Irrigation (FCDI) schemes. In this study the term FCD schemes refers to both FCD and FCDI schemes.

In most FCD schemes there are nowadays three distinct cropping seasons, Namely: Kharif-I, Kharif-II and Rabi. In Table 3.6 general features of different cropping seasons together with land type, irrigation, drainage and flood protection requirement are presented. From an agricultural perspective the FCD schemes are designed to:

- protect standing Aus against early river floods;

- expand the area under Aman by excluding flood waters from the schemes;
- retain water in the system during the post wet season.

Table 3.6 Land type and different cropping seasons

Cropping season	Period	Land type	Type of crop	Irrigation, drainage, or flood protection requirement
Kharif-I	Middle of April - middle of July	High to Medium highland	HYV Boro, Aus	Irrigation
		Medium to lowland	B. Aman, Jute	Irrigation Flood protection
Kharif-II	Middle of July - middle of November	High to Medium highland	T. Aman	Supplementary irrigation Drainage Flood protection
		Medium to lowland	Jute, B. Aman	Drainage Flood protection
Rabi	Middle of November - April	High to Medium highland	Rabi, Wheat	Irrigation Tidal and salinity protection may be needed
		Medium to lowland	HYV Boro, local Boro	

HYV = High Yielding Variety

The multitude of water management demands within one FCD scheme lead to many different water management options and critical moments in water management. The most important characteristics of water management in FCD schemes are that there are many different stakeholders, each with different, often conflicting water management demands. Stakeholders occupation or location determines his level of interest in water control. A review of types of stakeholders and their demands is given in Table 3.7. Water management planning in FCD schemes is also very sensitive to satisfy all the stakeholders demands, extremely complex and fundamentally different from traditional water management in irrigation systems. So, it is necessary to consider participatory water management in the context of FCD schemes.

3.4.1 Land Utilization under Different Water Use Practices

Use of land for agricultural purposes is dealt with respect to cropping pattern and farming systems practices. Land and water utilization practices for the different seasons are (Biswas and Salam, 1993):

- *Kharif-I (i.e. early wet season)*
  i) irrigated + rainfed: this practice is usually followed for transplanted Aus that needs irrigation at the beginning of the season for land preparation and transplantation as the monsoon arrives late. After the arrival of the monsoon, the crop grows as rainfed. This practice is done to maintain the planting time;
  ii) rainfed: broadcasted Aus and Jute that are sown after the wet season has arrived. The sowing time is uncertain;
- *Kharif-II (i.e. late wet season)*
  i) rainfed + supplementary irrigation: transplanted Aman grown as rainfed crop but at a later stage of the crop growth, due to shortage of water, the crop demands supplementary irrigation. If water is not added, yield losses occur;
  ii) rainfed: transplanted Aman grown totally under rainfed conditions;

- *Rabi (i.e. dry season)*
  i) rainfed: local variety of Boro usually at the bottomland, such as beels. In highlands, where Rice is not grown, Pulses, Wheat and Oil seeds are grown under rainfed conditions;
  ii) rainfed + irrigation: this type of practice is applied in local Boro cultivation as the above case. However, the land in this case is slightly higher elevated than the beels;
  iii) irrigated: this is applied for modern Boro cultivation. In some places Wheat is also grown as irrigated crop;
  iv) irrigated + rainfed: this is applied for modern Boro but the planting time is delayed where irrigation water is a factor (either unavailability or resource-poorness of the farmers). In late stage the crop is then grown as rainfed. The problem is that the crop overlaps with the next season crop, the Aus. This is why it is popularly called Braus rice.

Table 3.7 Types of stakeholders and their conflicting water management demands in FCD schemes (after Bangladesh Water Development Board, 1997)

Type of stakeholder	Demand in the dry season	Demand in the wet season
Highland farmers	Water retention (irrigation)	Drainage
Highland farmers in beels	Water retention in the beel (irrigation)	Flood protection
Lowland farmers	Drainage	Flood protection, water retention on highland
Lowland farmers in beels	Drainage of the beel	Flood protection
Professional fisherman	Almost full drainage	Free entry of water into the scheme
Leaseholders of water bodies	Almost full drainage	Maximized fish production through flooding
Shrimp farmers		High levels of saline water entry into the scheme
Salt producers	Low levels of saline water entry into the scheme	
Pump owners (LLP)	Water retention (irrigation)	Water retention (irrigation)
Boatmen	High water levels	High water levels
Households	Fresh water retention	Water retention
Agricultural labourers	Well managed schemes leading to improved employment opportunities in agriculture	Well managed schemes leading to improved employment opportunities in agriculture
Transporters and traders	Well maintained embankments	Well maintained embankments

Due to the influence of a number of factors such as the time, amount and duration of rainfall, farmer's preferences and market prices, the cropping pattern is not stable. The variability is more pronounced in rainfed cultivation due to the uncertainty of rainfall. Figure 3.3 presents the calendar of the country's most important foodgrain crops, Rice and Wheat, in relation to average land surface and water levels.

The farmers of Bangladesh at present apply irrigation water to a number of crops in order to achieve potential yields. Generally two types of irrigation are applied which are basin and furrow. However, exactness of irrigation is a crucial factor for two main reasons:

- insufficient application may hamper to reach potential yields;

- excess application may increase the cost of production and reduce production levels as well.

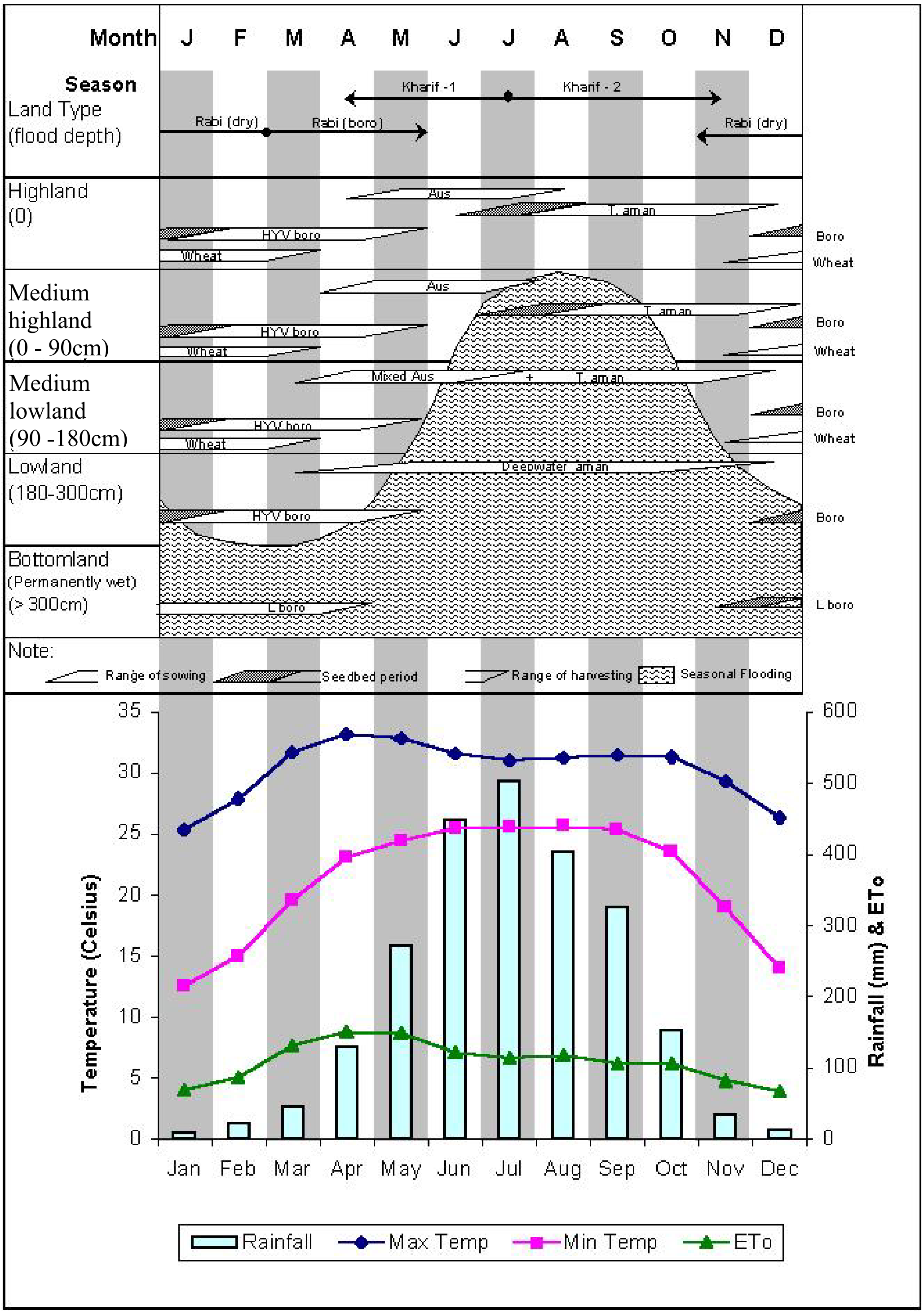

Figure 3.3 Crop (Rice and Wheat) calendar in relation to rainfall and temperature in Bangladesh (Brammer, 1999)

The exactness of irrigation is usually the theoretical demand of the crop. It has been reported that if the actual irrigation is 75% of the theoretical demand, 90% of the potential yield for most of the crops can be achieved (Jenkins, 1981). Studies of such aspects under conditions in Bangladesh have only been done to a limited extent. Dutta

(1993) explored the situation for a number of crops at farmer's fields. The irrigation schedule (frequency, interval, depth of application and total depth) significantly varied for different crops with respect to actual practice and theoretical demand (Dutta, 1993). The crops, Tomato, Onion, and Ginger were found to be generally under irrigated (less than 75% of their water demand) whereas Papaya, country Bean, sweet Gourd, Cucumber, and Chilli were generally excessively irrigated. Two crops, Potato and modern Boro were found to be optimally irrigated (more than 80% of their crop water demand) while transplanted Aman was not irrigated at all.

3.5 FCD SCHEMES AND IRRIGATION SYSTEMS

Actually, the multitude of water management options in FCD schemes makes water management extremely critical. Although it is difficult to realize success in irrigation systems, they have all the ingredients for success. In FCD schemes, on the other hand, it is much more difficult to realize success and all the ingredients for failure are present. In Table 3.8 some points of difference between FCD schemes and irrigation systems are presented.

Table 3.8 Differences between FCD schemes and irrigation systems (Bangladesh Water Development Board, 1997)

	FCD schemes	Irrigation systems
Infrastructure	FCD infrastructure has to cater for many, often mutually exclusive, demands at the same time. Moreover, the demands placed on the infrastructure are gradually changing, increasing and diversifying	All infrastructure elements (irrigation canals, drainage canals, and hydraulic structures) are designed for one specific purpose
Design	Only partly man-made and not designed for optimal performance	Completely man-made and designed for optimal performance
Users	Many different users with heterogeneous requirements and demands to an extent that these are contradictory and mutually exclusive	Homogeneous in their demands: the right amount of water at the right moment
Main management challenge	How to find and subsequently implement an acceptable compromise for conflicting demands, and how to decide on and implement the exclusion of particular uses of water or infrastructure	How to equitably distribute water in periods of water scarcity, when there are conflicts between head and tail end farmers

Besides the inherent differences between irrigation systems and FCD schemes from a water management perspective, water management in FCD schemes is complicated by the fact that hardly any appropriate management strategy has been developed for these schemes. Internationally, much has been written on improving water management in irrigation systems. This has resulted in the development of appropriate management models for irrigation systems. For FCD schemes this has not been the case and water management in FCD schemes remains much more behind than the irrigation schemes. Some reasons for the difference in attention that has been paid to irrigation systems and FCD schemes are given in Table 3.9.

Table 3.9 Differences in attention between FCD schemes and irrigation systems (Bangladesh Water Development Board, 1997)

	FCD schemes	Irrigation systems
Economic	Of moderate economic importance (conditions are less optimal for competitive farming, hence mainly subsistence farming)	Of great economic importance. Need large investments and are expected to greatly contribute to GDP
Profile	Have a low profile, as there is hardly anything to be gained for engineers as well as politicians for effectively managing a FCD scheme	Have a high profile (modern technology, high expectations) attracting attention and support from politicians and others. Success must be ensured
Design	A mix of man-made (designed) and natural infrastructural elements. Function and importance of each element is not always clear and multi-functionality complicates management	Designed to be managed (infrastructure is transparent and based on engineering logic)
Management models	In their infancy, with no straightforward solutions for conflicts of interest	Well established with workable solutions for conflicts of interest

3.6 TYPES OF FLOOD CONTROL AND DRAINAGE SCHEMES IN BANGLADESH

An important characteristic for classifying FCD schemes is the type of flooding they are subjected to. For example, it is possible to classify FCD schemes as drainage-only schemes, high level of protection against river flood schemes, protection against tidal flooding (coastal polders) schemes and protection against flash flood (haors) schemes. This classification ties in with the four different types of floods in Bangladesh, namely:

- rainfall floods;
- river floods;
- tidal or coastal flooding;
- flash floods. Flash floods may occur in the Eastern, Northern and the North-eastern areas of the country at any time during the wet season. A flash flood is characterised by a sharp rise followed by a comparatively rapid recession. The duration of high flood stages may be for a few days only. A rapid rise in river stage and associated high velocity may cause large damage to crops and properties.

By taking into account the various characteristics of FCD schemes (Table 3.12) (such as the types of infrastructure, the topography, the main water management challenges and the typical conflicts) the schemes can be classified in (Bangladesh Water Development Board, 1997):

- Hoar schemes (Figure 3.4);
- Chittagong polders (Figure 3.5);
- Khulna polders (Figure 3.6);
- Beel schemes (Figure 3.7);
- Floodplain schemes (Figure 3.8).

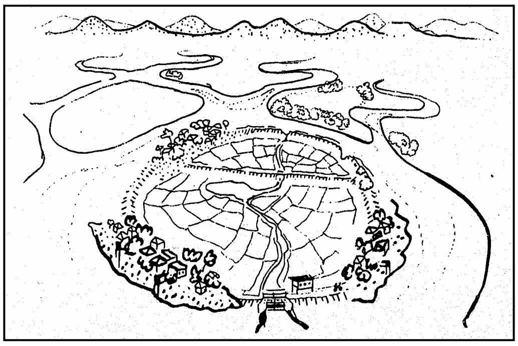

Figure 3.4 Haor scheme

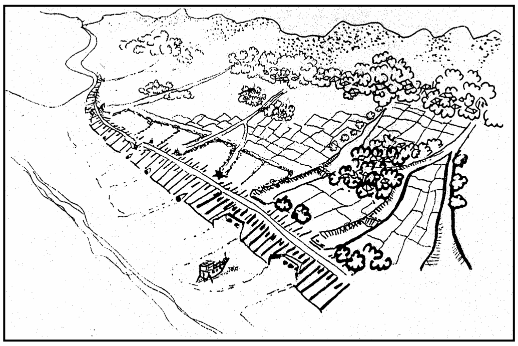

Figure 3.5 Chittagong polder

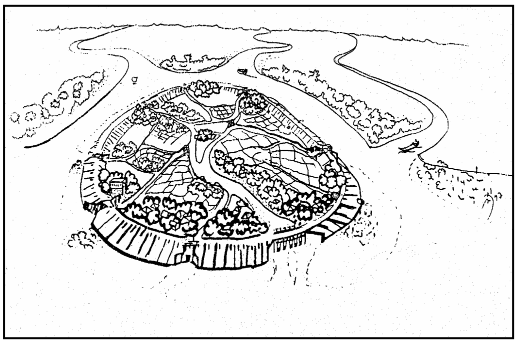

Figure 3.6 Khulna polder

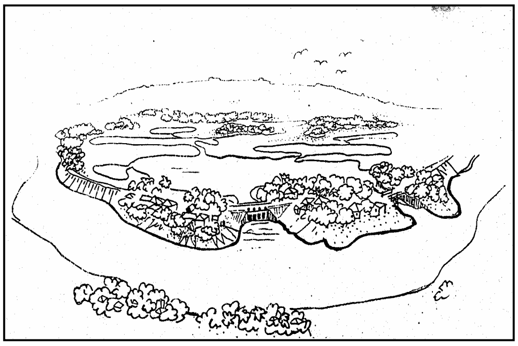

Figure 3.7 Beel scheme

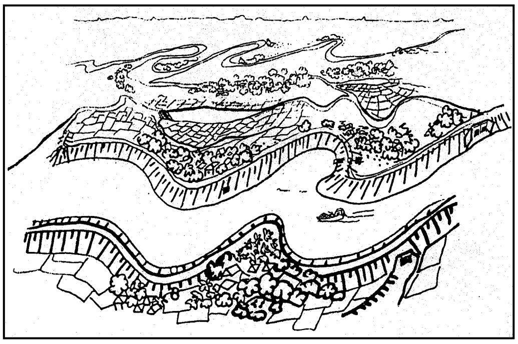

Figure 3.8 Floodplain scheme

Since its creation the Bangladesh Water Development Board has implemented different types of FCD schemes all over the country. As per classification described above, the benefited area of the different FCD schemes excluding the irrigation systems upto 2000 has been derived from the completed projects list of Bangladesh Water Development Board and is presented in Table 3.10.

3.7 SYSTEM ELEMENTS OF THE FCD SCHEMES

Water control in FCD schemes is characterised by two factors, namely the actual use of the water management infrastructure and the control over it. The performance of the schemes is fully dependent upon the proper operational strategy for the different system elements of the schemes. In Table 3.11 the favourable and unfavourable characteristics of the system elements and the subsequent consequences for the FCD schemes are shown.

Table 3.10 Benefited area of the different types of FCD schemes, excluding the irrigation systems

Type of scheme	Area in million ha
Beel schemes	0.28
Haor schemes	0.22
Chittagong polders	0.13
Khulna polders	0.72
Floodplain schemes	0.91
Total	2.26

Table 3.11 Advantages and disadvantages of the system elements for the FCD schemes in Bangladesh

System elements	Favourable characteristics	Unfavourable characteristics	Possible consequences
Embank-ment	Safe harvesting Reduce salinity intrusion Safe agriculture Good road communication Generally flood free land Increase of agricultural land Start of infrastructural development Increase of culture fishery	Major drainage congestion Navigation problems Less capture fishery Affect groundwater table Starts reduction of soil fertility Less floodplain area to accumulate flood Breaching of embankment	No involvement of beneficiaries in O&M Poor O&M
Main sluices	Limited drainage problems Scope for water retention Better capture fishery	Water logging in different small pockets Less availability of water for traditional irrigation Less openings for the capture fishery to enter into the floodplain Less soil fertility Less floodplain area to accumulate flood	No involvement of beneficiaries in O&M Public cuts in embankments Poor O&M
Minor sluices	Reduce small pockets, drainage problems Scope for water retention	Less availability of water for traditional irrigation Less water controlling facility in regulators Reduce fish productivity	No involvement of beneficiaries in O&M Poor O&M
Vertical lift gate and flushing sluices	Availability of water Change in cropping pattern Increase in cropping intensity	Shortage of irrigation water Limited water controlling facilities Reduce fish productivity Construction of many FCD schemes causes water level rise in adjacent rivers	Lack of people's participation during development Use of more fertilizer Operational problem Conflicts among different users No cost recovery
Khals	Improved drainage Improved navigation Water retention for irrigation and domestic use Improved capture fishery	Water quality problems More re-excavation needed	Unauthorized intervention No maintenance Conflict between fisherman and farmer

O&M = Operation and maintenance

3.8 DESIGN CRITERIA AND CHARACTERISTICS OF THE FCD SCHEMES

There is a wide variety of water control infrastructure in most FCD schemes, such as embankments, sluices, cross dams, private drainage pipes, shrimp inlets and pumps. The relationships between these different infrastructures are often complex. Large and small water bodies, such as haors, beels and khals are used for different purposes, such as fishing, water retention for irrigation, drainage and domestic use, and these uses differ throughout the year. Consequently, there are more water management options in FCD schemes than simply keeping the water out during floods and draining the area when river water levels are lower than countryside waters.

Local initiatives, such as construction of cross dams and the cutting of embankments are vivid examples of how people cope with water management challenges. A wide diversity of water management practices exist in the field, in which stakeholders with diverging objectives compete and struggle over water control. The outcome of these struggles largely determines who are and who are not getting benefits from the FCD schemes.

The type of water management varies widely throughout Bangladesh. Each type of water management scheme is unique and possesses its own distinct set of water management challenges. In Table 3.12 characteristics of different types of FCD schemes are presented.

The crest level of the high level flood and submersible embankments was determined at a 1:20 and 1:10 year flood level respectively. In case of submersible embankments extreme values until 15 May were considered. A freeboard of 0.9 m and a confinement set-up of 0.3 m were used for the high level flood embankments while for the submersible embankments this set-up is 0.3 m (Bangladesh Water Development Board, 1983). Sometimes an extra 0.3 m was added based on considerations regarding settlement of the embankment. The high level flood embankment was designed with a crest width of 3.6 m and side slopes of 1:3 on the river-side and 1:2 on the land-side. In case of submersible embankments, at a few places both side slopes were designed 1:2 because of less wave action (running North-south direction). The design parameters of embankments for the coastal polders were already mentioned in Table 2.2.

The sluices of the different schemes were designed based upon the area to be drained or flushed and the topography for a particular scheme. The river water level, drainage period, types of crops, the amount of water required for the area and rainfall pattern within the area were also the governing factors, which vary according to the place and the condition. To operate the sluices flap gates and vertical lift gates were installed as per requirement of the scheme. For the sluices two standard opening sizes were applied by the Bangladesh Water Development Board, which are: 1.52 x 1.83 m and 0.9 x 1.2 m. As per design requirement a multiple number of openings were used. For detail hydrologic calculation a design manual has been used in Bangladesh water Development Board.

Table 3.12 Characteristics of different types of FCD schemes (after Bangladesh Water Development Board, 1997)

Elements of the scheme	Haor scheme	Chittagong polder	Khulna polder	Beel scheme	Floodplain scheme
Embankment (river or sea-facing, main or minor)	Submersible river embankment surrounding most or all of the scheme	One main sea-facing embankment, some minor embankments	Sea-facing and river embankments all around the scheme	One main river embankment, and some minor embankments	One or two main river embankments
River (exterior)	Surrounded by rivers	Sea on one side, khals or rivers on one or two other sides	Surrounded completely by rivers and or the sea	One, and sometimes two rivers	In the middle of a network of rivers (in the floodplains)
Khal (interior)	Some	Many, relatively small khals, parallel to each other and perpendicular to the shoreline	Many interconnected khals, spider web type	Usually one main khal with one outfall	Many khals, more or less parallel to the main rivers, that are actually stream beds of the main rivers
Beels	Some	None	None	Several important large beels and many small ones	Few, relatively less important beels, or many small ones
Hydraulic structures	Few Cutting of the embankment is the main operational tool	Many minor sluices Many cross dams	Many minor sluices and pipes One or two main sluices	One main sluice and some cross dams, very few other minor sluices	Few, would require many hydraulic structures for optimal management
Catchment	Scheme area	Scheme infrastructure also has to handle runoff from adjacent highlands	Scheme area	Highland on two or three sides of the scheme, which results in runoff into the scheme	Scheme area and inflow from the floodplains
Main water management constraint	Flash floods	Drainage congestion and water retention	Drainage congestion due to blocking of khals	Drainage of internal flooding due to monsoon rains	River floods
Main water management challenge	Keeping the flash floods out until the Boro is harvested	Managing salinity levels inside the polder and controlling tidal flooding	Defining a coherent water conveyance system and controlling tidal flooding	Operation of the main sluice and management of the beel	Controlling river floods
Typical conflicts	Between fisheries (beel and haor leaseholders) and agriculture and between highland and lowland farmers in the scheme	Between farmers and salt and shrimp producers Between upstream and downstream farmers	Between farmers throughout the scheme relating to drainage congestion	Between fisheries (beel leaseholders) and agriculture and between highland and lowland farmers	Few conflicts
Other	Flooded six months of the year Homesteads at elevated locations	Salt and shrimp production is very important	Salt and shrimp production is important in some areas Navigation very important	Water retention is very important	Embankment cuts by neighbours to lower river levels Susceptible to river erosion

The khals were designed based on the area of the schemes to be drained. The sill level of the sluice, river stages, types of soil, topography of the area, other sources of water and the inside water level were the governing factors. The rainfall and drainage coefficient is also an important factor to design a khal. Normally existing khals were excavated but in some cases new khals were made. The side slopes of the khals are 1:2. The bottom width and longitudinal slopes were determined according to the field conditions.

One chief engineer is fully responsible for all the design activities in the Bangladesh Water Development Board. He does his work with some design offices posted under him. The request for any design and data collection for that design is the responsibility of the respective field offices.

Analysing the description presented above it is clear that the water development in FCD schemes has a wide diversity in demands and interests of the stakeholders. It shows a wide scope for integration among the various aspects of water development, especially environmental, agricultural and institutional, which has not been well addressed till now. In the past no legal framework and no water rights for stakeholders participation in the development and management of FCD schemes were defined. Recently this has been outlined for new reclamations, as well as for improvements in the existing schemes. Conceptual understanding and recognition of the importance of operation and maintenance in FCD schemes need to be improved.

4 LITERATURE REVIEW ON RELEVANT SOUTH EAST ASIAN COUNTRIES

4.1 LAND AND WATER DEVELOPMENT

The world's population had reached 6 billion in 2000 (Rosen, 2000). Projections for 2025 and 2050 show a world population of 8 billion and 9.3 billion people respectively. Most of them will live in Asia (Roberts, 1998). This expected growth, in combination with the expected increases in the standard of living in many countries will require a significant increase in food production. On the other hand loss of agricultural land and reduction in crop yields are caused by erosion, desertification, urbanisation and industrialisation, water logging, salinization, environmental concerns, or degeneration of existing flood control, drainage and irrigation schemes (Schultz, 1993). Urbanization and industrialization, for example, result in a loss of some 13 million ha cultivated land annually. Most of the extra food (about 90% over the next 25 years), is expected to come from the present 1,500 million ha cropland of the world. In addition it is expected that about 10% from the required increase will have to come from newly reclaimed lands (Hofwegen and Svendsen, 2000).

The demand for water all over the world is growing rapidly. The domestic and industrial use of water is increasing and there is a constant pressure to increase agriculture yields, which imposes greater water requirements for irrigation. Growing more food requires more water (rainfed or irrigated). Water supplies used in agriculture will have to be augmented by an additional 15 to 20% over the next 25 years to meet the food requirements under favourable water management and agronomic conditions (Hofwegen and Svendsen, 2000). Improved water management practices both on farm and in delivery systems, comprising new approaches, reforms in management institutions and rational pricing policies can help significantly to meet the future water supplies. The efficiency in developing the river basins and their natural resources depend, among others, on comprehensive river basin management plans.

All the countries in South East Asia have a monsoon climate and a large portion of precipitation results in unused runoff during the relatively short wet season. The percentage of water use varies greatly among the different countries, from 1% to 30% (Hofwegen and Svendsen, 2000). More than 70% of water use in the region is devoted to agricultural purposes, mainly Rice. Domestic and municipal water use is in the range of 10 - 20%, while the industrial water use is about 10%. Wet season rainfall is generally adequate for Rice cultivation. Cropping is often not possible in the dry season without irrigation. These conditions indicate the need for the region as a whole to increase investments in water saving, to secure dry season supplies and to reduce damage due to floods and inundation in the wet season, combined with improved management practices.

In addition to the increasing population of the world the average consumption per person is rising which can be observed from the grain fed to livestock as percentage of total grain consumption (grains include Wheat, Rice, Corn, Oats and mixed grains). For example in Asia, 8% in 1974 and 24% in 1997 (World Resources Institute, 1998 - 1999). There is no easy answer how long the growth in agricultural production can be maintained while our lands and other natural resources will come under increasing pressure and degradation. The population conditions in some South East Asian countries are presented in Table 4.1.

Table 4.1 Size and growth of population in some South East Asian countries (World Resources Institute, 1996 - 1997)

Country	Population in million				Average annual population growth in %		
	1950	1990	1995	2025	1980 - 1985	1990 - 1995	2000 - 2005
Bangladesh	42	108	120	196	2.2	2.2	2.0
Indonesia	80	183	198	276	2.1	1.6	1.3
Malaysia	6	18	20	32	2.6	2.4	1.7
Thailand	20	56	59	74	1.8	1.1	0.9
Vietnam	30	67	75	118	2.2	2.2	1.9

One of the major objectives of land development schemes in South East Asia is to increase the food production in order to have a balance with the population growth. The food production in the same South East Asian countries is presented in Table 4.2. To meet the effective demand for food products in the 21st century, food production and consequently water uses for agriculture need to be increased substantially. To meet this demand pattern in an efficient, equitable, and environmentally sustainable manner will be a major challenge, especially in the South East Asian countries.

Table 4.2 Agricultural production in some South East Asian countries (World Resources Institute, 1998 - 1999)

Country	Average production of cereals		Average yield of cereals	
	in 1,000 tons 1994 - 1996	% of increase since 1984 - 1986	in kilograms per ha 1994 - 1996	% of increase since 1984 – 1986
Bangladesh	28	14	2,602	18
Indonesia	57	23	3,895	11
Malaysia	2	19	3,052	13
Thailand	26	5	2,434	14
Vietnam	26	37	3,504	24

The policy in almost all the developing countries is self-sufficiency in food production. One of the means to increase the food production in these countries is to improve the existing water management schemes in uplands and lowlands. Large and small-scale land development projects can still be undertaken in the near future in the South East Asia region. In this Chapter, land and water development projects and water management in South East Asia will be presented in general terms.

4.2 WATER MANAGEMENT AND LOWLAND DEVELOPMENT

Much of the agricultural land in South East Asia suffers from water logging due to tidal and river flooding during high rainfall periods. Salinity in the coastal areas is also a problem due to intrusion of salt water from the sea and rivers during high tidal cycles. The drainage problem is further compounded by the fact that much of this agricultural land is located in flat deltaic regions. Because of tidal fluctuation, both pumped and gravity drainage schemes were developed. In addition due to the dry season, irrigation is also needed when crops will be grown during this period. In order to deal with the flooding of low-lying deltaic areas, a large number of flood control, drainage and irrigation schemes were implemented in this region.

Many of these developments have positive impacts and increased the agricultural production of the country but some of them had negative impacts too. Many of these schemes create significant environmental problems like reduction of different fish species and reduction of the floodplain, which ultimately results in bad water management in those systems.

The performance of many irrigation and drainage schemes is significantly below potential due to a variety of shortcomings. These include inadequate design, use of inappropriate technology, system layouts that do not adequately reflect existing conditions, inappropriate governance arrangements and poor management practices (Hofwegen and Svendsen, 2000). Injudicious planning of roads, canals and other infrastructure blocking the natural drainage ways also cause many of the drainage problems, especially in low lying irrigation and drainage schemes. There is considerable scope for preventing and alleviating drainage problems by more integrated planning and water management. Nowadays, within Asia pressures are building up for irrigation management so that organizational, technical, financial, and especially environmental aspects of water management have to be integrated in a sustainable way under democratic and local management (Jansen, 1997 and Japanese Committee of the International Commission on Irrigation and Drainage, 2000).

Over the period of time a common understanding has developed specially for the developing countries regarding the water management schemes. The land and water development activities have to shift from Government oriented decision making to community involved decision making processes. In rural development and the alleviation of poverty, particularly related to income generating activities, community participation is becoming more and more important and must be considered as a necessity.

Lowland development can be found all over the world, in different soil, hydro-topographical, climatological and hydrological conditions. Distinction can be made between reclamation in areas where a regional drainage base exists permanently (swamps, shallow seas and lakebeds) or temporarily (tidal coastal lowlands, seasonal flooded river plains) (Schultz, 1983 and Segeren, 1983). This study is primarily dealing with the low-lying coastal lands. The distribution of the coastal lowland development areas (existing and potential) in South East Asia is presented in Figure 4.1.

The agricultural land use in the South East Asia region is characterized by predominantly Rice growing, which is rapidly changing towards other valuable crops. For example, in Thailand Fruit crops and in Malaysia Oil palms are cultivated extensively. Generally the region has two types of soils, i.e. peat and coastal marine clay soils. The composition of the deposits varies locally and is related to the geomorphological processes. Climates generally display at least one season of intensive rain which supports large areas of agricultural lands. The annual precipitation is around 2,000 - 2,500 mm (Economic and Social Commission for Asia and the Pacific, 1991). The tides in this region are generally semi-diurnal with amplitudes between 1.0 - 3.0 m.

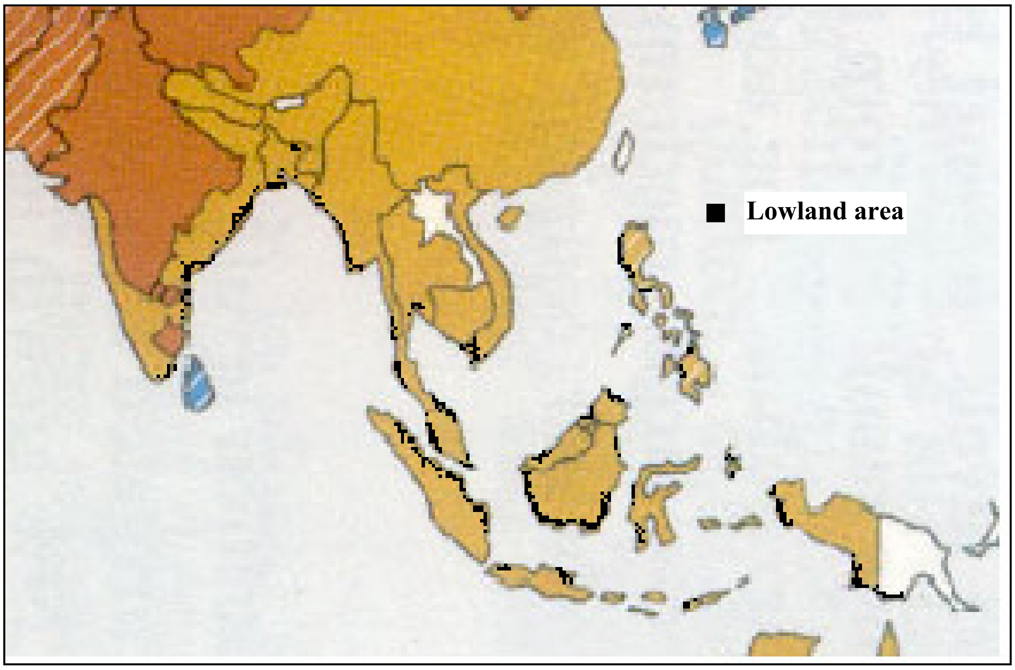

Figure 4.1 Distribution of lowland development areas (existing and potential) in South East Asia (after Van Breemen and Pons, 1994)

Salinity intrusion is very much influenced by tidal characteristics, river geometry and upstream discharges (Abraham, 1986 and The International Navigation Association, 1993). The original vegetation in tidal lands consists mainly of mangroves, which grow very dense. Water management schemes are concentrated on irrigation, drainage and flood control with or without hydraulic control structures. The key feature of the coastal lowland development of some South East Asian countries (more or less similar to the study area in Bangladesh), i.e. Indonesia, Thailand, Vietnam and Malaysia will be briefly described.

4.2.1 Indonesia

The total population of Indonesia is 217 million in 2002 and the projected population is 318 million by the year 2050. Out of the 162 million ha land resources in Indonesia, about 39 million ha are lowlands (24%) and about 123 million ha uplands (75%). The lowlands have their characteristics in accordance with their geographical and hydro-topographical conditions. Based on those conditions they can be divided into two sub-groups, i.e. coastal swamps and inland swamps. The coastal swamps are influenced by tidal fluctuations while the inland swamps are influenced by river floodplain characteristics.

In the Sumatra and Kalimantan islands the typical characteristics of tidal lowlands are (Heun, 1993):

- rainfall is in the order of 2,000 - 2,500 mm per year with 5 - 8 wet months and 1 - 3 dry months;
- evaporation (penman) ranges from 3.5 - 5.5 mm/day;
- field levels before reclamation are typically at about Mean High Spring water level in the wet season;
- tidal gravity irrigation can only be applied in 10 - 15% of the area;

- potential for pump irrigation is restricted by water quality (salinity, acidity).

2 million ha of land have been reclaimed so far along the Eastern coast of Sumatra (Riau, Jambi, South Sumatra and Lampung), and along the Western and Southern coast of Kalimantan (Manuwoto, et al., 1986).

The reclamation process of coastal strips in Indonesia was practiced by the Buginese and Banjarese since more than 100 years. The main purpose was to find living space for new generations because of the limitation of further expansion possibilities in the village of origin. The Buginese reclaimed those lands mainly for agricultural use and construction of their homestead.

Since 1960, the Indonesian Government has been reclaiming tidal lowlands. The reclamation has to create a suitable environment for agricultural development and settlement. The objectives were to (Swamps Directorate, 1980):
- increase the national food production, mainly Rice, in order to obtain self sufficiency;
- provide agricultural land for transmigrants, in order to support the Government transmigration programme;
- support regional development;
- increase the income per capita;
- increase the security on coasts along the border lines.

Some results of an inventory study on lowlands which was carried out in 1985 are presented in Table 4.3 and Table 4.4 (Ministry of Public Works, 1984 and 1991).

Table 4.3 Swampy land resources in four majors islands in 1,000 ha (Ministry of Public Works, Directorate General of Water Resources Development, 1984 and Ministry of Agriculture, Directorate General of Food Crops, 1992)

Type of swampland	Sumatra	Kalimantan	Sulawesi	Irian Jaya	Total
Tidal lowland	9,771	7,054	84	7,798	24,707
Inland lowland	3,440	5,710	385	5,181	14,716
Total	13,211	12,764	469	12,979	39,423

Table 4.4 Tidal lowlands in Indonesia in 1,000 ha that are suitable for agricultural development (Ministry of Public Works, Directorate General of water Resources Development, 1991 and Ministry of Agriculture, Directorate General of Food Crops, 1992)

	Sumatra	Kalimantan	Sulawesi	Irian Jaya	Total
Not cultivated	1,380	1,392	12	2,808	5,592
Cultivated	2,062	1,460	72	6	3,600
Total	3,442	2,852	84	2,814	9,192

The tidal lowlands are remote and uninhabited. Tidal lowland development by the Government took place primarily along the East coast of Sumatra, in South and West Kalimantan and in the Southern part of Irian Jaya to accommodate settlers from the over populated islands Java, Bali and Madura. Tidal lowland development gradually gained momentum for agricultural development in Indonesia because, mainly in Java, there is a continuous loss of fertile agricultural lands for residential and industrial development.

Coastal lowland development in Indonesia has been carried out as a gradual long term process, known as the stage-wise development strategy which started in stage-I, with open, uncontrolled water management systems and would have to end with fully controlled systems (polders) in stage-III. In stage-II some hydraulic structures would be completed in order to improve the agricultural performance of the scheme. This strategy was based on the following considerations (Soesanto Soedibyo, 1977):

- limited availability of construction budget, and the need to reclaim large areas;
- lack of knowledge, experience and design criteria;
- the social cultural background of the transmigrants. Most of them were coming from 'dry' land areas and not familiar with wet tidal land conditions.

The stage-wise development strategy was a good approach especially for Indonesia where the farmers were themselves involved in the establishment of schemes and learned to set up water board organizations for small hydrological (basic) units with relatively simple tasks. Besides this advantage of the stage wise approach, there were some disadvantages, i.e. (Heun, 1990):

- development of the reclamation unit(s) was too slow in general and it will take a long time to reach the final development stage;
- because of small investments during the first stage, it was very difficult to reach a production above the subsistence level;
- financial supports are still needed for the second and third stage of the development programme, so the total amount of financial support could be higher then if a high cost approach was applied immediately.

From 1985 – 1995 there were almost no new reclamation projects by the Indonesian Government, main focus was on improvement (phase-II) of reclaimed areas. Since 1996 new reclamations started in South and Central Kalimantan, mainly in river floodplains (Lieshout, et al., 1998). In these schemes, due to the different river water levels during the wet and the dry season, in addition to irrigation and drainage, also flood protection is needed.

Nowadays, most of the reclamation schemes are in the beginning of the second development stage. The large areas of tidal lowlands are not yet well developed but their potentials might be considered as important means for increasing food production (self-sufficiency) including crop diversification and providing settlement areas for transmigrants. Due to the need to increase food production it will most probably be a must for the Government to undertake new reclamation projects in future, together with phase-II and phase-III developments.

So far, the Indonesian Government (mainly the former Ministry of Public Works and the Ministry of Agriculture) had the responsibility for the design, operation and maintenance of primary and secondary drainage canals. Tertiary and field canals are the responsibility of the farmers.

Rainfall (amount and distribution) in the wet season is adequate for one Rice crop. Additional irrigation (low lift pumping) for wetland Rice may provide a high yield under proper soil and water management. But tidal lowlands are located in remote areas, hindering supply of inputs and marketing of products. In addition, close to the river mouth, salinity may create problems for agriculture and drinking water, especially during the dry season.

A substantial part of the tidal lowlands is covered by (potential) acid sulphate soils or peat soils. Soil development takes time before a stable situation is reached. Soil and water management and the related infrastructure have to be adjusted to the changing conditions.

Presently most of the schemes have operation and maintenance problems and there is lack of integration. Several attempts were made by the Indonesian Government to improve the water management in order to attain sustainability, but this has not been very successful. In 1999, a new set of policies was promulgated by the Government to hand over the responsibility of operation and maintenance to the water users associations regardless of the size of schemes.

4.2.2 Thailand

The area of Thailand is 51.4 million ha, with a population of 62 million and a growth rate of 1.5%. The average population density is 120 persons per km^2. The population projection for the year 2050 is 73 million. The country may be divided into four parts:
- Central plain;
- Northern mountainous plain;
- North-eastern zone;
- Southern zone.

The Northern, Central and North-east regions are subject to the South-west monsoon, starting between late April to June, and causing an annual rainfall of 1,000 - 1,500 mm. During a normal year water availability for Rice is sufficient but shortage can occur during a subnormal year (Hungspreug, 1997). In the dry season it is impossible to grow a second crop without irrigation. In the wet season, lowland areas in the central plain experience flooding and water logging. The Southern region has a sharply different climate from the other regions. The annual rainfall ranges from 1,800 – 3,500 mm. This region experiences water logging more than the other parts of the country.

In Thailand 41% of the lands are cultivated. Lowland development is mainly taking place to increase the agricultural production. Rice is the most important crop, not only as a staple food crop but also as a first ranking export crop. At present the expansion of Rice fields is very difficult. Opening up new areas, or deforestation is no longer practiced. The only way to increase the Rice yield is by introducing irrigation and drainage in the existing agricultural land. About 21.1 million ha is agricultural land which is categorized in million ha as follows (Boonkird, 2000):

- Rice land	10.88
- field crop land	5.12
- fruit trees and tree crops	3.52
- vegetables and flowers	0.16
- housing area	0.64
- grass land, idle land and others	0.84

The central plain region, forming the Thai heartland, is the largest region of the country, mainly consisting of the Chao Phraya river delta. This fertile delta, having a vast complex of canals and small irrigation projects, is the centre of the country's agricultural, commercial and industrial activities. The area of the Chao Phraya delta is formed from brackish water alluvium, with fresh water alluvium in the Northern part and a marine non-saline and saline part near the gulf of Thailand. The soils are poorly drained and contain clay with distinct red and yellow mottles in the profiles together with straw-yellow mottles of the jarosite crystal in the acid sulphate soil groups (800,000 ha). Wet season rain and the vast flat valley floor of the Chao Phraya river create conditions that are favourable for Rice production. The mean annual run-off of the Chao Phraya river basin is 33,800 million m^3 (including Ping, Wang, Yom, Nan, Sasae Krang and Pasak) and of the Mae Klong river basin 7,900 million m^3 (Department of Irrigation Engineering, 1997).

The first land reclamation scheme started in 1921 and was completed in 1931, covering a total area of 208,000 ha. The scheme is located on the Gulf of Thailand, South-east of Bangkok. The Rice cultivation in this scheme is successful. There are three more large reclamation schemes which are located West and South-west of Bangkok, i.e.: Petchburi scheme (3,200 ha), Pranburi scheme (3,200 ha) and Greater Meklong scheme (51,000 ha) (Framji, et al., 1983). There are also many small polders with a total area of 15,000 ha of which around 2,000 ha is situated near Bangkok for the cultivation of fruits and vegetables (Stoutjesdijk, et al., 1982).

A sea dike was constructed along the Southern edge of the country to prevent salinity intrusion. In the dike there are discharge sluices. The main water management schemes consist of open canals. Leaching of toxic materials is performed without groundwater control. The water is drained by gravity (Stoutjesdijk, et al., 1982). There is an infrastructure which is called 'ditch and dyke' for a better water control at the farm level.

As the water demand is increasing due to population growth, expansion of the industrial and service sectors, the Government Agencies concerned with water management are planning to construct more and more water sector schemes. In the concept towards developing more water, the other resources associated with water resources development are becoming constraints for new projects. Environment is an important issue which has to be addressed properly.

4.2.3 Vietnam

The area of the Vietnam is 33.1 million ha with a population of 80 million in 2002. The growth rate is 1.7% per year. The average population density of the country is 232 persons per km^2. Vietnam had shortage of Rice in the past but nowadays it has a surplus. Vietnam has 7.0 million ha of cultivated land, of which Rice fields account for 3 million ha. There are nine big river systems. Out of them six are flowing through Vietnam and neighbouring countries. In Vietnam fresh water alluvial soils, cover an area of 1,164,000 ha. There are two large lowland areas i.e. the Mekong delta and the Red river delta. Coastal lowland development is aiming at improving the agricultural production, which is mainly Rice. Nowadays Rice accounts for approximately 85% of total the cropped land and 90% of the total food production in the country (Cinet, 1999). Vietnam has assigned a high priority to expanding the production of food, export commodities and consumer goods in its national development plan. The average annual rainfall and average annual evaporation are 1,900 mm and 1,350 mm respectively.

Saline soils, covering an area of 703,500 ha of which 90,000 ha in the Red river delta, are generally suitable for Rice growing. Although the agricultural area in the Mekong delta is 2.7 times as large as in the Red river delta, the agricultural population is the same (Bank, 1994). This is due to significantly different soil and climatic conditions for agricultural development. The development of the deltas depends on the management of water resources through drainage, irrigation, flood control, acidity and salinity control.

Rice is the main crop in the Mekong delta (Do Hong Phan, 1993). The Mekong delta covers an area of 3.95 million ha in the most Southern part of Vietnam. This delta is flat, with differences of a few meters only. Rivers and tributaries dominate the landscape. Acid sulphate soils cover an area of 1.7 million ha in the Mekong delta (Sterk, 1992). The major portion of the delta is therefore not yet suitable for agriculture. 60% of the cultivated area has only one crop per year. Physical constraints for delta development are the large seasonal variations in the flow of the Mekong river and acid sulphate soils. In the past floating Rice was cultivated which can grow in a water depth of 3 to 4 m. The yield was low, around 1 t/ha only. The Mekong delta is the main food producing area in Vietnam. The delta still has significant potential to produce more food, fish and other commodities than at present.

The Mekong delta receives heavy rains as a result of typhoons, but generally with little wind damage. At the lower Mekong river the flows range between an average of 53,000 m^3/s in September and October and an average of less than 2,000 m^3/s in April (Do Hong Phan, 1993). During floods about 25% of the delta is submerged, while during low flow periods, salinity intrusion up to 50 - 60 km from the river mouth may occur.

Since 1970’s the water management schemes consist of hundreds of kilometers of complicated open, interconnected field, tertiary, secondary and primary drains. The tides and floods can freely flow through the schemes. Large coastal lowland areas have drainage constraints. Availability of fresh water ensures quick leaching and flushing of acid materials. Low lift pumps are used for the second crop cultivation during the dry season. There is only partial flood protection by low submersible dikes in order to keep the early floods out of the protected areas.

The Red river delta is located in Northern Vietnam in the low plain of the Red river catchment. Vietnam shares the catchment of the Red river with China. The Red river delta covers 1.5 million ha. The delta is bordered by the mountains in the North and the West, and the coastline in the East and the South. In the Red river delta 718,000 ha of fresh water alluvial soils are found suitable for agricultural production.

The rainfall distribution over the delta is fairly uniform. The average is 1,740 mm/year. The dry season, from November to April, contributes on average about 200 mm, while the wet season, from May to October, contributes 1,500 mm. In the Red river delta typhoons hit from May to the beginning of September.

About 25 years ago 240,000 ha had been identified in the Red river delta as acid sulphate soils. Since that time more than 100,000 ha of these acid sulphate soils have been flushed out and converted into productive Rice lands (World Bank, 1994). The major flood control measures are embankments along the canals. Some reservoirs in the upstream part are planned, in order to reduce the flood levels in the delta areas. The development of the delta area was mainly done by carrying out the following measures:

- excavating or dredging canal networks to enlarge the fresh water influence and to improve drainage systems;
- dike construction in order to protect areas from flooding and salinity intrusion. Installing of pumping stations and drainage sluices in order to have a water control in the agricultural areas.

In order to promote the development of agricultural production in general, it is essential that efforts be made to intensify farming, expand the cultivated area and diversify production. In the field of operation, maintenance and management of the schemes the Vietnam Government has achieved quite a lot compared to the other countries in this region. The state has successfully transferred the operation and maintenance mechanism of irrigation and drainage schemes from central to local levels.

4.2.4 Malaysia

The area of Malaysia is 33 million ha, with a population of 23 million in 2002 and a growth rate of 2.6%. The climate is equatorial with a high uniform temperature, high humidity and high rainfall. Malaysia receives an annual average rainfall of 2,500 mm. Agricultural development in Malaysia has expanded rapidly. In 1997, there was 1.8 million ha Oil palm, 1.7 million ha Rubber, 0.11 million ha Cocoa, 0.16 million ha Coconut and 0.5 million ha Rice (Who, et al., 1997). As far as the policy on food is concerned, Rice production is targeted to meet a minimum self-sufficiency level of 65% by the year 2010 and will be concentrated in the main and secondary granary areas (Who, et al., 1997).

Flood control and drainage improvement schemes were initiated in the country by the Government during the first decade of the 20th century. The first schemes included the Kapar Drainage scheme in Selangor and the Bagan Datoh drainage Scheme in Perak. Since that time several drainage schemes have been implemented and the latest included the Western Johor Drainage scheme in Johor, The North-west Selangor scheme in Selangor and the Samarahan scheme in Sarawak (Dorai, 1993).

The total zone of coastal lowlands in Peninsular Malaysia, Sabah and Sarawak is about 4,800 km long and 50 km wide (Salmah Zakaria, et al., 1994). The lowland reclamation works were designed in order to protect the areas against inundation during high tides, to prevent salinity intrusion, to create effective drainage conditions for the area and to drain the heavy run-off from the hinterland catchments.

In early schemes coastal levees and river bunds, some drainage facilities, such as primary drains and gates were the main components. In later stages of the development problems of soil water stress, land subsidence and shrinkage and acidification of the soil were observed, which showed the need to incorporate new technologies and measures (Dorai, 1993).

In Peninsular Malaysia there is 351,920 ha of acid sulphate soils and 2.6 million ha of peat soils in Malaysia as a whole. About 325,000 ha of peat soil have been developed and added to the agricultural land (Who, et al., 1997). Agriculture is also practiced in less acidic areas of the acid sulphate soils.

Progress has been achieved in the development of modern drainage schemes. However, there is a lot of room for improvement to increase the effectiveness of the modern technology adopted. The scheme has to be cost effective and environment friendly, but also socially acceptable to the users (Baharum, 1993).

The potential of the irrigated agriculture sector in Malaysia is yet to be fully capitalised. In the past all aspects of irrigation up to the tertiary level were fully governed and managed by the Department of Irrigation and Drainage. There was little attempt to incorporate farmer's participation in the decision making process. The National Agricultural Policy (1992 - 2010), aims towards a more efficient and commercially oriented agricultural sector, which will require a reformulation of farmers roles (Abdullah, 2000).

In the overall planning, farmers role in financing irrigation, allocation of water rights along the river or over an aquifer, diverting water from a source, rehabilitating schemes, providing support services and owning irrigation property will be re-established. The factors associated with irrigated agriculture for sustainable development are many and complex in nature. Policies and legislation must promote an integrated approach to land and water resources planning, development and management, supported by a comprehensive natural resources inventory and evaluation mechanisms (Abdullah, 2000).

4.3 IMPORTANT ISSUES OF LAND AND WATER DEVELOPMENT IN THE SOUTH EAST ASIA REGION

Based on the description of lowland development in the South East Asia region, it can be concluded that lowland development has been carried out due the following reasons (Lal, et al., 1981 and Hammond, et al., 1994):

- increase agricultural production of the country in order to cope with the population growth;
- compensate the loss of agricultural lands due to industrial and urban development;
- create new lands for industrial, urban and recreational use.

Most of the schemes (flood control and drainage), that were implemented to increase the agricultural production are not performing as envisaged. There are some good examples related to the performance in different South East Asian countries. The situation and hydrological conditions of the implemented schemes has changed with time. The user's demands are also changing, due to the changed situations. The performance of the constructed schemes is also reducing. The operation and maintenance of the schemes has often been neglected substantially by the

Governments and the users. Involvement of the farmers and their opinion was not considered as an important aspect in project planning.

New land and water development possibilities are reducing but not yet finished. In future the scheme planning should also take into account the related aspects of development and try to minimize possible negative environmental consequences. Water development and its management should be based on a participatory approach involving users, planners and policy makers at all levels. Public support for policy actions needs to be generated through awareness and education campaigns. To ensure adequate participation of the water users association (WUA) and the private sector in water saving activities, innovative approaches should be promoted.

Land and water development will have a vital role to play in improving the world's food production and standards of living within a proper environment. To develop land and water in lowland areas in a sustainable way, water management schemes should be based on two basic aspects i.e. soil and water conditions and their characteristics which are distributed non-uniformly in space and time. Besides the soil conditions, according to Schultz (1982) the main components of water management schemes, which have to be considered, are:

- area (percentage) of open water;
- capacity of the field drainage system;
- discharge capacity of the main system;
- type and capacity of the outlet of the system;
- irrigation channels and capacity;
- flushing through sluices;
- flood control measures.

These are the main components of a lowland scheme with a sluice, or a pumping station (polder). In case of a gravity drainage scheme in tidal lowlands, one important aspect also has to be considered: tidal characteristics (amplitude and period).

Integrated water management is required for sustainable development. Different aspects of sustainability are:

- technical sustainability (balanced demand and supply, no mining);
- financial sustainability (cost recovery);
- social sustainability (stability of population, stability of demand, willingness to 'pay');
- institutional sustainability (capacity to plan, manage and operate the scheme);
- environmental sustainability (no long-term negative or irreversible effects).

In the past, in many cases the planning process had largely ignored linkages between water users, river basin, water and some important considerations such as health, income, equity and ecology. Policies and plans in the near future have to consider the increasing interest of many stakeholders of water. Turnover of small water development and management schemes from the public to the private sector, and the important role of water user organizations and participatory management at the farm level should be ensured.

5 PERFORMANCE ANALYSIS OF THE FCD ACTIVITIES IN BANGLADESH

5.1 GENERAL

The rural economy of Bangladesh is changing under the influence of many other factors than water control interventions. New crops and cropping techniques emerge, new markets develop, transport patterns change, population pressure increases, new investments are made, technologies for managing land and water improve and many other developments imply that rural areas are experiencing dynamic transformations. It is consequently not realistic to consider that the expansion of HYV cultivation in FCD schemes is only achieved because of the implementation of the schemes, as was done in most of the previous feasibility reports.

Waterlogging has been identified as a key problem faced by a significant proportion of farmers in many FCD areas. Poor drainage, poor khal excavation and maintenance are key issues for many farmers in the operation and maintenance of the FCD schemes. This leads to a prioritization for many farmers to activities related to drainage congestion. Priorities which are often not adequately reflected in the operation and maintenance activities undertaken in the schemes. It is also reflected in the actions taken by the local people such as cutting of embankments and forcing the opening of sluices.

The FCD schemes, which were evaluated so far, achieved their technical objectives at least partially. There was little exception that was based on inadequate understanding of the regional hydrology. The alignments of the embankments for FCD schemes were poorly planned, leading to failure and frequent retirement (Flood Plan Coordination Organisation, 1992). There are numerous parameters to flood control, and each scheme has site-specific objectives. In general attempts to delay early floods were successful, and in many schemes normal monsoon flood depths were also reduced. Schemes aiming at salinity exclusion were also generally successful, but sometimes they led to social conflicts between shrimp growers and Rice farmers. The achievement of drainage objectives was more variable. The poor implementation and maintenance of drainage infrastructure undermined the possibility of achieving these objectives at some schemes. Sometimes the FCD infrastructure exacerbated drainage congestion problems. In some of the scheme areas subsequent development of groundwater irrigation has occurred (introduction of shallow tube wells and deep tube wells) which replaced the scheme's original irrigation objectives.

5.2 AGRICULTURE

5.2.1 Land Ownership and Stakeholders Diversity

The total number of households in Bangladesh is 17,828,000, 67% of which are farm households and 33% are non-farm households. The number of small farm households (0.02 to 1.01 ha) is 9,422,000, medium farm households (1.02 to 3.03 ha) is 2,077,000 and large farm households (3.04 ha and above) is 298,000. The total cultivated land is 7,194,870 ha and per farm cultivated land is on average 0.61 ha. The average areas for small farms, medium farms and large farms are 0.36, 1.66 and 4.82 ha respectively (Bangladesh Bureau of Statistics, 1999).

In the System Rehabilitation Project evaluation (1998) the livelihood systems showed that all the areas contained a wide range of livelihoods. Although agricultural activities were the most important source of livelihood in all areas, significant proportions of the population also depended on non-agricultural sources. This was true when the main source of income was considered. According to the evaluation on average 37% of the households interviewed were farmers with 0.2 ha or more farmed and with agriculture as the main source of income. The proportion varied from area to area, which ranged from 24% to 53%. Many farming households are diversifying their economic base to include other sources of income. This is often simple labour, agricultural or otherwise, but can include salaried employment, businesses or small-scale industry.

This differentiation of stakeholders is also applicable within households ranked as farmers. This has two dimensions: the amount of land farmed and the type of land farmed. Land distribution in the FCD schemes, as elsewhere in Bangladesh, is uneven with a large number of small farmers and a small number of large farmers. In most cases the proportion of larger farmers has fallen and that of small and marginal farmers risen. This reflects a dual process of land fragmentation for many and consolidation for a few, meaning that average farm sizes are declining and land distribution is becoming more uneven. The needs, interest and influence of small farmers are often very different to those of larger farmers, with the latter being often dominant figures in the local social and political set-up.

The second form of differentiation within the farming households is by the type, and in particular the elevation, of the land they hold. It is consequently clear that the category ‘farmers’ contains many different interest groups. This also applies to many of the poorest sections of the population, who are categorized as landless and land poor labourers. These households survive through a combination of selling their labour in agriculture, farming the small plots of land they possess (including homestead plots, which can be important sources of products that give variety to their diet) and working in other sectors. Their interests are affected by changes in the hydrological environment, which affect agriculture. Policies and schemes (especially which have poverty focus) need to take these effects into account.

A large proportion of households is involved in fishing at some time during the year. For many this is an important source of protein. Most fish is for subsistence purposes, with some also selling part of their catch. There are also professional fishing households in all areas, but their number is relatively small whilst their interests are important.

5.2.2 Land Use Practices

Land use practices are the result of several factors. Briefly those are soil physiography (land forms and soil parent material), depth and duration of seasonal flooding, length of rainfed Kharif and Rabi growing period, length of the early Kharif period of unreliable rainfall, length of the cool dry period, frequency of occurrence of extremely high (40 ^{0}C) early wet season temperatures, etc. (Bangladesh Agriculture Research Council, 1989).

5.2.3 Source and Use of Water

Water use diversification needs no elaboration. The different water bodies are being traditionally used for the following purposes:

- *surface water*: washing, cooking, bathing, animal bathing and drinking, irrigation in crop fields, utilization for fish culture, means of water transportation;
- *ground water*: drinking and irrigation;
- *rain water*: source for surface water, drinking and utilization for rainfed cultivation.

Other micro sources of water such as dew and fog often contribute to soil moisture and are useable by the plants. These sources are however predominantly dependent on climate variables such as temperature, wind and relative humidity along with elevation and the extent of forestation.

5.3 IMPACTS ON AGRICULTURE

Data analysis shows that FCD schemes have been successful in raising the agricultural production with about 35% (Datta, 1999). Thus, the primary objective of the FCD schemes of increasing food production has largely been achieved. The farmers are ready to invest in more input required by High Yielding Varieties (HYV), partly because there are fewer losses due to flooding (Flood Plan Coordination Organisation, 1992). In some of the schemes, the targeted agricultural growth rates were exceeded considerably. In others, the targets seem to have been too high. Most of the gain in production has come from the shift to improved varieties of Rice, which shows the confidence of the farmers in the performance of the schemes. Drainage congestion is the major constraint to further growth in Rice production. Improvements in design and maintenance would result in further increase, especially if the drainage problem can be dealt with adequately. In a floodplain setting, some drainage congestion is probably unavoidable and a costly solution may not be feasible. The agricultural performances in the four types of FCD schemes are summarized in Table 5.1.

Table 5.1 Pre and post project comparisons of agricultural performance for some selected FCD schemes, based on case studies (Datta, 1999).

Assessment indicators	Hoar and Beel scheme		Khulna polder		Chittagong polder		Floodplain scheme	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Rice production in ton	9,150	11,480	3,516	4,291	4,650	6,817	40,475	65,310
Cropping intensity in %	115	125	198	222	170	189	150	201
Crop damage due to flood in ton	2,420	2,820	554	292	459	115	5,945	3,355
Coverage of HYV Rice in % of cropped area	2	30	-	18	17	69	44	47

The FCD interventions normally increased the production of Rice by changing the cropping pattern from broadcasted Aus and Aman to transplanted varieties, either local or HYV. Where flood control has protected the Boro crop from early flash floods this has promoted expansion of Local Boro and adoption of HYV Boro, but this phenomenon is limited to certain geographical locations (haors in the North-east region of Bangladesh).

In most cases FCD schemes are justified on the grounds that they will improve conditions for agriculture. More particularly, depending on the scheme, it is argued that (Flood Plan Coordination Organisation, 1992):
- reductions in normal wet season water levels, duration, and rates of rise in water level will encourage farmers to adopt more productive crops (Rice varieties) which cannot tolerate unmanaged wet season conditions;
- damages due to unusual floods will be reduced, resulting in higher average yields for a given crop;
- reduced variation in wet season conditions will reduce the risks faced by farmers, who are then encouraged to adopt HYV technology (which would otherwise entail high losses in flood years, while the costs of production are higher);
- irrigation makes a change possible from low yielding Rabi crops to more profitable and productive HYV Boro in the dry season.

The eventual results of such influences may be increase in cropping intensity, more stable yields and outputs, and in a few cases an expansion of cultivated area. The ultimate aim has almost invariably been to produce more Rice.

5.3.1 Cropped Areas and Choice of Crops

Cropped Areas

There are two ways in which FCD schemes might change cropped areas:
- by bringing previously uncultivated areas under cultivation (impact on the net cultivated area);
- by changing the seasons in which land is cultivated (impact on gross cropped area and cropping intensity);
- improved water management and flood protection conditions, resulting in better conditions for cultivation.

In several schemes the area flooded by excess wet season water, in the form of permanent beels, has been reduced for such a period that for the first time a crop can be cultivated (effectively land reclamation).

Choice of Crops

FCD schemes have strengthened the dominance of Rice in cropping patterns. Particularly to the extent that they have promoted Boro at the expense of Rabi and Jute crops. The main impact of FCD is in inducing changes within the wet season cropping pattern. Particularly from B. Aman or B. Aus and Aman to local T. Aman, or even HYV Aman (in a very few cases Aus followed by T. Aman), and also from local T. Aman to HYV Aman. This is a direct reflection of the reduction in normal wet season water levels and risk of higher flood levels, which is the stable environment for encouraging the cultivation of varieties with higher costs of production and higher returns (Flood Plan Coordination Organisation, 1992).

5.3.2 Crop Yields and Crop Production Inputs

Crop Yields

Yield of Rice on a weighted average basis has increased. Increases in average yield following flood protection arise from three factors (Flood Plan Coordination Organisation, 1992):

- a switch to HYV;
- increased use of crop production inputs, given the lower perceived risk of crop failure;
- reduced annual or periodical losses due to floods.

Input use and the use of chemical fertilizers has increased significantly in the case of HYV crops and local T. Aman.

Crop Production Inputs

FCD schemes have generally succeeded in reducing crop losses due to floods. Farmers in the impacted areas have therefore to a considerable extent switched over to higher yielding crop varieties. More crop production inputs are now used. Farmers all over the schemes have been found to invest more in crop inputs - particularly in chemical fertilizers, pesticides and irrigation. One of the reasons for this increase is that the farmers in the impacted areas now give more weight to cultivation of HYVs or transplanted local varieties.

5.4 IMPACTS OF COASTAL EMBANKMENT PROJECTS

A comparative overview of the Coastal Embankment projects (polders) based on agriculture for different project conditions has been made along with the present desire of the people. Some characteristics are shown in Table 5.2, 5.3 and 5.4.

Table 5.2 Pre Coastal Embankment Project condition

Crop type	Rabi	Aus (LV)	Aman (LV)
Land use	Fallow	Fallow	Production
Problem	No problem	No problem	Damage due to flood Shortage of supplementary irrigation
Solution	Flood control and drainage project (polder)		

Table 5.3 Immediate post Coastal Embankment Project condition

Crop type	Rabi or Boro	Aus (LV and HYV)	Aman (LV and HYV)
Land use	Mostly fallow	Mostly fallow	Production
Problem	Limited salinity	Almost no problem	Damage due to localized drainage congestion Shortage of supplementary irrigation
Solution	Flood control and drainage (polder)		

Table 5.4 Present desire of people

<table>
<tr><td rowspan="2">Crop type</td><td>Option 1</td><td>Boro</td><td>Aus (LV and HYV)</td><td>Aman (LV and HYV)</td></tr>
<tr><td>Option 2</td><td>Rabi</td><td>Aus (LV and HYV)</td><td>Aman (LV and HYV)</td></tr>
<tr><td colspan="2">Land use</td><td colspan="3">To be cropped</td></tr>
<tr><td colspan="2">Problem</td><td>Irrigation, soil moisture availability</td><td>Irrigation for land preparation and drainage</td><td>Damage due to drainage congestion
Shortage of supplementary irrigation
Frequent breaching of embankment</td></tr>
<tr><td colspan="2">Solution</td><td colspan="3">Improvement of the operation and maintenance procedure of the project involving all related users and issues
Improvement of the drainage congestion
Ensure of irrigation and soil moisture availability</td></tr>
</table>

By considering the changing demand of the people and present cropping pattern of the area, an operational strategy has to be developed using the existing infrastructure of the polders including all relevant aspects of water management.

5.5 FISHERIES SITUATION

Fisheries play an important role in nutrition, employment and foreign exchange earnings of the country. Fish provides 80% of the animal protein requirements of the population. A significant part of the population depends either directly or indirectly and fully or partially on fish for their livelihood. Over 90% of the rural population largely depends on fish. About 1.2 million fishermen depend fully and another 10 million partly on fishery, which is about 10% of the total population of the country. Two major sources of fish are inland waters (sweet water) and the sea (saline). Inland water bodies are shaped by open water, such as rivers, khals, beels, floodplains and closed water bodies such as ponds, dighis (big ponds) and lakes.

Declining of fish, especially inland water fish, is a major concern of the country. Over the last four decades the pace of food grain production has been increased in line with the population growth rate. On the other hand the fishery sector has deteriorated which ultimately will create adverse impacts on the nutrition status of the population. The fishery sector accounts for about 4.7% of the GDP. Despite the relatively small contribution to the GDP, the fisheries sector is the major source of protein in people’s diet. Hence the Government of Bangladesh puts more attention to develop the fisheries sector through culture and capture fisheries.

Fishing is the main source of income for the professional fishing communities found throughout Bangladesh. These communities are increasingly facing problems, with declining fish stocks and reduced access to open water bodies. These processes are aggravated further by hydraulic structures, through interrupting fish migration and excluding floodwaters. The farmers on the other hand require more secure water management conditions by expanding both irrigation and farming areas. The present availability and future sustainability of both subsistence and professional fishing is a key aspect of water management in the polder areas.

Fisheries and FCD development are in principle in conflict with each other. The sweet water capture fisheries resources are dependent on inland water bodies. The annual flooding and post-flood standing water in the floodplains has a significant role in fish production. In the wet season floodplains play the primary role of re-population and increase of biomass in open water fishery production systems.

FCD schemes generally cause negative impacts on capture fisheries, which results from reduction of regularly inundated floodplains and beels and the blockage of past fish migration routes into the scheme area (Flood Plan Coordination Organization, 1992). In addition pesticides used in Rice lands may destroy fish species. Many fishermen have lost their livelihood or have been diverted to river fisheries, leading to over-fishing in those areas, which are also adversely affected by the change in the fish migration potential. Flood control of FCD schemes has provided opportunities for culture fisheries. Another essential impact of FCD works on fisheries is the change of water regime inside the protected area from a natural uncontrolled flow to a controlled regime. Other factors which were perceived to have been responsible for the decrease in capture fisheries concerned the expansion of agrochemical pollution (related to increased irrigated Rice production), increased incidence and severity of fish diseases, siltation in the rivers and floodplains and over-fishing.

The System Rehabilitation Project evaluation showed compartmentalized canals created by local people in several places for the purpose of culture fisheries, thereby interrupting the free flow of water through the canals into the beels (Bangladesh Water Development Board, 1998). This is quite predominant in most of the FCD schemes. The problem for fisheries in haor areas is not as acute because of the submersible nature of the embankments. These submersible embankments however, also create obstruction in early migration routes of fishes.

The absence of integrated flood control and fisheries planning has led in some cases to acute social conflicts between fishermen and farmers. However, the growing opportunities for culture fisheries within the FCD schemes do not go to the affected fishermen of the schemes. It creates opportunities for the rich farmers, those having ponds.

5.6 WATER MANAGEMENT

Water management is a dominant feature of life in rural Bangladesh. It has many forms and is regulated by many institutions, including customary rights, tradition and social norms, as well as more formal types of organization. Every farmer, every fisherman and the villagers who are not a farmer or a fisherman manage water, both individually and cooperatively. In addition, there are specialized groups whose whole livelihood depends on their ability to manage these resources: professional fishing communities, boatmen, net makers, shrimp farmers, salt producers, irrigation pump owners and many others. Water management in FCD schemes is the control of water surpluses, shortages and quality by adequate operation and maintenance of system elements as canals, sluices, embankments to obtain optimal conditions for activities within the boundaries of the FCD scheme.

The widespread development of Boro Rice cultivation is largely dependent on the spread of small private diesel pumps. Effective local water markets are emerging all over Bangladesh and their development is a key to water management (shortage of surface water during that period). For many farmers, the main issue is not excess of surface water in the wet season, but it is increasingly the sustainability of access to surface and groundwater supplies during dry spells. These dynamics of changing human-water management issues are again specific to the local conditions and need to be reflected in the development of policies and interventions in water management in the FCD schemes.

The system components in irrigation systems is well defined and planned (e.g. main, secondary and tertiary). But the system components of the FCD schemes are not so well defined. The embankments, sluices, existing canals and sometimes excavated canals are system elements in FCD schemes. Within a scheme there are numerous canals which have a link with a sluice. It is very difficult to find an independent influence area of a hydraulic structure (sluice). This situation is even more complex in coastal polders. There are some human interventions within the existing canal systems, which aggravate the situation further. Normally the main sluice, which has a big canal in connection, is used for drainage and flushing purposes. Nowadays farmers want to store water in the main canal and use it through low lift pumps or some traditional devices. In coastal areas farmers are still in favour of natural spreading of water over their field during spring tide which they had earlier. But from a technical and management point of view that is very difficult. There are some small sluices, which are connected to some small local canals, used for local drainage and flushing. The main canal which is connected to the big sluice has some branch canals which help the farmer to store water and drain it when required. In some cases the branch canal may be further divided. For coastal polders almost every canal is linked with another. But nowadays the rural development disturbs the situation greatly. The schemes were originally designed to provide flood protection, drainage and little irrigation facilities (storing water in the khals). The improved situation has changed the water requirement scenario of the farmers inside a polder.

5.6.1 Water Management Conflicts

The land elevation within a polder is not all over the same. That is why conflicts arise on water management. All the stakeholders of a polder do not have the same interest. So, conflicts are found in almost all types of FCD schemes. The operation and maintenance of the FCD schemes is not upto the mark. Lot of effort is still needed to improve this situation.

Large Farmers and Small or Marginal Farmers

Generally, a large farmer has the opportunity to follow a diversified, cropping pattern according to the suitability of his land. He can bring maximum return from his investment. The existence of a FCD scheme is likely to enhance his benefits further. A small or marginal farmer can rarely make choices concerning crop diversification, he has to work on the rented land of a surplus owner along with his own small plot. This forces him for Rice cultivation.

FCD schemes open up the opportunity to switch over to transplanted HYV Rice. A smaller farmer or a tenant may be less willing or able to take advantage of it, since it entails higher input costs. Thus, the tenant would like to continue with a traditional crop, which requires less input and less labour.

Highland and Lowland Farmers
Farmers, who have plots at higher elevations, prefer high water levels to ensure sufficient soil-moisture. Lowland farmers, on the other hand, prefer as little flood depth as possible. The degrees of water control achieved by FCD efforts have given rise to serious conflicts between highland farmers, who want to allow maximum amounts of water through the sluice prior to the wet season, and lowland farmers, who want to close the gates as early as possible. Examples of such conflicts are numerous. One extreme example occurred in 1984, at a newly completed Early Implementation Project near Sharishabari, where the gate operator was beaten and driven away from the area by the influential highland farmers.

Farmers and Fishermen
A typical FCD scheme needs a peripheral dyke, closure of khals and hydraulic structures at the off-take of such waterways, to prevent entry of flood during the wet season. Such waterways can also be re-excavated, to facilitate efficient drainage in the post wet season. Unfortunately, these hydraulic structures restrict not only water but also fish fingerlings, from entering into the floodplains.

A scheme often has the option of re-excavating drains to remove congestion. This, however, can lead to over-drainage and disrupt the habitat of species that thrive in the muddy water of the basin during the dry season.

Thus FCD schemes give rise to serious conflicts between agriculture and fisheries.

Farmers and Boatmen
Flood control infrastructure, such as closures and sluices, separates floodplains from adjacent rivers, and also disrupts seasonal navigation by country boat operations. These are serious problems for rural Bangladesh, which is criss-crossed by numerous waterways, where rural boats represent the cheapest available mode of transportation.

Protected versus Un-protected Neighbourhoods
Flood protection measures involve the replacement of the floodplain and storage areas of a flood flow system, by a protected area. Such a change invariably increases the water levels in the neighbouring unprotected areas, whether these are adjoining areas or areas downstream. When a severe flooding occurs, worsened conditions are always attributed to the flood control measures of the nearby, protected neighbourhood. This situation creates anti-social behaviour, often resulting in public cuts in the embankments.

5.7 ENVIRONMENTAL IMPACTS

Flood protection schemes bring about overall improvements, through the reduction of flood depth to ensure more secure environments for living as well as for agriculture. However, they can also bring about drastic changes in the natural water regime, which may result in an imbalance in aquatic environments and ecosystems. For example, structural interventions disrupt the free flowing environment of the floodplains.

Moreover, continued congestion, or stagnation can prevent natural flushing and lead to the spread of water-borne diseases that may threaten public health. Total elimination of floodwater can also severely impact groundwater recharge. Cultivation, land settlement, vegetation clearance, hunting and fishing, all have increased in the scheme areas as population density has increased at an alarming rate over the last few decades. The FCD schemes undoubtedly contribute to the ecological decline.

The most common positive direct environmental impacts were (Flood Plan Coordination Organization, 1992):
- reduced flooding, in terms of level, occurrence, rate of rise, duration and extent of floods;
- improved soil moisture status at critical periods, due to reduced wetness in the wet season and, in some cases, to irrigation or water retention for post wet season and dry season use;
- improved land use through the reduction of the flood hazard and increased cropping severity and flexibility;
- increased land availability due to the reduced extent of wetlands;
- improved opportunities for culture fisheries;
- greater opportunities for afforestation and other tree planting.

These in turn have provided significant benefits to the population, including:
- some improvements in human health and nutrition;
- greater protection for infrastructure, with increased human safety and diminished disruption;
- improved access and communications, if only via the embankments themselves;
- substantial, if somewhat inequitable, economic benefits to the people in terms of incomes, employment, land values and credit-worthiness;
- overall improvement in the quality of life due to these positive physical and socio-economic impacts.

The most common negative environmental impacts were (Flood Plan Coordination Organization, 1992):
- cumulative influences in the external areas resulting in increasing river flows, bank erosion and bed scouring, siltation, and flooding levels;
- drainage congestion due to inadequate design, operation and maintenance of drainage sluices and channels;
- high risk in certain areas of future catastrophic flooding, with associated hazards to infrastructure, life and property;
- possible decline in the quality of subsurface, river and wetlands waters, and thereby in the quality of domestic water supplies;
- reduced extent of wetlands, which is ecologically negative;
- decline in soil fertility due to diminished aquatic vegetation;
- contribution to the general decline in fish especially the capture fisheries;
- in one or two study areas, contribution to a continuing decline in bird communities and habitats;
- some decrease and deterioration in the livestock sector;
- loss of land to the embankments and other scheme works, often with inadequate compensation;
- disproportionate distribution of scheme benefits and some strains on social cohesion.

5.8 GOVERNMENT AND USERS INVOLVEMENT IN OPERATION AND MAINTENANCE

Routine and preventive maintenance of the FCD schemes is not executed regularly. Over the years system elements have been deteriorating. These are rehabilitated normally with externally borrowed funds, which is normally done after a major damage. In many areas annual maintenance works are being done through food for works programmes, especially the maintenance of embankments and khals. But the quality of the work is poor, due to poor supervision and other malpractices. The hydraulic structures are operated by Government Agencies as anticipated where their physical conditions permit it. The sluice operating committees, though they exist officially, generally do not function effectively. Operation is frequently carried out under the influence of powerful local individuals. In some areas operation practices are subject of serious dispute. Three key issues relating to operation and maintenance can be mentioned (Flood Plan Coordination Organization, 1992):

- resource constraint;
- poor quality of maintenance activities;
- absence of public participation in operation of hydraulic structures and maintenance work.

Water management schemes, encompass a complex set of interrelated systems which are socio-technical in nature, consisting of water control infrastructure (embankments, sluices, canals), water bodies, land and people, as well as institutional issues and frameworks. To cope with this complexity of issues and the range of perspectives involved, an integrated approach is required. The recent investigation of the Early Implementation Project (EIP) shows that for sustainability due attention needs to be given to all of the issues throughout the various stages of planning, design, implementation and operation and maintenance. Traditionally, considerable attention is given during the planning, design and construction stages of new schemes. However, little attention is paid to the operation and maintenance issues. Related studies and in-depth investigations suggest that the major constraint to scheme sustainability and its potential is weakness in operation and maintenance (Datta, 1999).

Studies have shown that farmers are slow to respond to the improvements offered by the schemes for a number of reasons. Some of these are listed below (Datta, 1999):

- the reliability of the services is uncertain. Generally, by the time the farmers respond, facilities have deteriorated due to poor operation and maintenance and the scheme is no longer delivering the intended services;
- the conflict of interest among the various water users, i.e., sluices obstruct navigation, embankments disrupt fish migration, shrimp culture has displaced farmers in many polder areas;
- these conflicts could probably be minimized if rules can be drafted for the equitable operation and maintenance of hydraulic structures, taking into account the needs of the various users. Institutions could then be developed to oversee the enforcement of these rules.

5.8.1 Operation and Maintenance Funding and Cost Recovery

FCD schemes need to develop sustainable means for the operation and maintenance of hydraulic structures and watercourses. This requires a sound and sustainable financial base for these activities. This has never been the case within any responsible Agency, specially the Bangladesh Water Development Board, which continually suffers from inadequate Government budget in this respect. Although there have been increases in this budget, the need for alternative financing has long been recognized. This need resulted in the proposal that the stakeholders should pay for, or contribute to the services they receive. Measures would have to be taken to transfer at least a part of the responsibilities and financial contribution to operation and maintenance of irrigation and drainage infrastructure from the public sector to the stakeholders. Legal provisions for collection of water fees have been brought in place for some years. Application of these rules has been inadequate and the collection of fees is minimal.

Findings of the System Rehabilitation Project (1998) clearly demonstrate that efforts towards recovering of cost were not effective and the method is certainly not appropriate. The farmers were paying a fee (Tk 700 per 0.4 ha) to the pump manager (low lift) appointed from the user's group as collector. These collectors were not depositing the collected money to the Agencies. In fact the experience of the Karnaphuli Irrigation Project is almost wholly negative (Bangladesh Water Development Board, 1998). Attempts in this regard from outside are unlikely to succeed. Mobilizing local resources to meet local needs is a sound and a key element for development. Any future institutional structure for the local level management of hydraulic structures is that these local organizations would have to be mandated to mobilize resources to meet their needs. Efforts should be made to mobilize operation and maintenance funds from stakeholders through Water Users Associations. Initially, contribution amounts are not as important, as the willingness and commitment to participate. Interestingly enough, studies have shown that people are willing to pay, provided there is a guarantee that they will have a say in the use of the money (Soussan and Datta, 1998). Taking this into account, water rates or service fees could be agreed upon and through a proper institutional arrangement, people could be given the opportunity to participate in the planning and decision making process. Area based charges will usually be applied for flood protection and drainage. These can be flat rates dividing all cost over the area served. Sometimes the level of rates can vary reflecting the value of the protected property.

Clients are only willing to pay for services if these are reliable, the price is reasonable and they cannot get away with not paying. If good services are provided and the level and cost of services are agreed upon with the clients, the capability and willingness to pay will not be argued. For pricing to be effective one should pay careful attention to the following aspects (Koudstaal and Savenije, 1997):

- willingness to pay;
- ability to pay;
- objective of water resources management is primarily social, not financial;
- who should pay, for what and to whom?
- sometimes other incentives are more effective, such as group dynamics or the traditional power structure.

In many developing countries the contribution from the clients is in kind instead of in cash. Clients either pay a fixed amount or a percentage of their production in kind. This requires an often-costly mechanism to convert the agricultural produce into money. Moreover, income is than made dependent on market prices for the main commodities in which payments are made. Another form of payment is contribution in labour. This gives the marginal income farmers an opportunity to sell their labour to the better off farmers to take their part of the work to be done. Such system can only be practiced on a small scale if no capital for operation and maintenance is required to pay for wages and salaries.

The concept of ‘no money - no water’ is being tested in countries such as Indonesia, Sri Lanka and Nepal and applied in countries like France, the USA and The Netherlands. In The Netherlands it is enforced by the Water Boards, in France by the Basin Agencies and in the USA by the Water Banks. In reference to the above, it could be argued that in Bangladesh, stakeholders should bear the costs of a certain part of scheme improvement and the regular operation and maintenance costs through water rates or irrigation service charges. The recently published National Water Policy has addressed this issue in a limited way for the FCD schemes. It is hoped that legal provisions will shortly be put in place.

5.8.2 Institutions and Responsibilities

In order to ensure the desired benefits of the FCD schemes, achieve adequate returns on investment and achieve scheme sustainability, there is a need for an organizational set-up which involves the various stakeholders - each with a clear definition of task, responsibility, line of communication and procedure (Bangladesh Water Development Board, 1998).

Presently two operational arms of the Government of Bangladesh are directly concerned with the development of water resources. The first one is the Bangladesh Water Development Board, a semi-autonomous executive Agency, under the Ministry of Water Resources (MoWR). The second one is the Local Government Engineering Department (LGED), under the Ministry of Local Government, Rural Development and Cooperatives (MLGRDC). As these two organizations are concerned primarily with infrastructure development, both are predominantly staffed with engineers.

As the executive Agency of the Ministry of Water Resources, the Bangladesh Water Development Board has been largely responsible for providing technical support during the design and implementation stages of water development schemes. The Early Implementation Project had a special programme or cell under the Bangladesh Water Development Board, dealing with planning and monitoring of small-scale FCD schemes. There were six directorates in the Bangladesh Water Development Board under the Chief Planning, who works for the Additional Director General (ADG) in charge of planning. Of them, three directorates deal with specific donor funded schemes. While these directorates initiate the FCD schemes, they have to depend for the execution of works on the implementation division, which supervises the organization of field activities. The actual construction works are not, however, carried out by the Bangladesh Water Development Board, but partly by private contractors and partly by Landless Contracting Societies.

With regard to operation and maintenance, the Bangladesh Water Development Board has a set of guidelines, however they do not seem to be followed. As a consequence, many schemes tend to define their own procedures and guidelines and apply them in the field. In 1985, a member with the responsibility for operation and maintenance was added to the Bangladesh Water Development Board. All the zones headed by chief engineers were placed under him and the field divisions became responsible for operation and maintenance.

The local Government bodies most likely to be involved in the planning and design phases are the Thana or Upazila Parishads and the Union Parishads. That is all theory, as in practice links between these Government bodies and actual project planning and designing are absent. There is also a lack of interaction and coordination between the Agency and local Governmental bodies. In general, the local Government organizations have not been instrumental in the development of an efficient water management system in the scheme areas. Other poor social groups (e.g. fishing community) remain similarly underrepresented in the operation and maintenance committees.

Since the Bangladesh Water Development Board had begun to implement local-level water management schemes, khalashis were frequently employed for the operation of sluice gates. Over the years, they have become an institution and have played a crucial role in the day-to-day water management through the operation of the various hydraulic structures. In theory, they were supposed to work under the overall supervision of the local operation and maintenance committee. Where local operation and maintenance committees were not active, khalashis had to work on their own initiative.

Since the early 1980s, various Government and non-government Agencies, under various programmes and schemes, such as Local Government Engineering Department's Intensive Rural Works Programme, Bangladesh Water Development Board's Delta Development Project and Proshika, have been experimenting with the maintenance of earthen structures, specifically, rural roads and flood embankments through the Landless Contracting Societies. In the late eighties, experiences of such efforts have led the Early Implementation Project to test new modes of construction, particularly with regard to earthwork. Since then, the use of Landless Contracting Societies for the mobilization of labour has significantly increased.

Limited progress has been made in the operation of the hydraulic structures. Sluice and water management committees have been formed in some cases but this is only the first of many steps. Though lack of institutional development has not hindered the operation of the sluices fully, in some cases, conflicts have been reported over the operation of the sluices. The major problem lies in maintenance. In all the schemes, maintenance deficiencies have been identified, sometimes to such an extent that the whole scheme is threatened by the uncertain state of the embankments. The involvement of the local people through local Government is not a reality in the majority of the scheme areas. Responsibilities have not been well defined and adequate financial mechanisms have not been put into place. The formation of Landless Contracting Societies and Embankment Maintenance Groups is just a minor contribution to the institutional development.

6 CASE STUDY: POLDER 43/2A

Based on the experiences of the Early Implementation Project, the Government had decided to create a planning cell with a planning team within the Bangladesh Water Development Board, where planning has to be done considering all new concepts and techniques of planning. Accordingly the cell had started a programme by the name Integrated Planning for Sustainable Water Management (IPSWAM) financed by the Netherlands Government. Initially polder 43/2A was chosen as starting point for this programme and later the developed concept would be applied in other parts of Bangladesh. The researcher is a member of the planning team. He also choose polder 43/2A as the pilot area for his research work to develop a new approach and water management strategy for the whole year. The idea was that because of this the researcher could get logistic support and data facilities for his fieldwork. It would also enable him to strengthen the planning team by his study findings. Unfortunately the Integrated Planning for Sustainable Water Management (IPSWAM) programme is still waiting for final approval to start and the researcher has finished his study.

6.1 PRESENT CONDITIONS IN POLDER 43/2A

6.1.1 General

Polder 43/2A is located under Patuakhali sadar thana of Patuakhali district. The gross area is 5,100 ha and the net cultivable area 3,500 ha, surrounded by the Payra (Bighai) river West to North and the Gulisa Khali river on East and South. The area consists of 19 administrative wards in three unions namely Boro Bighai, Choto Bighai and Madarbunia of Patuakhali sadar thana. The area lies in a moderately flat land with average ground elevation varying from 1.10 to 2.10 m+PWD. The land area along the periphery is relatively high and the middle is relatively low, forming a saucer shape.

Roughly one hundred twenty large and small canals having different length of 0.5 to 8 km form a criscross canal or khal network system. Out of which there are 16 major khals and 104 minor khals. The main channels are called Kalia khal, Bastala khal, Khatasia khal, Titkata khal, Dhanger khal, Matibhanga khal, Butumia khal, Bazbari khal, Patukhali khal, Alia khal and Chaltabunia khal. These major canals have a connection with the rivers around the polder through hydraulic structures.

Before reclamation tidal water entered into the area through the khals. During the wet season, heavy rainfall together with tidal flows created severe flooding and drainage congestion in the area. This flooding and drainage congestion caused recurring damage to the crops, homestead and property, resulting in huge losses to the people. To overcome the situation of continuous flooding and drainage congestion, the area was included under the proposal of the Coastal Embankment Project phase II (as 43/2). Due to the huge money requirement and non-interest of the donors the said project did not start. Later the polder (43/2) has been sub-divided into seven small polders, 43/2A is one of them. It was completed in 1988. The original objective of the reclamation was to increase food production by protection against floods, preventing of salinity intrusion and improving drainage. The area is surrounded by 40 km of peripheral embankment. Six drainage and surface drainage sluices (DS and SDS) at six connecting khals, out of sixteen, have been constructed as shown in Figure 6.1.

The other khals were closed completely by the peripheral embankment and closures. The infrastructure is now as follows:

- embankment (marginal and interior), length 40 km, of which 20.9 km is interior dyke and the rest is marginal dyke having a top width of 4.2 m and 2.4 m respectively. The interior dyke has a slope 1:3 (riverside) and 1:2 (countryside). The marginal dyke has a slope 1:2 (riverside) and 1:2 (countryside);
- 12 canals or khals, excavated at the time of implementation;
- 4 closures construction works for closing the bigger canals and linked with the surrounding embankment;
- 3 drainage sluices and 3 surface drainage sluices. The surface drainage sluices have a higher sill level than the drainage sluices and were constructed for particular problematic areas.

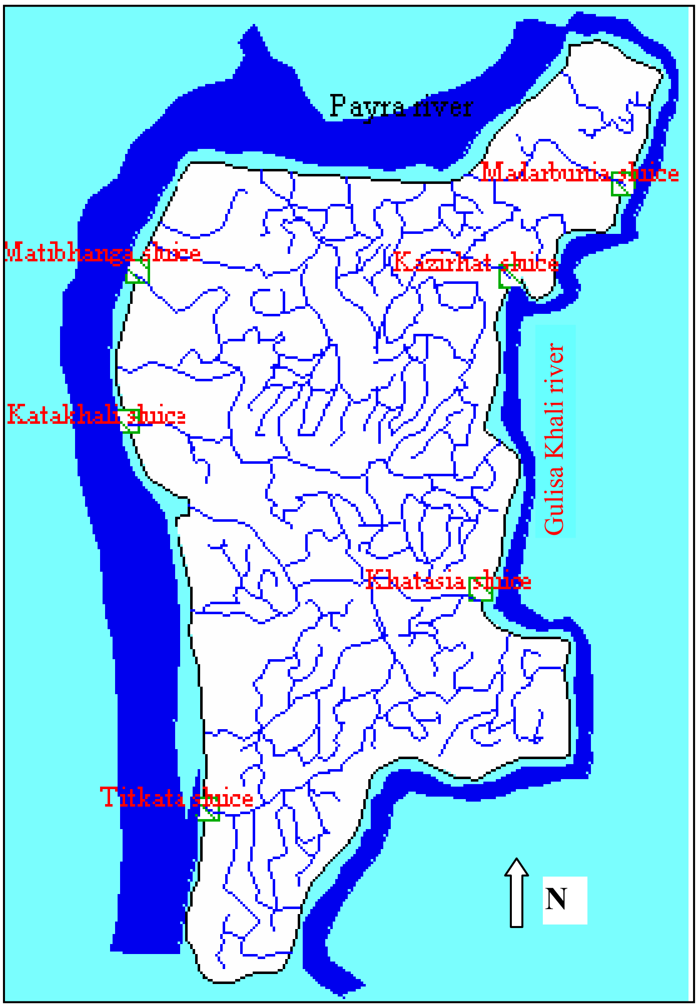

Figure 6.1 Map of polder 43/2A

6.1.2 Physical Conditions of the Area

During field investigation it was found that at some locations the embankment was not constructed as it was designed. For certain sections of the embankment the top level was found below design level. At some places the embankment faces serious threats from river erosion due to insufficient set back distance and changing morphology of the adjacent river.

Out of the six sluices three are located on the Western side connected with the river Payra and the others are on the Eastern side connected with the Gulisa Khali river. Table 6.1 provides the description of the six sluices and their present condition.

Table 6.1 Physical condition of the six sluices

Name of sluice	Type of sluice	No. of vents	Size of vents in m	Type of gate		Sill level in m+PWD	Present status
				R/S	C/S		
Titkata	DS	1	1.52 x 1.83	Flap	Lift	- 0.30	No flap gate. Gate repair needed
Kata-khali	SDS	1	0.90 x 1.20	Flap	Flap	0.46	No flap gate. Gate repair needed
Mati-bhanga	SDS	1	0.90 x 1.20	Flap	Flap	0.46	Flap gate and rubber seal damaged. Gate repair needed
Madar-bunia	SDS	1	0.90 x 1.20	Flap	Flap	0.46	Barrel or conduit badly damaged and soil eroded at R/S. Gate repair needed
Kazirhat	DS	3	1.52 x 1.83	Flap	Lift	- 0.30	Flap gates missing, hoisting device and vertical lift gates are out of order. Gate repair needed
Khatasia	DS	3	1.52 x 1.83	Flap	Lift	- 0.30	Vertical gates with hoisting devices are out of order. Gate repair needed

DS = drainage sluice; SDS = surface drainage sluice
R/S = river side; C/S = country side

6.1.3 Present Status of Operation and Maintenance

In this polder operation means managing and maintaining an appropriate water level in the canals or khals and in the floodplain area for both irrigation and drainage. Operation for water quality control related to salinity within an allowable range for the crop production has not been considered for this polder.

Maintenance is also an essential part of water management of the polder, but it has been neglected. The condition of the infrastructure deteriorates, eventually affecting the operations. No maintenance work was carried out during the first three years after completion of the polder. Afterwards very little operation and maintenance works were done under the Annual Development Programme (ADP) of the Bangladesh Water Development Board. It concerned mainly repair work of sluices and construction of retired embankments. Some maintenance work on the embankment has been done under the Food for Works (FFW) programme.

The six sluices were constructed to serve the following:

- in the wet season, the sluices stop the entry of flood water during high tide, drain out the excess water during low tide and keep the polder free from flood and drainage congestion;
- in the dry season, the sluices allow water to flush in during high tide and retain water during low tide for irrigation.

Immediately after construction the sluices were serving well, when the internal water management system was undisturbed and free from man-made interventions.

Moreover the sluices were operated by an operator called khalashi, who was appointed by the Bangladesh Water Development Board. After a certain time lack of regular repair and maintenance work, damage of rubber seals, damage of gates, gate lifting devices, damage of barrels and finally malfunctioning of the sluices occurred. As per decision of the Government, khalashi's were withdrawn and the hydraulic structures were left for operation by committees formed by the local people under the guidance of the Bangladesh Water Development Board.

Accordingly institutional arrangements were made by local initiative for the operation of three sluices (Khatasia, Titkata and Madarbunia). Sluice committees were formed and those committees engaged people for operation. The operators were having the assurance of payment in cash or kind by the stakeholders. The payment by the stakeholders was supposed to be proportional to the land they owned under the catchment area of the respective sluice. But those arrangements did not continue due to lack of initiative, non-fulfillment of the commitment of payment to the operators and sometimes mechanical faults of the sluices. At present all the sluices are in a very poor condition due to lack of repair and maintenance for a long time. Most of the time the gates of the sluices remain open and during high tide water enters inside the polder with debris.

In a number of locations stakeholders cut and close the embankment every year at their own initiative. Forty public cuts (made by the local people) were found in the embankments through which stakeholders take tidal water to irrigate their high lands near the peripheral embankment (Bangladesh Water Development Board, 2000). These cuts are made at the same places every year to withdraw river water for irrigation during the dry season. Although the stakeholders close those cuts, they do it far below the design level, leaving those locations in vulnerable conditions to coming floods. The cost for cutting and closing are shared by all the stakeholders benefiting by that practice either in the form of manual labour - small and marginal farmers or by contributing in cash - comparatively large farmers.

It may be mentioned here that there was no planning and design for such irrigation practices by the farmers. So, no irrigation inlets - small pipes in the embankment - were included for this polder. Also a number of major khals were closed without any drainage or flushing provision. After reclamation most of the khals of the polder connecting to the river were silted up. Unplanned village roads, cross bunds in the khals, homestead construction, and growing of water hyacinths cause major impediment against flushing and drainage through the existing sluices. It limits the operation of the polder as a whole. In course of time new demands have been created especially for crop production with irrigation facilities.

6.1.4 Hydro Meteorological Data

The relative humidity is high throughout the year but the highest - from 85% to 94% - occurs mainly during the wet period from June to September. The lowest humidity is 62% and occurs in February. Average wind speed is 106 km/day in December with a highest speed of 882 km/day between April - July. The average number for hours of sunshine is 5.3 with a maximum value of 11.4 hours in November and December (Water Resources Planning Organization, 2000).

The rainfall data of Patuakhali station show an annual rainfall from 2,100 to 3,000 mm. The maximum monthly rainfall is 886 mm. Evaporation data of the same station show an annual evaporation from 670 to 980 mm. Mean monthly rainfall and evaporation, as well as the rainfall duration frequency curves are given in Figure 6.2 and Figure 6.3.

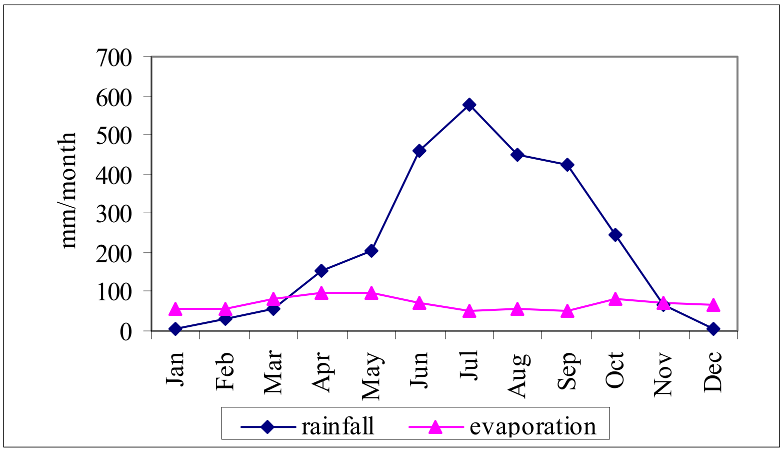

Figure 6.2 Mean monthly rainfall and evaporation at Patuakhali station

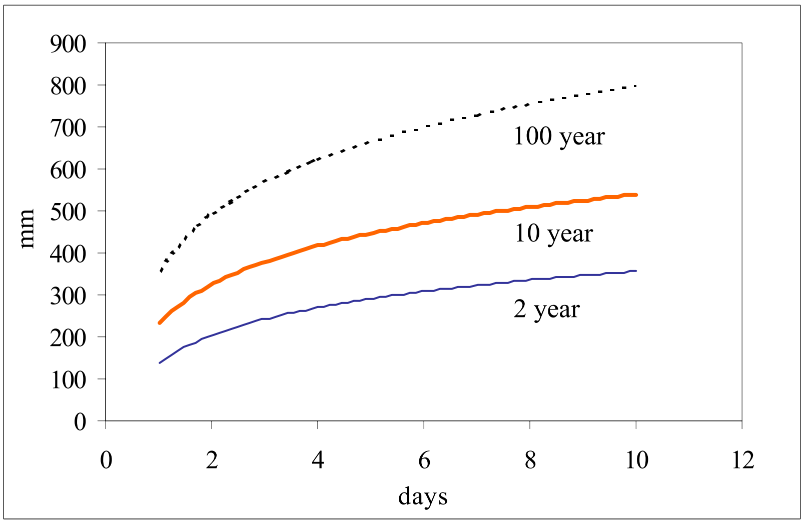

Figure 6.3 Rainfall duration frequency curves for Patuakhali station

In order to determine the drainage and irrigation requirement of the polder the cumulative rainfall minus evaporation data during the wet and dry season have been statistically analyzed. The result is presented in Figure 6.4.

Water level data have been used from Mirjaganj station in the Payra river, located opposite to the polder and from Amtali station, located 10 km downstream of the polder. The water level in the Payra river varies from -0.72 to 3.36 m+PWD. The area is subject to semi-diurnal tidal effects. The mean maximum and minimum tidal range is 2.53 m and 1.57 m respectively.

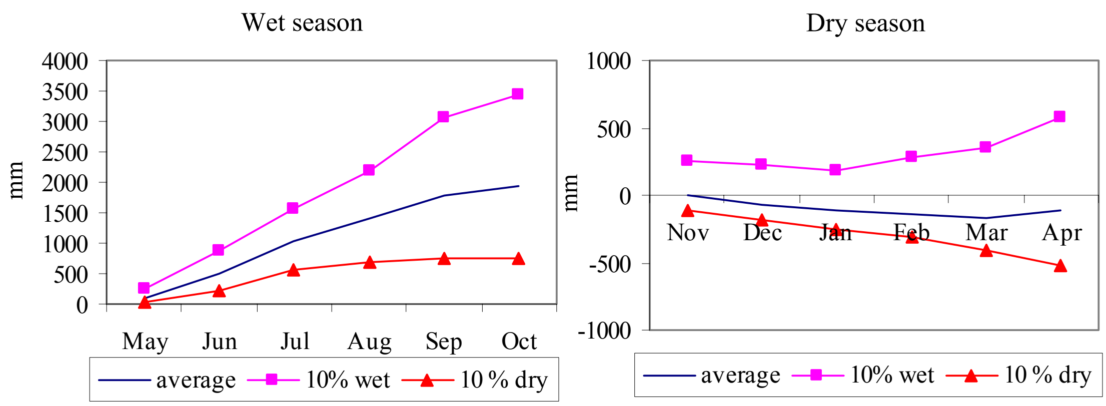

Figure 6.4 Cumulative rainfall – evaporation at Patuakhali station for the wet and the dry season

The rainfall, evaporation and water level data have been used in the hydrodynamic simulations with the DUFLOW model (described in Chapter 9) and to develop tools for the polder. The drainage situation has been simulated using these data during low tides. The flushing situation has been simulated to calculate the possible water levels for irrigation. The results of these simulations have been used in the development of the water management strategy and the land suitability zoning.

6.1.5 Surface Water

During the dry season, the static water bodies (beels, haors, baors, ponds and borrowpits) are the possible sources of water used for various purposes. These water bodies are generally connected with rivers and khals during the wet season. As floodwater recedes, they become disconnected from the streams and become isolated water bodies. During the driest part of the year, many of these static water bodies are completely dried up. Some of the static water bodies, however, retain water, which is utilized not only for irrigation but also as a fish habitat, for homestead gardening and for fish culture. These static water bodies, though small, may play a significant role as a source of water in the dry season when rainfall is scarce. It has been found that there were approximately 1,190 ponds covering an area of nearly 50 ha and borrowpit areas covering an area of 40 ha (Bangladesh Water Development Board, 2000).

The pond water salinity varies from 0.33 mmhos/cm to 0.45 mmhos/cm and the salinity level of the surface water in surrounding rivers and khals varies from 0.39 mmhos/cm to 0.65 mmhos/cm (Bangladesh Water Development Board, 2000). The salinity levels of the major rivers are given in Table 6.2.

In order to reduce water scarcity, water which comes directly from the Payra river and Gulisa Khlali river through the existing sluices of the polder can be stored in the existing canals or khals during the wet season by means of controlling the sluices. This storage may provide a significant source of water for dry season irrigation, fishery production and other purposes. The inflow into the polder depends on the tidal river water levels. The maximum tidal water level occurs at spring tide during the wet season.

Table 6.2 Salinity level of major rivers and khals (Soil Research Development Institute, 1999)

Name of rivers and khals	Salinity level (EC in dS/m or mmhos/cm)
Payra river (Nandipara)	0.41
Payra river (Kalikabari)	0.42
Payra river (Matibhanga)	0.41
Payra river (Patua)	0.41
Payra river (Titkata)	0.52
Gulisa Khali river (Madarbunia)	0.40
Gulisa Khali river (Gulisa Khali)	0.39
Gulisa Khali river (West Keorabunia)	0.42
Gulisa Khali river (Khatasia)	0.44
Gulisa Khali river (Hartokibaria)	0.65
Gulisa Khali river (Madarbunia)	0.43
Gulisa Khali river (East Matibhanga)	0.50
Bharani khal (Boro Bighai)	0.40
Dhanger khal (Choto Bighai)	0.39

From the Table 6.2, it is clear that the surface water available in rivers and khals is safe for irrigation. The allowable surface water salinity level for irrigation purposes is shown in Table 6.3.

Table 6.3 Allowable surface water salinity level (Food and Agriculture Organisation, 1985)

Surface water salinity level for irrigation in mmhos/cm	Remarks
< 0.7	Safe
0.7 –3.0	Slight to moderate
> 3.0	Detrimental

Canal System and Drainage

Before construction of the embankment, tidal water could easily enter through the khals from both the Western and the Eastern side and be drained accordingly. The closing of the major khals during reclamation obstructed this easy movement of natural tidal flow. The internal canals or khals of the polder are used:

- for flushing water into the interior area to facilitate irrigation;
- to drain excess water;
- to serve different households and domestic water demands;
- to act as potential resource for fishing and also for facilitating internal navigation.

After reclamation, the flow was limited to the six sluices and as a result tidal flow could not enter or leave easily from the area. During the last decade, the Bangladesh Water Development Board’s operation and maintenance work of the polder was mainly concentrated on the peripheral embankment and some minor repairs of sluices. No attention was given to improve the internal water management capacity of the canals. Only one canal, called Dhanger khal was re-excavated jointly by stakeholders and the Bangladesh Rural Advancement Committee. The unplanned internal development hinders the easy distribution of flushing water to interior parts of the area and at the same time prevents the easy flow of drainage water resulting in drainage congestion. It takes a longer time to drain the waterlogged areas.

The khals having an average water depth of more than 1.5 m are considered as perennial khals and the khals having an average water depth less than 1.5 m or dried up during the wet season are considered as seasonal khals.

The unplanned internal road system and local earthen dams close the canal system at several places which accelerates the siltation process and results in drying out of canals. High growth of water hyacinth and aquatic weeds in the drainage canals reduces the drainage capacity of the canals. Water hyacinth in stagnant water deteriorates the water quality significantly. Inadequate drainage in the existing situation causes inundation.

Irrigation System

Like in other parts of the country, there are three distinct cropping seasons in the area. These are: (a) Rabi (b) Kharif-I, and (c) Kharif-II.

The traditional methods of irrigation using indigenous irrigation equipment like dhun, swing basket, sweti, etc. were common in this area. These irrigation methods were laborious but not expensive and could be managed easily.

In the past irrigation was hardly practiced in this polder during the Rabi season. Recently, the Rabi crops became more and more popular among the local people and more areas were being brought under Rabi cultivation and irrigation was necessary for these crops. Main demand for irrigation was reported for the cultivation of T. Aus. Sufficient rainfall is generally not available during the transplantation period of T. Aus. Timely irrigation is therefore seriously needed for transplanting T. Aus. Irrigation water may be supplied to the medium lowland and medium highland through the existing sluices during the spring tide. This happens very rare because of bad operation. Irrigation to the relatively high land around the periphery is provided through public cuts. But indiscriminate flushing through these cuts is often causing submergence of the low-lying areas. During drought, flushing can be carried out through the sluices and the public cuts to supply irrigation water for T. Aus and Aman.

Although there is a wide scope for use of low lift pumps to take the water from canals to the field, these were hardly practiced in this coastal region. It has been reported that in 2000 only one low lift pump was used in Pasharibunia. The Thana Agriculture Officer, Patuakhali Sadar Thana informed that the Directorate of Agriculture Extension had some low lift pumps on nominal rent basis but that there is almost no demand for these pumps from the farmers.

6.1.6 Ground Water

The polder lies within the less saline zone of Bangladesh. The ground water at shallow depth was reported as saline (Bangladesh Water Development Board, 2000). According to the local people use of ground water for irrigation would be costly while the well pipe would have to penetrate to a great depth for quality water. A sweet water aquifer is available within a depth of 229 to 335 m (Bangladesh Water Development Board, 2000). Extraction of ground water has been done only to meet the demand for drinking water through the use of hand tube wells. The groundwater of the area is free from arsenic contamination. The iron and chlorine contents of the ground water are shown in Table 6.4. The salinity of the ground water in the nearby area is shown in Table 6.5.

Table 6.4 Ground water contents of the area (World Health Organization, 1984)

Parameter	Amount in mg/l	Limiting value in mg/l
Iron	60 - 100	5
Chlorine	0.5 - 2.0	0.3

Table 6.5 Groundwater salinity level in nearby areas of polder 43/2A (Soil Research Development Institute, 1999)

Location	Depth of Groundwater in m	Salinity Level (EC) in mmhos/cm
Lebukhali Union (Lebukhali Mauza)	40	1.30
Lebukhali Union (Kartikpasha Mauza)	60	2.00
Kalikapur Union (Purbasarikkhali Mauza	90	3.00
Marichabunia Union (Patuakhali Mauza)	250	8.00

6.1.7 Road Networks

The embankment is being used as road for year round communication. About 163 km of road networks developed by different Agencies greatly improved the communication status within the polder. Thana Parishad and Union Parishad developed the internal road network within the polder. A 2 km road from Choto Bighai Office Hat to Butumia Bazer was the only pucca road constructed by the Local Government Engineering Department in 1996 - 1997. In the rainy season the earthen roads become loose and muddy and become difficult to walk. A list of the internal road system developed by different organisations is given in Table 6.6.

Table: 6.6 Inventory of roads in km implemented by different Agencies (Bangladesh Water Development Board, 2000)

Location	Implementing Agencies				Total
	District Council	Thana Parishad	Union Parishad	Others	
Madarbunia UP	0.0	4.00	4.00	0.0	8.00
Choto Bighai UP	0.0	12.00	54.63	7.50	74.13
Boro Bighai UP	5.00	7.50	59.41	8.50	80.41
Total	5.00	23.50	118.04	16.00	162.54

UP = Union Parishad

However, the road network significantly deteriorates the internal water management situation due to inadequate culverts and bridges for drainage and flushing. Sometimes, this unplanned road development splits a drainage system into two, or even three subsystems, complicates the natural drainage process and creates different water related problems.

6.2 INTEGRATED PLANNING FOR SUSTAINABLE WATER MANAGEMENT (IPSWAM)

Many schemes of the completed Early Implementation Project could not achieve their planned objectives. One of the important causes of this was identified as inadequate participation of beneficiaries as well as of negatively impacted stakeholders, such as fisherman, boatman and people both inside and outside of the area where the water regime was affected by the reclamation.

The Integrated Planning for Sustainable Water Management (IPSWAM), started with an initial plan for a five year programme as continuation of the former Early Implementation Project which is concerned with sustainable development of the water management for medium and large scale polders. The programme focuses on multi-disciplinary planning and on sustainable operation and maintenance through active participation of stakeholders. It will also try to break through the vicious circle of deficient operation and maintenance, poor performance and continuing rehabilitation. Integrated Planning for Sustainable Water Management builds upon lessons learnt in the water sector in the past decades.

6.2.1 Integrated Planning for Sustainable Water Management Approach

The Integrated Planning for Sustainable Water Management approach will be as follows (Government of Bangladesh (GoB) - Government of the Netherlands (GoN) joint formulation Mission, 1998):

- people's participation is considered essential and refers to the active involvement of the population in all phases of the planning cycle from the identification phase to the operation and maintenance phase;
- the approach will be flexible, meaning guidelines (e.g. on people participation) should be considered as general guidelines to be interpreted in a flexible way depending on the actual situation, e.g. taking into consideration existing local level water management arrangements and specific needs;
- it will concentrate on public water schemes located in the South central region of Bangladesh with a command area over 5,000 ha which in future will probably be jointly managed by the project implementing Agency along with local Government and community organizations. These larger schemes generally require a participatory, multidisciplinary approach due to their complexity, e.g. larger schemes often have multiple objectives and a higher potential for conflicting interests as compared to the small, single objective schemes;
- it will be closely related to the recently published National Water Policy as well as to the two major activities of the future Water Sector Improvement Project. Transfer of smaller schemes and institutional improvement of the Bangladesh Water Development Board to effectively manage large schemes.

Integrated Planning for Sustainable Water Management will be an integral part of the Bangladesh Water Development Board to be effective in institutional strengthening. It will assist the Bangladesh Water Development Board in better performing its assigned tasks in future with special reference to participatory, multidisciplinary planning, implementation, management and operation and maintenance of larger schemes.

The Integrated Planning for Sustainable Water Management programme shall use a new concept in the planning and implementation of medium and large-scale water sector projects. This new concept is the participatory integrated planning and institutionalization process. The main features of this planning process are (Government of Bangladesh (GoB) - Government of the Netherlands (GoN) joint formulation Mission, 1998):

- adequately addressing the different sectoral water demands and uses, viz., domestic water, agriculture, forestry, fisheries, navigation, recreation and others;
- environmentally sound participatory water management planning;
- due attention to social parameters and gender balance;
- sustainable planning for ensuring the participation of stakeholders, Thana administrations, field level officials and based on their need, opinion and willingness;
- development of a good institutionalization process linked with all the steps starting from planning to implementation and operation and maintenance for sustainability of the area.

6.2.2 Institutional Framework

The overall objectives of the institutional framework considered in the Integrated Planning for Sustainable Water Management programme are the development of institutions at three tiers i.e. local level (ward level), block or sub-catchment level and polder level (Bangladesh Water Development Board, 1998). The institutions at local level involve stakeholders in all phases of the project cycle and will have to establish a sustainable operation and maintenance mechanism at this level. The main tasks of the institution at this level are familiarisation of the water management concept, identification of water management issues, preparation of inventories, water management mapping, motivation, arrangement of formal and informal meetings, formation of committees and training of stakeholders. Block level (sub-catchment level) institutions will be formed based on hydrological units (based on sluices). System level (polder level) institutions will be formed considering the total polder.

6.2.3 Financial Management and Cost Sharing

One of the main tasks of the institutional process is financial management and cost sharing apart from the structural development at different levels. Resources mobilisation for sharing the cost of operation and maintenance is crucial for the long-term sustainability of a water management scheme. Resources mobilisation may take place in the following forms:

- financial contribution from the stakeholders;
- contribution in terms of labour from the stakeholders;
- land contribution by the landowners for the construction of physical infrastructure;
- contribution from local Government institutions;
- income mobilisation from common properties;
- optimum use of resources inflow mobilized through different Agencies.

It is, however, difficult to quantify the contribution in cash from the stakeholders, but it may be anticipated that the stakeholders themselves carryout small on farm operation and maintenance works. Stakeholders have already showed their potential in this regard and participated by contributing land, labour, etc. It has been aimed in the Integrated Planning for Sustainable Water Management programme that the contribution to operation and maintenance by the stakeholders will be made phase wise, viz. 0%, 25%, 50%, 75% and 100% during the 1st, 2nd, 3rd, 4th and 5th year respectively. The directions as indicated in the National Water Policy will be followed and 25% of the earthwork will be offered to specific target groups of beneficiaries.

6.2.4 Training

Training to the central planners and field level professionals is necessary for capacity building and to enhance their capabilities to fulfil the tasks ahead under the Integrated Planning for Sustainable Water Management programme. Similarly training for stakeholders is also necessary to create awareness among them in the process by participatory project planning and to accept the operation and maintenance responsibility of the water management scheme according to the operation and maintenance plan.

6.2.5 Monitoring and Evaluation of Operation and Maintenance

Monitoring in relation to the planned operation and maintenance with the objective to improve system operation and maintenance will be required. For the purpose of monitoring and evaluation it is necessary to record the actual operation and actual water levels and/or discharges accurately. Deviations from the operation and maintenance plan and their reasons should also be recorded and evaluated accurately.

6.3 INTEGRATED PLANNING FOR SUSTAINABLE WATER MANAGEMENT IN POLDER 43/2A

6.3.1 Field Observations and Data Collection

As a result from discussions of the multidisciplinary professionals of the planning cell it was decided that the required data that could not be collected from secondary sources, would be collected by field observations. Nine field organizers were recruited with the objective of stakeholder motivation as well as data collection in different disciplines. Two of them were female. The female organizers were assigned to motivate the women as well as to collect the data and information on women and gender issues. The male field organizers were responsible for collecting data on all other issues i.e. agriculture, engineering, environment, fisheries, social and institutional aspects. In addition to that two field coordinators were appointed to facilitate the activities of the field organizers.

A group of two field organizers was assigned for approximately 6 wards. The group collected information and data on engineering, social, institutional, existing problems and possible remedial measures. They prepared presentation sheets, summary reports, performed motivational activities and organized ward meetings. One field organizer was exclusively engaged in the collection of data related to agriculture, environment, fisheries and forestry in the given formats of the planning cell. In addition to that he also attended the ward meetings and explained agricultural phenomena to the stakeholders. The two female field organizers conducted surveys on selected bari (small houses cluster) as per consultation with the female ward member of that area.

They also gathered information on non Government organization activities. Considering the ward as a basis the field organizers arranged meetings among various stakeholders and formed the ward-level committee in that meeting for proper operation and maintenance activities of that ward.

The professionals of the planning cell made several extensive field visits to the polder area during the data collection and motivational works by the field organizers. During these visits, they observed the existing conditions of the infrastructure and collected all necessary information from the field. The professionals also made interaction with the stakeholders, local elite, Union Parishad chairman and members, other Agencies and also attended several ward meetings organized by field organizers for stakeholders.

6.3.2 Problems

One of the main objectives of the Integrated Planning for Sustainable Water Management programme was to identify and visualise the prevailing water management problems in polder 43/2A. The problem identification and possible measures were formulated based on stakeholders opinion and also satisfying the five criteria i.e. regional economic growth, social equity, environment, fisheries and institutionalisation. The existing water management problems in polder 43/2A were identified using the following steps:

- consultation with stakeholders;
- listing the water management problems and ranking them as per stakeholders' opinions and needs;
- preparation of summary sheets with problems and their causes;
- cross-checking of identified water management problems;
- validation of problems and their causes in the ward meeting.

Roughly eleven water management problems were identified in polder 43/2A, those are (Bangladesh Water Development Board, 2000):

- drainage congestion;
- shortage of irrigation water;
- water quality hazard;
- effects on livestock;
- pest and insecticide diseases;
- mosquito problem;
- water hyacinth;
- skin disease;
- navigation problems;
- communication problems;
- drinking water crisis.

6.3.3 Possible Measures to Solve the Problems

The possible measures associated with the individual problems were primarily noted down through interaction with the stakeholders during the data collection and motivational phase. The stakeholders suggested these measures on basis of their practical experience. The planning cell professionals visited the problematic areas to see the existing problems and to understand the causes associated with each problem.

Table 6.7 presents the suggested measures for each problem considered in the Integrated Planning for Sustainable Water Management programme. From these suggested measures different interventions were chosen to solve the individual problems of the polder.

Table 6.7 Problems and suggested measures in polder 43/2A (after Bangladesh Water Development Board, 2000)

Problems	Measures
Irrigation water shortages Pest and insecticide disease	Provision of irrigation inlets at all public cuts along the peripheral embankment Provision of internal water management structures Efficient operation of existing and proposed sluices Re-excavation of khals Provision of compartmental dyke inside the polder Formation of water management committees for the efficient operation of sluices Use of low lift pumps Practice of modern agriculture
Drainage congestion Navigation problem	Re-excavation of canals and removal of all blockages and cross-bunds from canals Provision of more sluices at key locations of the peripheral embankment Removal of water hyacinth Efficient operation of existing and proposed sluices Formation and efficient operation of a water management committee
Water quality hazard Water hyacinth problem Effects on livestock Mosquito problem Skin disease	Development of a good water management system Planned development of infrastructure without creating obstruction to natural flow Voluntary removal of water hyacinth Use of sanitary latrines by the people Increase of awareness among the stakeholders Use of water hyacinth as fertiliser
Drinking water problem	Installation of more hand tube wells Construction of drinkable water tanks
Communication problem	Development of the peripheral embankment as road Construction of internal roads without hindering the natural drainage process

6.3.4 Proposed Interventions

The interventions needed for water management of polder 43/2A have been identified from the inventories prepared by the field organizers on the basis of the stakeholder opinions. Initially the number of interventions proposed by the stakeholders was very high. The planning cell team then visited the proposed intervention sites and discussed with the local people about the necessity. Listed interventions were discussed in the ward-level meeting and the stakeholders were asked for a ranking on the basis of priority. Based on that and know how of the planning team, the number of interventions was reduced. Some informal discussions were held with existing and ex-Union Parishad chairmen of the area. The types of intervention were also verified with the stakeholders.

6.3.5 Water Management Options and Strategies

Considering the identified problems and their importance given by the stakeholders and other aspects of water management, three water management options were formulated to mitigate the aforesaid problems. The alternative options are as follows:

- *Option – I*
  According to the suggestions and views from the stakeholders, this option involves some new interventions considering present drainage, irrigation and institutional problems. The change scenario of irrigation demand that was not considered during the implementation of the polder would get priority. The flood protection works and other infrastructure of the polder will be maintained. An institutional development component for efficient operation and maintenance was included;
- *Option – II*
  In this option some new interventions will be implemented like in option I, but the intervention required for the present irrigation problem was not considered. Maintenance of the existing infrastructure was included in this option. The institutional development mechanism will be applied without considering the new intervention for the irrigation problem only;
- *Option – III*
  In this option all the existing infrastructure of the polder will be repaired as required. The institutional development mechanism will be applied without considering any new intervention.

In Table 6.8 a list of proposed interventions for the three options as described above is shown.

Table 6.8 List of proposed new interventions under the three alternative options (Bangladesh Water Development Board, 2000)

Intervention	Option-I	Option-II	Option-III
Drainage cum flushing sluices in nos.	1	1	Nil
Surface drainage cum flushing pipe sluices in nos.	1	1	Nil
Re-excavation of khals in km	50	50	Nil
Irrigation inlets in nos.	42	0	Nil
Gated pipe culverts in nos.	18	0	Nil
Gated culverts in nos.	8	0	Nil
Normal pipe culverts in nos.	2	18	Nil
Drainage and flushing outlets in nos.	7	7	Nil
Compartmental dyke in km	10	10	Nil
Maintenance of peripheral embankment in km	15	15	Nil
Maintenance of existing sluices in nos.	6	6	6

6.4 EVALUATION OF INTEGRATED PLANNING FOR SUSTAINABLE WATER MANAGEMENT

6.4.1 General Observations

It was observed by the researcher that most of the FCD schemes are not functioning well. However, the main objective of safe and improved agricultural production is realized to a large extent. After the completion of the FCD schemes, the operation and maintenance remained inadequate. The stakeholders in the areas did not come forward to take over the responsibilities of operation and maintenance. The Bangladesh Water Development Board has not sufficient manpower, nor finances to perform the operation and maintenance responsibility for the completed FCD schemes. The annual repair and maintenance funds allocated to the Agency for the FCD schemes are not sufficient to meet the actual requirement. On the other hand it is also not possible to allocate these funds continuously from Government budget. Due to inadequate attention for operation and maintenance, the problems of the FCD schemes increase sharply together with the changing hydrological scenario inside and outside the areas. The demand for irrigation water and priority of the problems is also changing, which affects the scheme performance and the real benefit. To improve the present water management, some attempt was made by the implementing Agency. Some committees within the areas, like sluice committees and others to operate the sluices as per requirement and needs of the stakeholders were formed. But it did not work. In most of the cases the committee does not exist anymore and some committee members do not even know that they are a member of the committee. It is true that earlier the FCD schemes were not properly discussed with the local people - including affected people - during the preparation and formulation stages. So the people don't have any affiliation with the schemes and their operation and maintenance. They are getting the benefits of the FCD schemes, but they are not gathered or united for the common interest. They don't think of the consequences of the mismanagement as a whole.

There is a trend of endless cycle within the Bangladesh Water Development Board regarding any problem of the completed schemes. They investigate the problems and come up with a proposal of some physical intervention. After some time it is found that the problem was not solved. Again they will go and investigate and come up with another type of physical intervention. In this way the Bangladesh Water Development Board's staff is trapped with an endless cycle of physical interventions.

The Government of Bangladesh realised the need to constitute proper guidelines for peoples participation in water management. Therefore the Government published the guideline for people's participation in water sector schemes of the Bangladesh Water Development Board. In the System Rehabilitation Projects of the Bangladesh Water Development Board, an attempt was made to follow this guideline strictly, but it was not successful. The guideline was prepared mainly considering the concept of irrigation systems. While the concepts of FCD schemes are not the same. The Local Government Engineering Department is working with its own guideline of people's participation (cooperative concept). Appendix B shows the different guidelines prepared or attempted in Bangladesh for people's participation, legal status for the institutions and cost recovery for the operation and maintenance.

In Bangladesh people in one district are not as active as in other districts. Agricultural know how and practices are also not the same. So during modifying the guideline for institutional arrangements it should be kept in mind that there should not be such rigid guidelines, there should be some flexibility.

There are no means or arrangements of benefit for the committee members. Why people will come into the committee and why will they work for others? There should be some sort of arrangement of financial incentive for the committee members and provision of empowerment in the decision making process.

6.4.2 Present Trend

Presently, a general consciousness has been formed in Bangladesh to incorporate the views of the local people and consider their water right in all stages of scheme planning (as per National Water Policy of 1999). Also the multidisciplinary and integrated planning concept has got much more attention than before. It has been agreed upon by the Agencies that the consequences of the water management in FCD schemes should be well described to all the levels of the local people before starting any activity. The operation and maintenance responsibilities should be clear, especially their share, Government of Bangladesh and Agencies limitations be described and arrangements for motivation should be developed so that the local people co-operate in the form of some institutional arrangement like a committee or an association. It is also found necessary to address all the aspects of land and water development projects - social, environmental, fishery, economical, agriculture and institutional - and clearly discuss the probable consequences of water management with the local people. It is mandatory to include the negatively affected people's views and demands during scheme planning. All the positive and negative impacts should be discussed with and presented to the people in a simplified manner. This has to be done in such a way that they can understand well ahead what will be happening after the improvement of a scheme.

6.4.3 Polder 43/2A

During field investigation by the researcher in polder 43/2A it was observed that the newly developed concept of peoples participation and consultation is also not getting momentum. The Government of Bangladesh has finalized a common guideline as per size of the schemes considering the lowest tier of the local Government institution named Gram Parishad for any water management institution. Accordingly the Integrated Planning for Sustainable Water Management programme is following the lowest level management institution as a ward or gram committee. However, for polder 43/2A it was found that the ward-level committees need a ladder or higher institutional arrangement to communicate with the higher bodies or institutions. The solution for a particular problem for a ward may create problems for the other ward. In the next step, the planning cell people were trying to form these committees (block committees), which will be formed including a few wards based on the influenced area of the existing hydraulic structures. But they could not achieve this because of uncertainty of the future of the Integrated Planning for Sustainable Water Management programme. It is very difficult to find a coastal scheme where one block is completely independent in terms of its management. The canal system of polder 43/2A is so complicated that the canals are almost inter-liked. It is also very difficult to identify the influence area of a particular sluice. On the other hand the FCD schemes have a flood protection component for which no system (primary or secondary) could be applicable. One breach at any place of the scheme is sufficient to damage the whole area.

The field organizers of the Integrated Planning for Sustainable Water Management programme did not have any previous water management experience and knowledge.

They were not trained how to conduct a field survey and gathering information for water management of a FCD scheme. They simply asked the local people what are the problems they have with respect to water management and what type of solution they need. But in reality it was required to explain all the consequences of water management to the local people and the justification of their demand. It is also very much important to explain the responsibility of the stakeholders in this situation. They just prepared the list of demands by the stakeholders and formed the ward level committee. The local people are waiting eagerly for the proposed interventions to be implemented.

Before doing any new intervention demonstration of the existing sluice operation is very much needed to see what are the real causes of the identified problems. It would have been very useful if the Integrated Planning for Sustainable Water Management people had done some repair works on the sluices and then some practical demonstrations together with the stakeholders. The interventions would have been reduced automatically. All the internal new interventions proposed for water retention have no basis because it is not sure yet how much water can be flushed and stored in the canals. The unwanted interferences made by the stakeholders within the area reduce the effect of the operation of the existing sluices. An attempt is necessary to bring back the conveyance capacity of the canals and khals first by removing obstructions. This has not been done for polder 43/2A so far.

The Integrated Planning for Sustainable Water Management programme is moving towards the polder within the polder concept. The whole polder will be divided into a number of small hydrological units considering the existing hydraulic structures and canal system. Still the Agency's planning people are giving much more attention to the agricultural aspects than the other aspects of the schemes. During their water management planning they consider that flushing through the sluices will be used only for agriculture. Domestic use of khal or canal water, homestead gardening, cattle bathing, fisheries, water quality and other issues were neglected during the planning. In fact it is obviously true that there is no proper operation and maintenance practice in the area.

The researcher visited the area together with the planning cell team. During the visit it was observed that water is needed everywhere in the area for transplantation of Aus Rice and land preparation. But the sluices of the area were not operated for flushing and storing. The initial plan of the researcher to operate all the sluices at a time to see how much water can flush into the area was not possible. It was, however, possible with one of the sluices (3 vents). According to the field investigation and results of the experiment (presented in chapter 9) made by the researcher with a large sluice shows that the sluices can be operated on the basis of the needs of the stakeholders upto a certain level. It takes some time for the water to reach the central part of the area. It was found that water enters into some of the canals, which are identified for the siltation programme of the Integrated Planning for Sustainable Water Management programme. Since tidal rivers surround the area the gates have to be operated at midnight also. During the experiment the gates were operated only in daytime and for five days. The sluices were operated only for storage. At the third day some complaints were registered by people who have pulses in the lowland. The percentage was not high. If this demonstration could be done for the whole scheme then local people will be more interested in the operation.

Until now the influential persons or farmers in the area are trying to control the gate operation for their interest only and they are successfully able to do this. They are capable to ignore the demand of a large portion of the people and other aspects of water issues even while they do not know the consequences. Considering these problems, the possible operational strategy should be demonstrated to the local people to show the consequences of water management. This should be mandatory before doing any new intervention. At the same time the local people could be included in these demonstrations to show them the consequences. Then they can easily understand the good or bad consequences of water management. After that need assessment surveys can help the planners for future interventions. If the people find everything in reality, then they are motivated further towards committee formation. The operation and maintenance of the area has to be done jointly with the stakeholders and be organized through a formal institution.

The Government of Bangladesh has published guidelines for Environmental Impact Assessment in 1992 (Flood Plan Coordination Organization, 1992) addressing different stages of preparation of a project. Attempts were made to incorporate legal aspects in a few peoples participation guidelines (Appendix B), which were not mentioned in the Environmental Impact Assessment guideline. Later this was strengthened by specifying the water resources rights of the stakeholders in the National Water Policy of 1999. While polder 43/2A was reclaimed before the Environmental Impact Assessment had got momentum in Bangladesh, no Environmental Impact Assessment was done during the preparation. The Integrated Planning for Sustainable Water Management programme has started with such approach. But the programme could not complete this due to the uncertainty of the approval by the donor. The researcher continued his work in polder 43/2A to develop a water management strategy evaluating the Integrated Planning for Sustainable Water Management programme and considering all relevant aspects of an Environmental Impact Assessment as much as possible.

7 PRESENT PRACTICES AND ENVIRONMENTAL CONDITIONS OF POLDER 43/2A

7.1 AGRICULTURE PRACTICES

7.1.1 Land Utilisation and Crops of the Area

In polder 43/2A the homesteads, water bodies, homestead gardens and roads cover about 1,500 ha of the gross area of 5,100 ha. Based on the Master Plan Organization classification land types with respect to seasonal flooding caused by rainfall and tidal effects are distributed as highland 945 ha, medium highland 2,380 ha and medium lowland 175 ha (Master Plan Organization, 1986). The land types have been considered on the basis of inundation depth, which is caused due to drainage congestion when there is excess rainfall and entrance of tidal water during the wet season.

Depending on the land type, soil and other input facilities Rice cropping may be single, double or triple. According to information received in the field, about 74% is used for double crop cultivation, 16% for triple crop cultivation and about 10% for single crop cultivation. Land type distribution with major crops grown in the area are summarized in Table 7.1.

Table 7.1 Land type distribution with identified crops in polder 43/2A (after Bangladesh Water Development Board, 2000)

Land type and area	Crops of the different cropping seasons with area		
	Kharif-I	Kharif-II	Rabi
Highland 945 ha, 27%	T. Aus (LV), 430 ha T. Aus (HYV), 150 ha	T. Aman (LV), 750 ha T. Aman (HYV), 195 ha	Khesari, Sweet Potato, Mughbean, Groundnut, Chili, total 420 ha
Medium highland 2,380 ha, 68%	T. Aus (LV), 1,450 ha T. Aus (HYV), 420 ha	T. Aman (LV), 1,580 ha T. Aman (HYV), 800 ha	Khesari, Mughbean, total 825 ha
Medium lowland 175 ha, 5%		T. Aman (LV), 175 ha	

LV = Local Variety, HYV = High Yielding Variety

Khesari (Grass-pea) is extensively cultivated in the medium highland area. It is broad casted in Aman crop fields just after the recession of floodwater. Chili is mainly cultivated along the banks of khals and areas where water sources are available.

7.1.2 Present Cropping Pattern and Cropping Calendar

A cropping pattern is a spatial and temporal arrangement of the crops within a cropping year and is largely determined by physical, biological and socio-economic factors. Rice, being the major crop, is dominating the cropping patterns of Bangladesh as well as the cropping pattern of the area. The cropping patterns are shown in Table 7.2.

Table 7.2 Present cropping patterns in polder 43/2A (Bangladesh Water Development Board, 2000)

Kharif-I	Kharif-II	Rabi	Area in ha
	T. Aman (LV)		350
	T. Aman (HYV)	Mughbean, etc.	125
	T. Aman (LV)	Khesari	575
T. Aus (HYV)	T. Aman (LV)		255
T. Aus (LV)	T. Aman (HYV)		850
T. Aus (LV)	T. Aman (LV)		800
T. Aus (HYV)	T. Aman (LV)	Khesari	325
T. Aus (LV)	T. Aman (LV)	Chili	50
T. Aus (LV)	T. Aman (HYV)	Chili	20
T. Aus (LV)	T. Aman (LV)	Mughbean, etc.	150
Fish			110

The cropping calendar indicates the time adjustment of different crops grown in a sequence. Such sequences play a vital role in the yield of individual as well as total yield of crops grown in the Rabi and Kharif seasons. The cropping calendar also helps to formulate a good water management plan for different crops in different cropping seasons. The cropping calendar and the relationship of cropping seasons of the area are shown in Figure 7.1.

Yields for T. Aus vary from 1.5 to 1.9 t/ha for LV and from 2.3 to 3.0 t/ha for HYV. The yields of T. Aman vary from 1.5 to 2.0 t/ha for LV and from 2.5 to 2.8 t/ha for HYV. The average yield for Khesari is 1.25 t/ha. It may be mentioned here that the average yields of different crops in the area are found to be low with respect of the other parts of the country. The reasons for these lower yields are:

- water in the area is not properly managed due to the conflicts that exist between highland and lowland farmers;
- scarcity of water in early Kharif-I season and excess in September and October cause damage to T. Aus and T. Aman crops;
- modern practices of cultivation are almost absent in the area and the farmers are not using fertilizers, pesticides and other inputs in proper doses;
- hailstorms, cyclones and other natural phenomena may damage the crops at different stages.

7.1.3 Inputs Used

Both traditional and irrigated agriculture are practiced in the area. The available irrigation facilities along with embankment cuts have created opportunities for the cultivation of High Yielding Varieties, which has resulted in an increasing use of fertilizers, pesticides and other inputs over the last 5 - 8 years. The local farmers informed that the inputs are available in the local markets but that the prices are high. The small and marginal farmers who have not sufficient cash can not purchase these inputs as per requirement, which ultimately binds them to use those inputs in small quantities. The farmers also expressed that they have insufficient know how about the application of inputs, like fertilizers and pesticides, in the right amounts.

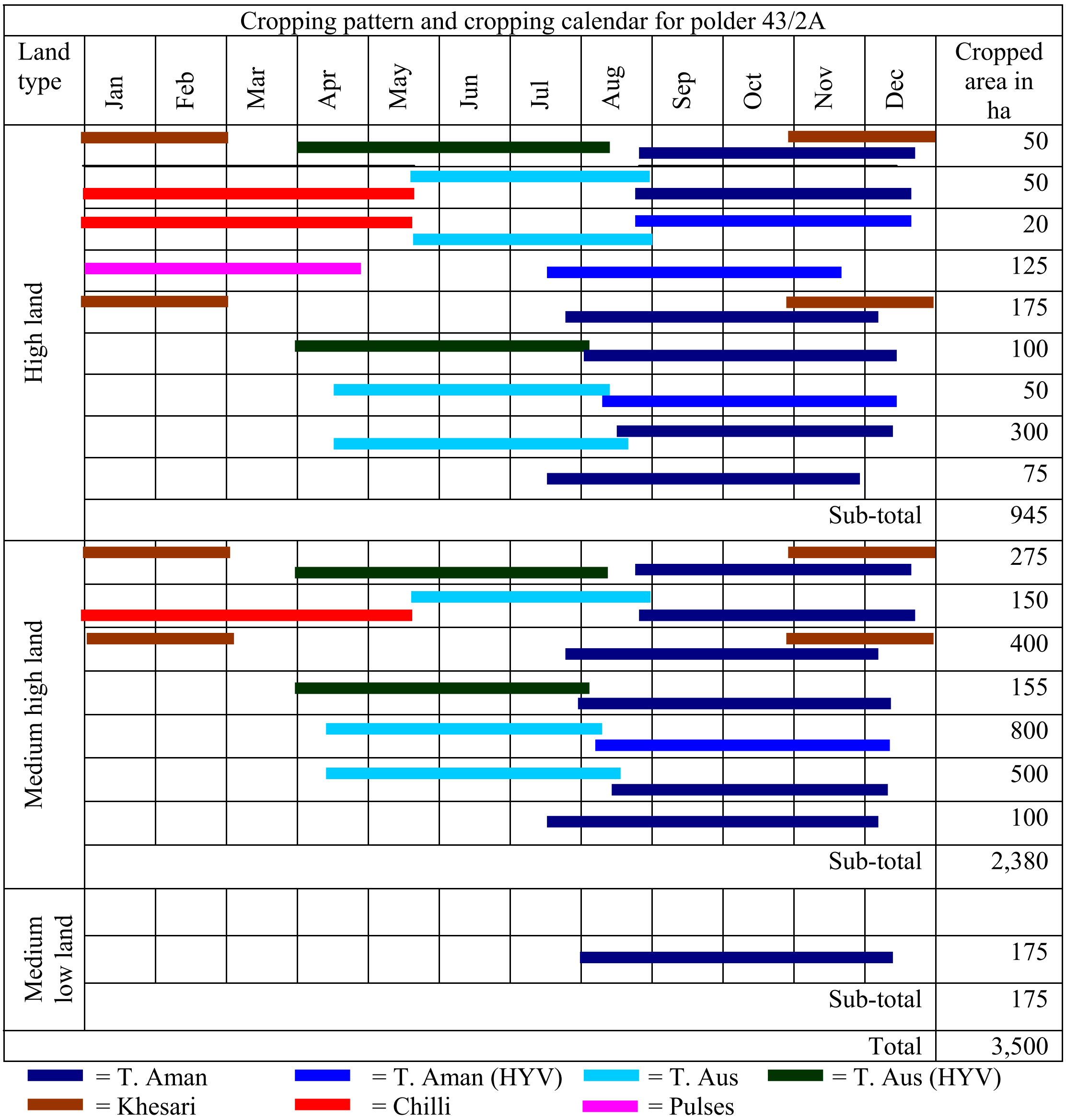

Figure 7.1 Cropping pattern and cropping calendar of polder 43/2A

7.1.4 Crop Damage

Farmers in the area informed that crop damages due to drainage congestion in the rainy season, scarcity of water in the dry and beginning of wet season and other natural phenomena occur almost every year. Of the problems, drainage congestion is the most severe and a repeated cause of crop damage or failure. Scarcity of water due to lack of management practices and irrigation inlets (small pipes in the embankment) is also responsible for crop damage at different stages of growth.

A crop damage of 20% or less is usually considered a good harvesting year, while an extent of damage ranging from 20 - 40% is considered as a normal year. On the basis of this comparison the yield of different crops at different land levels for the good, normal and bad years could be estimated. Table 7.3 shows an assessment of crop damage due to different natural calamities in polder area.

Table 7.3 Crop damage assessment for the different crops in polder 43/2A (after Bangladesh Water Development Board, 2000)

Problems and natural calamities	Affected crop	Stages of crop damage	Time of damage		Extent of damage in %
			Year	Month	
Scarcity of water	T. Aus T. Aman	Vegetative growth stage Matured stage	1996 - 1998	April - May Oct - Nov	40 - 50 30 - 40
Drainage congestion	T. Aus T. Aman Rabi (Khesari)	Matured stage Seedling to young stage Seedling stage	1996 - 1998	June - Aug July - Sept Nov - Dec	30 - 40 60 - 75 50 - 60
Soil virus	T. Aus T. Aman Rabi	Seedling vegetative growth stage	1996 - 1998	April - May July - Aug Dec - Jan	20 - 30 20 - 30 30 - 40
Pest attack	T. Aus T. Aman	Vegetative growth stage	1996 - 1998	May - June Aug - Sept	20 - 30 40 - 50
Hailstorm	T. Aus	Vegetative growth stage	1996, 1998	July - Aug	30 - 40
Cyclone	T. Aman	Matured stage	1998	Nov	30 - 40

7.1.5 Critical Moments for Agricultural Practices

Both rainfed and irrigated agriculture are practised in the area. Some critical moments for Rice cultivation that were identified by the researcher are:

- for T. Aus (LV and HYV):
  - seedbed preparation and transplantation are not possible if insufficient rainfall occurs in April and May;
  - yields reduction when there is insufficient rainfall during the vegetative growth stage in the months of May and June;
  - sometimes the crops are severely damaged in the matured or ripening stage when there is excessive rainfall in the months of July and August;
- for T. Aman (LV and HYV):
  - it cannot be cultivated in time in some years due to drainage congestion caused by excessive rainfall in the months of July and August;
  - it is sometimes damaged in the matured, or flowering stages when there is no, or limited rainfall in the month of October.

7.1.6 Practices for Different Rice Crops

In the area, both T. Aus (HYV) and T. Aus (LV) are cultivated using mainly river water through local cuts and sluices. Indigenous methods are also used for irrigation using canal water. Water is used in different stages and in different amounts, which mainly depend on the critical moments of the crops. The different scenarios for different Rice crops, considering the critical moments and amounts of water as reported by different stakeholders are presented in Table 7.4.

The low tide starts before water is reaching the lands situated far away from the sluices. The farmers informed that this is due to the insufficient number and too small dimensions of sluices and lack of proper operation and maintenance. Consequently, these lands can not be intensively used for Aus cultivation. In a few places the highland contains salinity to some extent, which damages the Rabi crops.

T. Aus (HYV) cultivation is increasing day by day as its yield is higher than that of local varieties. However, due to scarcity of water and lack of proper water control measures, farmers can not cultivate this crop in their fields as they expected. The farmers seem to be idle and not interested to do the hard work for Boro (HYV), as presently they are cultivating T. Aus under partial irrigated conditions which requires less cultivation cost and effort than Boro (HYV) cultivation.

Table 7.4 Scenarios for T. Aus (HYV and LV) and T. Aman (HYV and LV) (after Bangladesh Water Development Board, 2000)

Stages	Period of irrigation	Amount of water in m	Remarks
T. Aus (HYV)			
Land preparation	April - 15 May	0.12 – 0.15	Irrigation is given through public cuts and from canal water through sluices
Plantation to flowering or matured	15 April - 15 June	0.15 – 0.20	Irrigation is given only if there is limited or no rainfall during this period
Matured to harvesting	July - 15 August		Irrigation is not given, as sufficient rainfall is available in this period
T. Aus (LV)			
Land preparation	15 April - 30 May	0.10 – 0.15	Irrigation is given through public cuts and sluices if there is limited or no rainfall
Plantation to flowering or matured	15 May - 15 July	0.12 – 0.15	Irrigation is given through public cuts and sluices if there is limited or no rainfall
Matured to harvesting	July - August		Irrigation is not given due to sufficient rainfall
T. Aman (HYV and LV)			
Land preparation	1 - 20 July	0.10 – 0.15	Irrigation is not given due to sufficient rainfall
Transplantation to vegetative growth	15 July - September	0.12 – 0.15	Irrigation is not given up to August, due to sufficient rainfall, but supplementary irrigation is needed in September when rainfall is insufficient.
Matured to harvesting	October - December		Supplementary irrigation is needed in October.

7.2 FISHERY PRACTICES

7.2.1 Fisheries in Polder 43/2A

Due to the reclamation fishes like Aire (Mystus aor or Mystus Seenghala), Boal (Wallago attu), Koral (Lates calcarifer), Pangus, Ruhi (Labeo rohita), Catla (Catla catla) cannot spawn freely anymore inside. These species have reduced in number inside the area. But species like Shoul (Channa striatus), Koi (Anabas testudineus), Magur (Clarias batrachus), Puti (Puntius sophore) have increased due to some stagnant water bodies (Bangladesh Water Development Board, 2000). In case of pond culture (extensive) catch percentages of Ruhi and Catla have increased though they are not subsistence after the reclamation. Before reclamation, during flood those species entered into the area with flood and tide water and could move away during recession of flood and tide. Under the present condition in the area, the following impacts can be identified:

- loss of flooded habitat during the wet season resulting in loss of fish catches and interference of their life cycles;
- blockage on movements of fish (adults, juveniles and hatchlings) between external rivers and floodplains;
- reduced diversity of fish by preventing migratory species entering into floodplains;
- increased fishing pressure on smaller areas of water during the wet and dry season resulting in damage to the long-term sustainability of fisheries;
- adverse environmental conditions such as stagnation of water filled with water hyacinth, which could trigger disease outbreaks among fishes.

Fisheries potential in the area includes inland open water capture fisheries in khals and floodplains and culture fisheries, mainly in fresh water ponds and other closed water bodies. These water bodies are believed to contain more than fifteen species of fresh water fishes.

7.2.2 Capture Fisheries

The open water capture fish output of the area has been estimated on the basis of a sample survey in 50% of the total area. The average annual catch in the khals is 427 kg/ha and in the floodplains 14 kg/ha. Annual catch in the floodplains per household within the area is estimated at 7.6 kg. According to the Department of Fisheries (DOF) it is 10.6 kg for the Patuakhali District (Department of Fisheries, 1996 and 1997). The total annual production from open water (khals and floodplains) within the area is estimated at about 34 ton. The water storage area of different open water bodies along with the yearly output is shown in Table 7.5. The average return per household is estimated to be 20.5 Tk/day. Presently the khals, especially those that have been closed without any hydraulic structures, are almost silted up and filled with water hyacinth. These water hyacinths are deteriorating the water quality, making the water unsuitable for domestic and animal use.

Table 7.5 Present annual fish catch per year within polder 43/2A (Bangladesh Water Development Board, 2000)

Water body	Number	Area in ha	Output in ton	Percentage in %	Net return in 10^6 Tk
Ponds	1,187	47	61.0	64	2.90
Khals	38	111	30.8	33	1.95
Floodplains		267	3.1	3	0.36
Total			94.9	100	5.21

Tk = Bangladeshi currency (Tk 58 = 1 US $)

A sample survey of the village Matibhanga showed that before the reclamation 45 fishermen were active. But now the quantity of the catches has been decreased. Accordingly 50% of the fishermen have changed their profession. It has also been observed that about 75% of the village population catch fishes for subsistence consumption (Bangladesh Water Development Board, 2000).

Fishes of carp groups, especially major carps, do not breed in the khals or other water bodies situated in the area, but rather at some point adjoining major rivers and the resultant concentrations of flooding spawn and pelagic fry are swept downstream. The return of fry and fingerlings to the floodplains for development is obstructed by the hydraulic structures and cause reduced annual harvest. Fishermen want more water through hydraulic structures to allow migration of fishes and Rice farmers want no water to save their crops from flood.

A sample survey showed that, within the area the percentage of open water catching fish varieties to the total catch are (Bangladesh Water Development Board, 2000):
- Koi (Anabas testudineus) 16%
- Taki (Channa punctatus) 15%
- Shoul (Channa striatus) 15%
- Shingi (Heteropneustes fssilis) 13%
- Puti (Puntius sophore) 12%
- Magur (Clarias batrachus) 8%
- Small shrimp 7%
- Boal (Wallago attu) 6%
- Fali (Notopterus notopterus) 5%
- Mola (Amblypharyngo-don mola) 1%
- Others 2%

7.2.3 Culture Fisheries

Out of 1,187 ponds (47 ha), presently only 429 ponds (22 ha) are used for culture fisheries. In most cases the culture fisheries in the ponds are at subsistence level. Before the reclamation, culture fisheries could not develop because of regular bank spilling of the ponds and other closed water bodies during the wet season. After reclamation, while the capture fisheries are gradually decreasing, the people started to develop their ponds for culture fisheries. The embankment protects now the area from regular flooding. So, digging of new ponds and development of the old ones has started. The people have introduced at a limited scale pen cultures in the perennial canals. The annual catch from the ponds as estimated from the field survey is 61 ton (Bangladesh Water Development Board, 2000).

Presently in Patuakhali district the culture fishery activities suffer from scarcity of fish fry and fingerlings due to non-availability of fish hatcheries, nurseries and spawn collection units. Fish farmers and traders collect fish fingerlings from Khulna or Jessore region. Consequently the cost is high. The Department of Fisheries in Patuakhali district limits its activities to advice to the interested farmers who are in contact with them regarding culture fisheries. In general, the awareness of the farmers towards culture fisheries is very low. The constraints regarding culture fisheries were identified as follows:
- lack of motivation or awareness;
- insufficient infrastructure development for culture fisheries (ponds development);
- non availability of fish fry and fingerlings;
- absence of extension services for fish cultivation;
- lack of credit and training facilities to the fish farmers (pond owners and leases).

According to the sample analysis, local carp fish varieties like Ruhi, Catla, Mrigal and China Puti are the dominating culture fish types in the area. Other varieties are Magur, Mirror Carp (Cyprinus Carpio var. specularis), Silver Carp (Hypophthalmichthys molotrix), Grass Carp (Ctenopharyngodon idellus) etc. The percentages of present culture fish varieties in the area are (Bangladesh Water Development Board, 2000):

- Ruhi (Labeo rohita) 19%
- Catla (Catla catla) 19%
- Mrigal (cirrhinus mrigala) 17%
- China Puti 15%
- Grass carp (Ctenopharyngodon idellus) 9%
- Silver carp (Hypophthalmichthys molotrix) 9%
- Magur (Clarias batrachus) 6%
- Mirror carp (Cyprinus Carpio var. specularis) 4%
- Others 2%

The species (Koi, Magur, Shingi (Heteropneustes fssilis) and Shoul) which are usually growing in stagnant water have increased after construction of the embankment. But the quantity of catch of other common species like Boal, Air, Koral, Ruhi, Catla has decreased significantly.

For subsistence consumption, the local people catch fishes both in perennial and seasonal khals within the area. Also the professional fishermen catch fishes from these khals for daily sale. In some parts of the perennial big khals there exist some local initiated informal groups for catch fish. Those groups have their individual identified water area in the khals to make their catch. The ponds are mostly privately owned (perennial and seasonal) and cultured in an ordinary way both for subsistence and commercial purposes. Catches from floodplains during the rainy season are very little in comparison to the khals and ponds.

It has been estimated that fish catch in the ponds is almost double that of the total catch from khals and floodplains. Table 7.6 presents a summary of the qualitative change of fish species before and after the reclamation.

Table 7.6 Qualitative changes in fish species for the polder 43/2A (after Bangladesh Water Development Board, 2000)

Species	Before reclamation		After reclamation	
	Inside (khal or pond)	Outside (river or khal)	Inside (khal or pond)	Outside (river or khal)
Boal	A	A	A (R)	A (R)
Aire	A	A	A (R)	A (R)
Koral	A	A	A (R)	A (R)
Fali	A (less quantity)	A (less quantity)	A (RF)	NA
Ruhi	A	A (less quantity)	A	A (RF)
Catla	A	A (less quantity)	A	A (RF)
Mrigal	A	A (less quantity)	A	A (RF)
Koi	NA	NA	A	NA
Shingi	NA	NA	A	NA
Magur	NA	NA	A	NA
Taki	NA	NA	A	NA
Shoul	NA	NA	A	NA
Exotic Carp (Silver and Grass carp)	NA	NA	A	A
Small Shrimp	A	A	A	A (near the sluices)
Baila	A	A	NA	NA
Pangus	A	A	NA	NA
Mani	A (less quantity)	NA	A (R)	NA

A = Available; NA = Not available; R = Reduced; RF = Reduced further

7.2.4 Fish Pass

Fish migration is most commonly brought about a behavioural response to water flows. However, the nature of this response can change during the life cycle of the species. The species of fish differ greatly in the extent of their movements. The fish of the area has been divided into ‘black fishes’ which are essentially resident on the floodplain and ‘white fishes’ which show migration within the river system, usually associated with spawning.

The ‘black fishes’ include for example Koi, Shoul, Shingi, Taki, Gajar (Chauna marulias), Baral Baim (Mastacembellas armetus), Khalisha, Lal Khalisha (Colisa SPP) and some species of Puti. They normally retreat into beels or other residual water bodies. The ‘white fishes’ can be exemplified as major carp species and Hilsa (Teniolisa illisa).

The behavior of fish is crucial in fish passage design and is often typical for the individual species. Important parameters which may influence planning are the shore and depth orientation of the fish during migration, where they rest, how they respond to barriers such as gated sluices and associated hydraulics, how do they react to light and enclosures and possible diurnal variation in migration.

There are several physical and chemical factors, which influence migration and behavior of fish. The physical factors are depth of water, bottom materials, pressure, temperature, intensity of light, photo-period, nature of water current and turbidity. The characteristics like pH of water concerned, smell and taste of water, salinity are some of the important chemical characteristics. In addition to the above factors, there are some biological factors as well, which include food memory, sexual maturity, physiological clock and endocrine glands. Presence or absence of predators and competition are also considered as biological factors.

Knowledge about the distribution of migratory fish within the river or water bodies system is important in planning the location of access channels to or from the fish pass structures. Poorly located access channels will delay rather than attract migrants. Lack of knowledge of fish behavior and leaping capacity of migratory fish, combined with cost of fish passes, may prevent the construction of the right type of fish passes.

In the area there is no beel, lake or baor except many large and small canals. From the information discussed above, it is evident that separate fish pass structures will not be feasible. Moreover, because of the high cost, fish-pass structures will not be economically viable for this medium scale polder area. The sluice gates can be operated to provide an easy access for fish considering agricultural requirements. It is not harmful for fish migration if the head difference over the sluice is upto one meter. The sluices can be operated in such a way that it causes least damage to fishes and allow passage from river to floodplain. Inside and outside water levels may reach the same height twice a day. Velocity of the water through the sluices is for a considerable time favourable for fish migration.

7.2.5 Fishing Community

Fishing provides an important seasonal source of food and income for many of the poorest of the poor in the area. There are three principal categories of people who catch fish, viz.:

- professional fishermen, whose income depends entirely on full time fishing;
- part-time fishermen, who supplement their income from other seasonal employment and fishing for part of the year;
- occasional fishermen, who catch fish mainly for subsistence, especially during the flood season.

The traditional fishing community 'Jele' would only be used with extreme reluctance as it carries significant negative social connotations in relation to the rest of the rural society. In the polder area these 'traditional' fishermen are rapidly being outnumbered by new entrants to the profession who are mostly farmers or labourers who have moved into fishing in spite of the negative social connotations of the occupation and their relative lack of skills and knowledge regarding the fisheries resources. Fishing as an occupation and principal source of livelihood was almost entirely limited to specific social groups whose position in the society and identity as a community was defined by their involvement in fishing. These traditional fishermen are frequently thought of as being almost all Hindu but they are poor Muslims, they have been involved in fishing for many years and they have become traditional fishermen. Effectively they occupy the same social role as Hindu fishermen.

During the study no formal cooperatives or community groups were found in the area except one informal village group who is preserving a part of a khal for capture (Boro Bighai khal near Office hat). Most of the fishermen catch fishes in khals or rivers under individual arrangement or in a group for sharing the catch.

Most of the households in the area catch fish for their own consumption. But it is the poor fishermen who make their living from fishing in the internal water bodies. They cannot afford to buy nets or boats required for catching fish in the big river just outside the polder. Some of the poor fishermen do fishing in the big rivers and in the sea, but only as paid labourers under richer fishermen.

There is no organized fish marketing system in the area. The small traders (Faria), who purchase fish from village farmers and fishermen and sell it to relatively big traders (Bepari) are very dominant in the local fish market. Due to the limited transport network in the region the fishermen and or fish farmers cannot transport the fish to the big market. As there is no cold storage and ice factory in the area fish output can not be preserved for a long time. They have no other choice then selling the excess catch at the same day at a very low price. The local fish market is very volatile and is not enabling the fishermen and the fish farmers to improve their livelihood.

7.3 SOCIAL CONDITIONS OF POLDER 43/2A

The description of the social aspects will be done from two standpoints: the present social conditions, and impact of interventions and arrangements on different social factors. The socio-economic part of the study consisted of executing household survey and focus group discussions in seven sample wards, using questionnaires and checklists during the Integrated Planning for Sustainable Water Management (IPSWAM) programme. Care was taken to select representative wards from the point of view of land elevation (high or low) and geographical distribution over the polder area.

7.3.1 Demography

According to the population census of 1991, the total population of the area was 33,986. If extrapolated with the annual population growth rate of Bangladesh, the present population of the area would be about 40,000. A total of 5,997 households were reported in the area (Bangladesh Bureau of Statistics, 1991). The average household size was 5.7 persons, which was slightly higher than that of Patuakhali Sadar Thana as a whole (5.5 persons). Population distribution by age is presented in Table 7.7.

Table 7.7 Distribution of population by age groups in % in polder 43/2A (Bangladesh Bureau of Statistics, 1991)

Age group	Choto Bighai UP	Boro Bighai UP	Madarbunia UP
Up to 14 years	49.7	46.2	46.3
Up to 34 years	29.3	28.1	28.6
Up to 59 years	17.7	18.9	18.4
60 years and above	3.3	6.8	6.7
Total	100.0	100.0	100.0

UP = Union Parishad

From Table 7.7 it appears that the population in the non-working age groups (≤ 14 years and ≥ 60 years) is bigger than that in the working age group (15 to 59 years). The literacy rate of the area is 36.4% that is slightly higher than the national average (32.4%).

7.3.2 Livelihood

As like most of the rural areas of Bangladesh, three basic resources upon which the livelihood of the majority of the population depends are land, water and employment. The baseline conditions of those three resources, as far as they affect the livelihood of the people, will be described here.

Land

The well being of a rural household largely depends on the access to and control over land. A discussion on the existing patterns of land ownership and land operation is, therefore, important to understand the livelihood of the majority of the people in this area.

In this study a household has been considered as the basic unit, and the classification of households has been done in the same way as in Government statistics so that the findings are comparable with the official statistics. The classification of households is shown in Table 7.8. According to the household survey conducted in seven wards of the area, 81% of the households appears to have agricultural land, while 19% have none. Average land holding per household is only 0.6 ha. The land ownership pattern of the area is also shown in Table 7.8.

Table 7.8 Classification of households (based on farm sizes) and land ownership pattern in polder 43/2A (Bangladesh Water Development Board, 2000)

Category of household	Farm size in ha	Number of households in %	Land owned in %
Landless household		19	
Marginal farm household	0.01 – 0.40	36	13
Small farm household	0.41 – 1.01	29	32
Medium farm household	1.02 – 3.03	14	40
Large farm household	3.04 and above	2	15
Total		100 (1,812 households)	100 (1,085 ha)

Land Operation

It appears from the household survey that about 60% of the land is operated by the landowners themselves while the rest is given out to others under different tenurial arrangements (sharecropping, leasing and mortgaging). The present operational pattern of land is shown in Table 7.9. It is a common practice that the landowners share out their land for Aus and Aman crops and take back their land for the Rabi crop. Some landowners share out their land for the whole year.

Table 7.9 Land operation pattern (Bangladesh Water Development Board, 2000)

Category of households	Share crop in %	Leased in %	Mortgage in %	Share crop out in %	Leased out in %	Mortgage out in %	Total operated land in %	Owned operated land in %
Landless	9	13	5	4	1	0	4	0
Marginal farm	33	32	29	20	16	12	17	8
Small farm	39	31	35	30	43	33	32	31
Medium farm	17	21	28	36	33	46	34	42
Large farm	2	3	3	10	7	9	13	19
Total in ha	176	171	42	272	144	35	1,035	645

Of the three types of tenurial arrangements, sharecropping is the most common one. Leasing is also widely practiced while the cases of mortgaging are relatively few. Sharecropping and leasing have increased during the last few years, mainly because of crop damage. People having small land holdings share out or lease out their lands mainly because:

- lack of agricultural inputs, most important of which is ‘haal’ (plough with draught animals);
- they engage themselves in some other works.

The conditions of sharecropping vary from crop to crop. For Aus, the most common practice is that the landowner provides 50% of inputs (seed, fertilizer and pesticide) and gets 50% of the harvest. Sometimes it differs depending on the agreement between the landowner and the sharecropper. The landowner provides 2/3 of the inputs and takes 2/3 of the harvest. For Aman, the general practice is that the landowner provides 2/3 of inputs and gets 2/3 of the harvest. Sometimes the landowners agree to share the harvest 50 : 50, in which case they would provide 50% of the inputs. As for Rabi crops, the most common practice is that the sharecropper supplies all the inputs and he takes 2/3 of the harvest.

About 44% of the operated land is under leasing tenurial practice. As per period and conditions, leasing can be of three types (Bangladesh Water Development Board, 2000):
- thika patta, is for 7 years;
- nagad, is for a year;
- egrim kobla, is for 5 - 10 years.

The rates of thika patta vary from Tk 7,000 to Tk 12,000 per kura (0.25 ha). The landowner may not take back his land for own cultivation within 3 years. In that case he will have to refund an amount, proportionate to the number of years remaining before the expiry of the contract. The rates for nagad range from Tk 2,000 to Tk 3,000 per kura. The rates for egrim kobla range from Tk 10,000 to Tk 15,000 per kura. Land mortgaging is not so common but it does occur. The rates for mortgaging normally range from Tk 15,000 to Tk 20,000 per kura, but sometimes the rate may go as high as Tk 40,000 per kura.

Water
Water is another basic resource of the area, upon which livelihood depends for a number of people. Apart from agriculture, the availability and access to water bodies is vital for fishermen and boatmen. Water is one of the means of communication from which the boatmen make a living while fishermen make a living from catch in water-bodies available in the area.

The scope of navigation has considerably been reduced due to the reclamation. Most of the khals have no open connection with the rivers outside. Boats can carry on only in some of the khals during the wet season and only for short distances.

Employment
Like most rural areas of Bangladesh, agriculture is the main employment opportunity for the majority of the population. It is also true that agriculture cannot provide full employment to all, especially to the labourers. The employment situation for agricultural labourers has been especially grim because of low yields during the last couple of years. They take up some other works, even if it means temporary migration from the area.

The occupational pattern, as derived from the survey on the primary occupation of the household heads of the area in the seven sample wards, is shown in Table 7.10.

It is more common for rural areas to have a larger number on farm labourers than off farm labourers but in this area the on farm labourers account for only 8% of the working population. Two things are mainly the cause of this peculiarity:
- for the last few years yields have been low in the area;
- the district town is close by so day labourers can easily go there for work. Besides, labour migration to distant places was also reported.

The socio-economic condition of the area also influences the wage rates. Group discussions in different wards revealed that the scope of employment is limited. Agriculture can absorb only a small part of the total labour force, mainly because of low yields in the area. The overall economic condition of the people is rather bad. As a result, wage rates of labourers are lower than in many other parts of the country.

The daily wage rates, as found during group discussions in the sample wards, are given in Table 7.11. Other wage rate types are also practiced in this area (monthly, quarterly, half-yearly and yearly).

Table 7.10 Occupational pattern in polder 43/2A (Bangladesh Water Development Board, 2000)

Category of household and farm size		Farmer in %	Labourer		Fisherman in %	Boatman in %	Petty Businessman in %	Others in %
			On farm in %	Off farm in %				
Landless		4.2	33.9	51.0	24.7	25.0	24.8	16.4
Marginal farm (0.01 - 0.40 ha)		33.5	42.3	32.0	52.8	35.0	32.8	27.5
Small farm (0.41 - 1.00 ha)		38.6	20.4	11.6	13.5	40.0	26.7	32.8
Medium farm (1.01 - 3.00 ha)		21.3	3.2	5.4	9.0	0.0	13.9	21.2
Large farm (3.01 and above)		2.4	0.2	0.0	0.0	0.0	1.8	2.1
Total	Households	795	147	407	89	20	165	189
	% of total households	44	8	23	5	1	9	10

Table 7.11 Daily wage rates in polder 43/2A (Bangladesh Water Development Board, 2000)

Labourers		Daily			
		Peak season		Slack season	
		With food	Without food	With food	Without food
Male	Farming	Tk 50 - 60	Tk 70 - 100	Tk 30 - 40	Tk 40 - 60
	Non-farming	Tk 50 - 60	Tk 60 - 100	Tk 30 - 40	Tk 50 - 60
Female	Farming	1 kg of Rice		Only food	
	Non-farming	1 kg of Rice	2 kg of Rice	1 kg of Rice	1 kg of Rice
Child and Juvenile		Tk 15 - 30	Tk 50	Only food	

As shown in Table 7.11, the daily wages vary between peak and slack seasons. The periods when there is a rush of works are called peak seasons and the rest are called slack seasons. Mid August to mid September and mid November to mid February are considered peak working periods. The other months are slack periods. Women are rarely engaged as farm labourers but, if they do so, they are paid much less than male.

7.3.3 Credit System

Credit is one of the important issues in rural livelihood. Being poor, most of the people in the area do not easily go for credit. In the past local money lenders, called Mahajans, were the only source of credit. The terms and conditions of this type of credit often go against the interests of poor people. The situation is changing now with the introduction of alternative credit sources. Government and non-government organizations (NGO) have taken initiatives to meet up people's credit needs. Access of different categories of households to sources of credit is shown in Table 7.12.

The rates of interest on credit vary depending on the source of credit. The interest rates of institutional credits are lower than the non-institutional ones. Banks charge an interest of 13 - 15.5% per annum and the non-government organizations, including Grameen Bank, charge 10 - 12.5% per annum. The credit from relatives is not always interest free. The Mahajans charge the highest rates of interest, i.e. 80 - 120% per annum.

Table 7.12 Sources of credit in polder 43/2A (figures in %) based on a sample size of 1,029 (Bangladesh Water Development Board, 2000)

Sources of credit	Categories of households					Total
	Landless	Marginal farm	Small farm	Medium farm	Large farm	
Banks	2.4	10.7	17.2	9.2	1.0	40.5
NGOs	3.9	8.8	5.4	1.9	0.0	20.0
Relatives	2.8	9.7	7.9	2.3	0.3	23.0
Mahajans	1.5	7.3	5.4	1.9	0.4	16.5
Total	10.4	36.5	35.9	15.3	1.9	100.0

7.3.4 Power Structure

The powerful people in the area are the local elite and leaders having authority or influence in the affairs of a given area. The ordinary village people do not (in fact, cannot) by-pass them, even in many personal matters. It appears from group discussions that land is an important source of power, but not all the powerful people are big landowners. A number of them are leaders by hereditary and some have acquired leadership because of their personality, personal wisdom, achievements or wealth. Others are elected representatives at Union Parishad (members and chairmen).

The usual functions of such leaders include settling disputes in Gram salish (informal village court) and to take initiatives and pursue at Government offices for works of public interest, like construction of educational institutions and village roads. In some instances they take leadership in local initiatives which may be considered as some form of water management such as cutting and closing of embankments. For any work of common interest, people approach Union Parishad members and chairmen as well as village Matbars. Thus, the Union Parishad members and chairmen play a very important role within the power structure of the area.

7.3.5 Social Conflicts

Conflicts occur in society for many reasons but only those conflicts that result from, or have anything to do with water management issues that have been observed by different stakeholders in polder 43/2A are described below.

Farmer - fisherman Conflict
Fishermen in the area catch fish at the mouth of the existing sluices, especially at the 3 bigger ones – Kazirhat sluice, Khatasia sluice and Titkata sluice. The fishermen operate the gates for fishing purposes hampering the interest of the farmers.

Highland - lowland Conflict
The land along the periphery is usually high. The highland people have control over the sluices as they live near to the sluices. Because of land elevation, the highlands starts getting water only when the lowlands have been inundated to a certain depth. Inundating the highlands to the required depth often means crop damage in the lowlands.

Conflicts on Cutting of the Embankment or Roads
Conflicts on cutting of the embankment or a road occur between the landowners where the embankment or the road has been cut by other groups. This kind of conflict occurs frequently over cuts in the embankment near the Bhajna Primary School, near Madarbunia sluice and at the crossdam over the Tillar khal, and the cut on the road near the Kazirhat sluice.

Conflicts on Closing of Khals
Conflicts on closing of khals arise when people with vested interest close off the khals for personal gains (making ponds for cultivating fish) disregarding the interest of the whole area. Such conflicts are reported for example at the Madarbunia Sluiser khal, the Saichabunia khal, the Gauwatala khal and the Farider khal.

7.3.6 Cooperation and Initiatives

Any action that is initiated and accomplished jointly by local people to achieve a common objective is called local initiative. It requires social cohesion and cooperation among the involved parties. Local initiatives for water management purposes have been reported in almost every ward. The need to supply water in fields is well recognized by the local people as the most important factor of water management. Other major requirements of water management are drainage, water retention and conveyance of water. The local initiatives in the area include installing pipes, construction of small dikes, re-excavation of khals, cutting and closing of embankments and roads.

7.3.7 Gender Aspects

This section attempts to point out the position of women in relation to men and the role of women in water management. The position of women in relation to men will be presented in terms of gender division of labour, gender-related access and control over water resources, and socio-political dimensions of women's position in decision making.

Activity Profile
The activities of men and women and the workload of women in comparison to men can be discussed under three main categories of work, productive, reproductive and community work.

From the survey on randomly selected households, it appears that men and women are equally involved in some of the productive activities (Bangladesh Water Development Board, 2000). Women usually do not do the agricultural works outside homes. Only in exceptional cases women are found to do some works like weeding and irrigation. Generally the work of women in agriculture starts with harvesting. Women do most of the post harvest activities. Besides, women are involved more than men in homestead gardening and exclusively in poultry raising. In the activities related to livestock, women and men participate more or less equally.

As for the division of labour in reproductive activities, it are the women who do most of the works except for buying different items from markets and construction and repair of houses. Women do all the activities related to care and maintenance of household (including its members).

In activities related to community at large women participate in preparatory works. In ceremonies and celebrations women participate as silent participants. Women have very little or no voice in the decision making on any affairs of the community (especially water management).

Access and Control Profile
Like most of the rural areas in the country, access to and control over resources in the area are in favour of men. Irrespective of the socio-economic condition of households the control over most resources like land, capital and employment opportunity are not in women hands. Further, it was found that even access to resources is much restricted. It is only the women of large farm households who have some access to resources.

Socio-political Profile
At the household level it is the man who take decisions in most occasions. At community level women participation is not customary. Some changes are taking place in this respect. Women have a recognized position in the local Government structure. They are now elected members of Union Parishad. Whereby a scope is created for them to play an important role in water management issues. In the Integrated Planning for Sustainable Water Management (IPSWAM) programme, the water management committee formation process for the polder area enhances the position of women towards better water management by including them in the committee.

7.4 DESCRIPTION OF THE EXISTING ENVIRONMENT

The existing environment of the area will be described in three different types such as natural physical environment, natural biological environment and socio-economic environment.

7.4.1 Natural Physical Environment

The important elements representing the existing natural physical environment of polder 43/2A have been described in the previous Chapter and the rest (related to this study) will be presented here.

Drinking Water
The overall drinking water situation within the polder area is not good. There are inadequate hand tube wells for drinking water supply and other purposes. Some people have no other alternative but to have river or pond water for drinking. There are 340 hand tube wells in the polder area of which 296 are serviceable and the remaining 44 are out of order.

Water Quality
There is no industry within or adjacent to the polder area. So water pollution from industries is not a problem here. The water quality is a very important factor, which

affects the environment. The water quality in the khals is deteriorating by the depletion of dissolved oxygen (DO) and algae growth.

The water of the khals is polluted as some of the people use either open latrines, located in the banks of the khals, or closed latrines, but the wastes are discharged directly to the khals. Serious water borne diseases like dysentery, diarrhoea, and skin diseases were reported. It was also observed that every year about 5 to 7% of the total domestic animals die due to the use of this polluted surface water.

7.4.2 Natural Biological Environment

Some of the important elements representing the natural biological environment are presented below.

Forest and Homestead Vegetation
In polder 43/2A, there is no forest, but there are a good number of trees in roadsides, banks of ponds and khals, in the premises of schools, madrasas, and mosques. Homestead vegetation includes natural vegetation, plantations, groves and gardens. It was estimated that about 18 to 20% of the total area is covered by forest and homestead vegetation.

Wetlands
There is no permanent nor temporary wetland area. Hence, migratory birds do not come in the area. Birds are generally found in riverside wetlands and along other water bodies. Such birds will not be affected due to structural interventions.

Wildlife Species
The wildlife habitats of the area are terrestrial and aquatic. During the reclamation the construction of the embankment and sluices did not result in significant adverse effects to the area. Birds of different kinds were observed in the area during investigation. Different types of mammals, frogs and reptiles are also present in the area.

In the area endangered identified species are Mecho bang (Felis viverrena), Mechopacha (Bubo zeylonensis), and Shamuk khor (Anastomas oscitans). Five types of species such as Sona bang (Rana tigrina), Kalo gui (Varanus bengalensis), Kura (Icyhthophaga ichthyaetus), Nol bok (Ardea cinerea) and Sowkoon (Gyps bengalensis).

Some wildlife causes damage to crops at cultivation or harvesting stages. These include mainly different types of rats and some bird species such as Tiya (Psittacula krameri), Chorui (Passer domesticus), Baui (Ploceus philippinus). It was reported that birds cause maximum damage. Rats damage embankments by making holes. Before harvesting people make sound with empty containers to control birds. Rats cannot be controlled easily. Local people use traps to catch rats, but the general practice of the people to control rats is the use of poison in foods and put it at corners of houses, holes and other places where they live. The use of poison is extremely detrimental to the environment.

7.4.3 Socio-economic Environment

The social environment has already been covered while describing the present social condition in the polder.

As the polder is aimed at integrated water management, the present land utilization could be increased further to increase crop production. This will increase the number of farm families who will get farm benefits from the polder. The employment opportunities especially the farm labour utilization can be increased.

The fish catch in the rivers and khals both inside and outside of the polder contributes significantly to the fish consumption for the people of the area. Still there is a possibility to create an opportunity for incremental fish production.

The polder in its present form has already limited the navigation within the area. Re-excavation of existing khals will, however, facilitate further improvement of internal navigation mainly for transporting goods to the market places for trading.

8 WATER MANAGEMENT APPROACH FOR THE FCD SCHEMES

8.1 GENERAL

Initially the primary objective of the FCD schemes was to increase agricultural production. However, in the course of time, the agricultural needs have changed. Due to alteration of hydrological conditions within the schemes, the irrigation coverage is increasing and more lands are brought under HYV Rice cultivation, which demands a careful water management in order to maximize the output. Many of the FCD schemes have been built quite a long time ago, consequently there is a need for improvement of the water management practices and to a certain extent modernization to meet the requirements of integrated water management.

In this study an approach has been developed to mitigate the water management problems. In this approach the needs of agriculture, fisheries, navigation and environment are being considered in an integrated way.

In a country, there are three defined levels of water management. Which are national waters, main and distributary systems and field level. Responsibility for the national level lies with the Government. Associations take care about the main and distributary systems while the farmers are generally responsible for the field level systems. Success of water management completely depends upon the coordinated efforts by Government, associations and farmers. A good understanding has to exits between them because they are ultimately responsible for the success or failure of the schemes. However others also play important roles in water management (Figure 8.1). But their role is a contributing one. From the above it is very clear that all agreement and arrangement should be achieved between Government, associations and farmers.

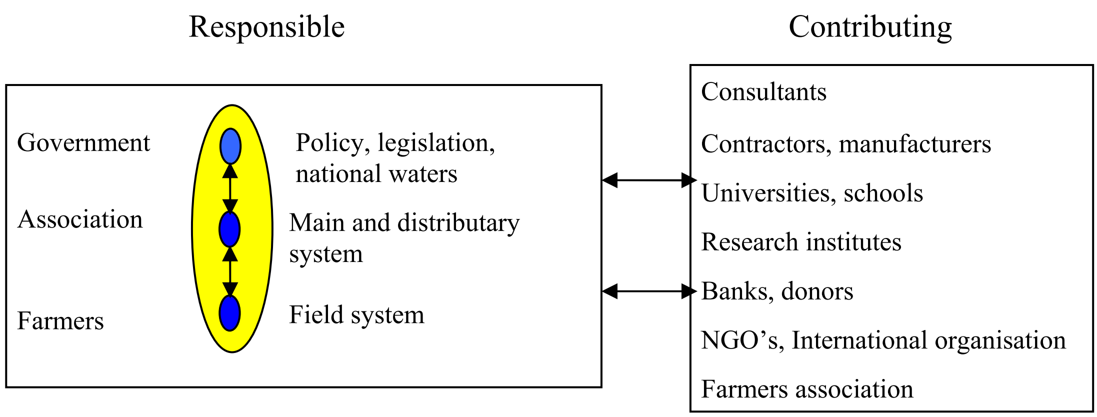

Figure 8.1 Role of different actors in agricultural water management (Schultz, 2001)

In Bangladesh the local Government representatives (mainly Union Parishad chairmen and village leaders) play an important role in the water management in FCD schemes, either as mediators or as initiators of new developments. People's participation in water management will necessarily involve people's representatives, especially at the field level, as a basic principle of the delineation of water management responsibilities is the delegation of decision-making power to the lowest possible level.

Participation is a function of many variables like scale, type and location of scheme, stage of the scheme cycle. It is also influenced by the socio-political environment, local customs and heritage (practices and prejudices). So one model, or one way of implementing participation is next to impossible. However, there are a number of rich experiences which can help practitioners confronting a similar situation (Oakley et al., 1991).

In the past, many attempts have been made to involve stakeholders in operation and maintenance of the FCD schemes. In absence of a workable guideline, different institutional arrangements for water management were tested in different projects in Bangladesh. For the sake of efficient water management, this situation is not favourable.

8.2 INSTITUTIONAL FRAMEWORK

An effective and sustainable water management scheme requires an institutional framework, which can ensure the democratic representation of the various water users and their interests. The set-up of the framework should be such that it can accommodate various interests of the different users. Efforts should be made to create opportunities for various users to participate in different stages of the scheme cycle. Organizations to manage the schemes should be established as the starting point, in order to facilitate the process. If the representation of the stakeholders is ensured and the process of decision making is made transparent, stakeholders generally feel committed to contribute in terms of cash, kind and time, in planning and implementing programs in support of sustainable water management.

In the past, efforts in forming the different water users groups the sociological aspects were not sufficiently taken into account. It is generally considered that the best approach is when the stakeholders themselves through discussion in meetings develop the institutional arrangements. Agency staff should communicate with the stakeholders to assure that the combined roles and responsibilities of Agency and stakeholders guarantee a sustainable water management. Institutional arrangements should not have too many tiers and should be as simple as can be comprehended by the stakeholders.

After evaluating the Integrated Planning for Sustainable Water Management (IPSWAM) programme and analyzing the different attempts (Appendix B) made in this regard, a two-tier organization is proposed for medium-type FCD systems. The lowest tier Water Management Group (WMG) would be structure-based, and organized based on the conditions in a scheme. All the Water Management Groups in a specific scheme will be put under the umbrella of a Water Management Association (WMA). The Water Management Association will be an autonomous body and function as within the provision of the law. The Water Management Association will have to be financially autonomous and sustainable to enable them to fulfil their duties. The Water Management Association can be financially sustainable by the following activities:

- raise a levy for operation and maintenance;
- lease the water bodies located within the scheme for fishing;

- lease the unutilized khas lands (lands owned by the Government) or the lands owned by the Bangladesh Water Development Board for agricultural purposes. The profit from economic activities on these lands will be used by the Water Management Association as part of their contribution to the operation maintenance of the scheme;
- grow trees on vacant land along the drainage and irrigation canals and sales revenues may be utilized for funding of operation and maintenance;
- provision of bank loans in case of any emergency should be granted by the Government for the Water Management Association. Which may be arranged by the Agency.

The formation of Water Management Groups and the Water Management Association for a specific scheme is considered to be of crucial importance for the sustainability of the future water management. Therefore even if this may take a long time, this time will have to be allowed. Unless the groups are formed properly, no modernization or rehabilitation of the scheme would have to be undertaken (Schultz, 1993). Also, if a Water Management Association does not agree to take over the management of the scheme after its modernization, no modernization will be done. In Figure 8.2 the schematic diagram of the Water Management Group and Water Management Association is proposed.

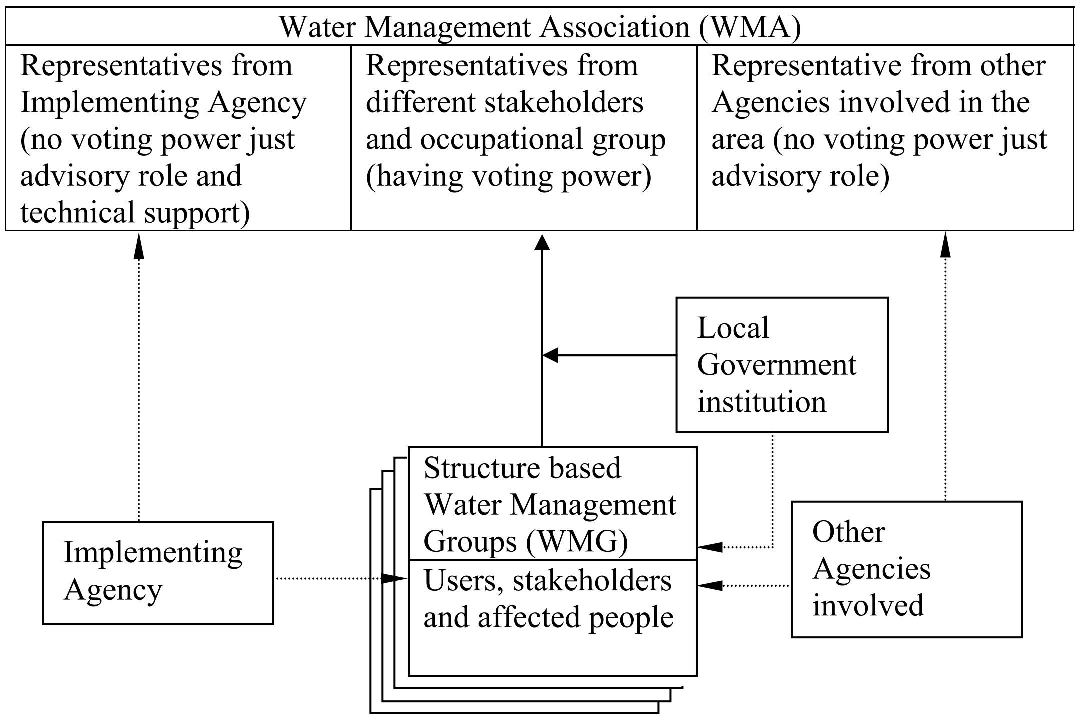

Figure 8.2 Structure of Water Management Association (WMA) and Water Management Groups (WMG)

8.3 PLANNING FRAMEWORK

Water sector projects cannot be planned or designed in isolation, either from a spatial or a sectoral point of view. Water sector development needs to be conceptualized and defined within the broader framework of a national and regional development plan. In future, projects should be designed based on co-operation between Government, association and farmers. Moreover, proper attention needs to be paid to long-term impacts on the national water management policy as a whole. In concrete operational terms, this would entail integrated water management and institutional arrangements.

Water management can be improved by integrating western oriented technocratic and administrative models with local traditional approaches. Improved water management should include:
- effective decentralization and decision making at local level;
- adequate participatory processes in planning and development of water management strategies;
- dynamic use of indigenous water management practices and informal norms.

The growing scarcity of water, resulting from the expansion of irrigation and changes in consumption patterns, received almost no attention for a long time. Only recently development planners have acknowledged the uses and functions of water for both consumptive (crop production, domestic use) and non-consumptive (fisheries, navigation, ecosystem, hydropower, tourism and landscape) uses. Consequently, accommodation of conflicting interests and multiple uses of water emerge as a prime need. Thus, integration becomes the pivotal concern in the planning of water management. An effective integrated water management approach also requires a well functioning monitoring and evaluation system.

During the implementation stage of the FCD schemes an integrated approach of planning was not considered. To address the present operational and management problems of the FCD schemes several steps have to be taken. The operation and maintenance approach has to be developed based on the different aspects of water management along with the existing problems and the possible contribution of each party.

It is proposed that an FCD scheme will only be improved, modified and rehabilitated when the stakeholders agree to participate in the improvement works and to take over the responsibility and to take care for the resulting operation and maintenance. This implies that the stakeholders will have to be involved right from the beginning of the planning exercise. They will have to be involved in planning, design and implementation (if any) of the modernization and resulting operation and maintenance and have to commit themselves for their future share in those activities. After acceptance of the results of the improvement works, the schemes can be handed over to them for operation and maintenance.

In order to facilitate such a process planning teams will have to go to the stakeholders, have meetings with them, explain to them the different improvement options and their related consequences and, that they (stakeholders) have to share responsibility and take care for the operation and maintenance activities within an institutional framework. It is then their (stakeholders) choice whether they will go for the improvement or not. Suggested planning steps as developed in this study for the improvement of water management in FCD areas are:

Step 1
Investigation among the stakeholders whether they are interested in improvement, if they are willing to contribute to the improvement and whether they are willing to take their share in operation and maintenance after improvement.

Step 2
An assessment of the existing water management situation, including:
- physical conditions;
- inventory of infrastructure;
- stakeholders and interest groups;
- maintenance and operational problems of structures;
- inventory of water management issues;
- water rights and water use;
- financial and socio-economical conditions;
- possible environmental impacts.

Step 3
Posting of a skilled guidance team in the scheme area. They have to be in the field till the handing over of the scheme to the association for operation and maintenance.

Step 4
Intensive discussions and meetings with the stakeholders and interest groups regarding alternative water management options and their related benefits and problems. Investigation of the causes of problems and possible solutions. Explanation of the possible consequences of the operation of the structures. Explanation of other aspects of water management and use, their role and the necessity of gate operation.

Step 5
Establishment of a Water Management Association (WMA) and Water Management Groups (WMG) of the stakeholders. Training of operators and stakeholders related to the relevant water management issues.

Step 6
Provisional agreement with the Water Management Association on the water management strategy and the required operation and maintenance, including the role and contribution of each party. Development of a preliminary operation and maintenance plan for the hydraulic structures and water courses, based on the provisionally agreed water management strategy.

Step 7
Identification of the required repairs in the hydraulic structures and the embankment as well as the share of each party in the repair.

Step 8
Repair of structures (gates) and the embankment in such a way that the structures can be operated as per requirement of the provisionally agreed water management strategy.

Step 9
Start of operation and maintenance as per provisionally agreed water management strategy and based on the agreed roles, responsibilities and shares.

Step 10
Operation of the structures and maintenance of the system for at least one wet season and one dry season by the Water Management Association and the Water Management Groups with support and advice of the guidance team. Discussion on the positive and negative consequences of the operation among the stakeholders and revision where it is agreed to be required.

Step 11
Finalization of the operation and maintenance plan by the Water Management Association. The guidance team will provide technical support if needed.

Step12
Transfer of the operation and maintenance responsibility and the ownership of the agreed parts of the system from the Agency to the Association.

Step 13
Operation and maintenance by the Water Management Association and the Water Management Groups. In case of any major problem like severe flood damage the Agency will help the association.

In Figure 8.3 the schematic diagram of water management planning for modernization of FCD schemes is shown.

8.4 CONSIDERATIONS FOR THE WATER MANAGEMENT APPROACH

8.4 1 River Zonation

Tidal lowlands are characterized by rivers that split up in several branches. In most of the cases the delta area will be flooded when the discharge from upstream is large. The lower part of each branch will mainly be influenced by tides. Water level fluctuation and saline intrusion are important factors determining technical measures and agricultural development potentials in the coastal belt of Bangladesh. Both factors are dependent upon the tidal characteristics at the river mouth, river discharge, topographical conditions and distance from the river mouth. Water level fluctuations determine tidal irrigation and drainage possibilities. Salinity should first of all be considered in relation to shrimp culture and irrigation. A zonation of a river which is based on these factors is presented in Table 8.1. Saline intrusion in Bangladesh reaches its maximum in the month of April and then goes down gradually.

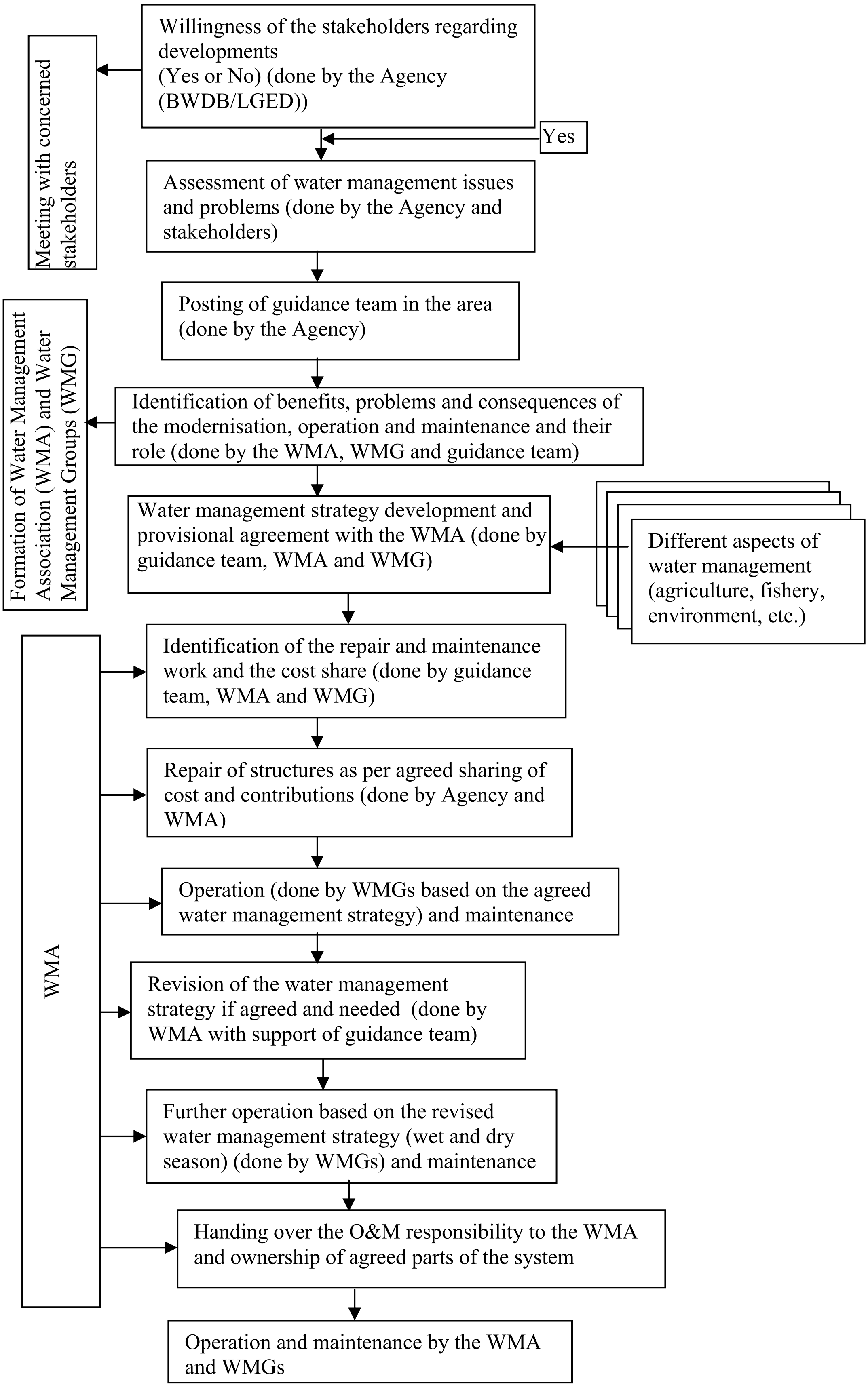

Figure 8.3 Water management planning for modernisation of FCD schemes

Table 8.1 River zonation system in relation to salinity, drainage and irrigation (Suryadi, 1996)

Zone	Water level	Salinity, drainage and irrigation
I	Influenced by the tides during wet and dry season	brackish, drainage by gravity during low tide, no possibility for supplementary irrigation
IIa	Influenced by the tides during wet and dry season	saline intrusion during dry season, drainage by gravity during low tide, supplementary irrigation only during wet season
IIb	Influenced by the tides during wet and dry season	fresh water coastal area, no saline intrusion, drainage by gravity during low tide and irrigation during wet and dry season
III	Influenced by river discharge, tidal influence only during the dry season	no saline intrusion, ground level is relatively high, irrigation only by pumps
IV	Determined only by river discharge	no tidal influence, upland

8.4.2 Hydro-topographical Categories

Tidal lands consist of sediments from the river and also from the sea (some parts). Flow velocities in the rivers are reduced or even reversed under the influence of the sea, which may cause flooding and sedimentation.

Soil conditions and water management practices, based on the relationship between hydrology and topography, mainly determine the agricultural development possibilities in the coastal area. This relationship is referred to as hydro-topography. Hydro-topography can be defined as the field elevation in relation to high or low river water levels at the intake point and in the field. Hydro-topography is expressed by the irrigation possibilities during the dry season and drainage possibilities during the wet season. During high tides, water can flow into the polders, and during low tides water can be drained to the rivers. The actual hydro-topographical conditions of a polder depend on tidal river water levels, gradually changing field levels and topography (Mudjiadi, et al., 1998). The hydro-topographical conditions define the range of agricultural and water management practices available to the farmers. The hydro-topography is not uniform and constant in time and space. For example, it varies with micro-level variations of the topography. The following hydro-topographical categories were defined by Suryadi for the tidal lowlands in Indonesia (Suryadi, 1996):

A: tidal irrigated areas, in both wet and dry season;
B: tidal irrigated areas, only in the wet season;
C: areas just above ($\leq$ 0.50 m) the average high water level in the wet season;
D: high areas, water levels independent from tidal influence.

In category A and B, flood protection will be required to a certain extent and drainage will be a problem in most cases. In category C flood protection may be required.

By combining the hydro-topographical information and river zonation, category A will be in zone IIb, category B in zone IIa, category C in zone III and category D in zone IV. For zone I of the river zonation, topographical and saline conditions are such that they form favourable conditions for aquaculture development instead of for agriculture.

To determine the hydro-topographical condition of an area, the basic concept is a combination of statistical analysis of the river water level fluctuations at potential inlet, or outlet points and a hydraulic computation of the water management of schemes.

8.4.3 Soil Types

The soils of the area were developed in seasonally wet or flooded, non-calcareous flood plain deposited by the river Ganges. The soils lie in the Ganges tidal floodplain. They are characterized by having a grey or olive-grey topsoil which is not very acidic. Most of the sub-soils are neutral or slightly alkaline (Government of Bangladesh, 1988). Permeability and moisture holding capacity vary with texture and with position on the relief. The loamy soils on the ridges have a high permeability and have a moderate or low moisture holding capacity because they commonly overlie sandy soils at a shallow depth. Rapid permeability and low moisture holding capacity of highland soils make them susceptible to drought in the pre-wet season and Rabi season. The low-lying silty clay loam or silty clay soils have a moderate to poor permeability and have a high moisture holding capacity. However, soils on highland and medium highland which are puddled for transplanting Rice crops have a compact topsoil and ploughpans may develop, which reduces the permeability and increase moisture availability.

The natural fertility of the soils of the area is moderate but well sustained. The soils are producing moderate to poor yields of crops, due to scarcity of water in the dry season and drainage congestion in the wet season. However, none of these soils is naturally fertile enough to produce sustained yields as they contain a lower amount of organic matter.

Saline Soils
Most of the soils in coastal lands contain salts. Salts are carried downwards (leached) with the percolating water from the unsaturated zone. Saline soils can be characterized by:

- the high concentration of soluble salts which hampers crop growth and may also be shown by symptoms similar in appearance to those of drought such as early wilting;
- the exchangeable sodium content in a high enough percentage to affect the stability of the soil structure.

The salinity of the soil column may vary greatly in time and space. The upward and downward flow of water frequently changes the vertical distribution of the salts in the soil column.

Leaching is the only strategy to improve salt-affected soils for agricultural development. The degree to which a soil will have to be leached depends on the initial soil salinity, the quality of the leaching water, the method of leaching and the physical and chemical soil characteristics. Results of analysis of soil salinity at different locations in polder 43/2A are presented in Appendix C.

8.4.4 Water Management Systems

The development of coastal land is very much a matter of land and water management. The performance of the schemes is completely dependent on the water management at the lowest level, i.e. the field level.

Crop diversification is not a new concept for farmers. They are quite skilled in adjusting the mix of crops to reflect changes in the profitability and risk of each activity. Conflicts in water use should be avoided. The crop diversification is determined by the following factors:
- farmers motivation and involvement;
- macro economic policies in the country;
- input supplies for the crops;
- institutional support.

The field level is the smallest water management unit in the schemes. The heart of the irrigation and drainage system is a field plot for agricultural purposes. The output from the field level is input to the system level and the output from the system level is input to the scheme level where water is part of the natural system or ecosystem. An analysis at scheme level should be made especially related to the impact of a development strategy on water level and saline intrusion in the delta area. The delta level development will influence the development at system level and at field level.

The water management of the polder area at the system level may have the following functions:
- drainage of excess water by means of gravity;
- in some spots, tidal irrigation (hydro-topography category A and B);
- in the later stage, irrigation by using low lift pumps or traditional methods (for category C and D).

8.5 WATER MANAGEMENT REQUIREMENTS

Water management needs are different for each type of land use and require different interventions. Rice crops call for inundated fields while Rabi crops need certain soil moisture and ground water conditions in the land. The canals and the floodplain require such a water level that adequate conditions for irrigation and drainage are created and where applicable proper conditions for fisheries and domestic use of water. The focus of water management in the polder areas must therefore be on water level control and on preventing stagnant water conditions. In coastal lands there are two options to improve adverse water management conditions that are drainage and flushing. In order to achieve this hydraulic structures will have to be operated to store water inside the polder when it is required due to dry conditions, which means that gates will be open during high tide and remain closed during low tide, or to discharge water from the polder when this is required due to wet conditions, which means that gates will be closed during high tide and open during low tide. In this study an attempt has been made to improve the present problems and cropping practices of the farmers from the drainage and flushing point of view. By taking into account the cost benefit aspect and the prevailing conditions of the FCD schemes, the gravity drainage and flushing is considered only.

Drainage Option (by gravity)

The drainage condition plays an important role in defining agricultural and water management practices available to the farmers. The excess wet season rains are normally drained through the hydraulic structures of the FCD schemes. Faulty gate operation and a changed hydrological situation of unplanned development by the farmers may cause huge drainage congestion and even flooding, which ultimately results in crop damages or reduced yields. Sometimes the homestead of people may be also affected. Proper drainage can improve the situation and reduce the damages. Due to this more area may be brought under cultivation. The drainage criteria of the FCD schemes should be developed on the basis of the inundation depth that may occur in the wet season. A generalized diagram of the drainage option in a coastal polder is presented in Figure 8.4.

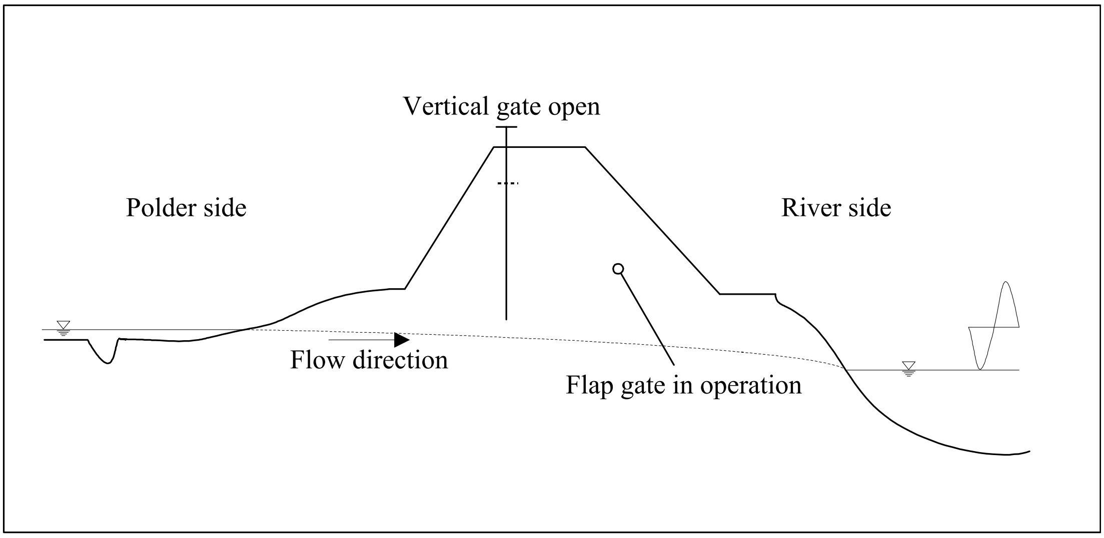

Figure 8.4 Drainage option of a polder (by gravity)

Flushing Option (by gravity)

Initially the schemes were designed for flood protection and drainage improvement. But subsequently with the changing requirements of the people flushing became one of the major demands for irrigation. The people in this area are still in favour of the flushing condition (gravity flow) that they had before the schemes were constructed. But after the reclamation flushing possibilities have been reduced due to less openings (hydraulic structures) compared to the situation before reclamation. The flushing option involves improvement of freshwater supply into the area. Flushing through hydraulic structures in the lower areas and low lift pumping, or traditional lifting, or irrigation inlets for irrigation in the higher areas. Flushing is mainly required in the month of April (pre wet season) for land preparation and transplantation of T. Aus Rice. Hydraulic structure operation needs proper attention during flushing regarding inland fisheries in the area. Flushing is also required in the dry season subject to the tidal water level fluctuation in the main river. If there is a dry spell in the wet season, flushing sometimes is important too. For basin irrigation for Rice small bunds are required in the fields to hold water upto a certain depth. Water from rain and irrigation cannot be stored in the field and may cause problems in the low-lying areas of the schemes.

The hydrodynamic simulation that was developed for this study and used to calculate the possible drainage and flushing options will be presented in the next Chapter. From the results of both options a hydro-topographic map has been developed. The water management strategy as it will be developed in the next sections has been developed based on the hydro-topography with support of the hydrodynamic simulations considering the polder as a reservoir. The hydro-topography and the developed water management strategy determine to a large extent the land suitability zonning of the area. A generalized diagram of the flushing option in a polder is presented in figure 8.5.

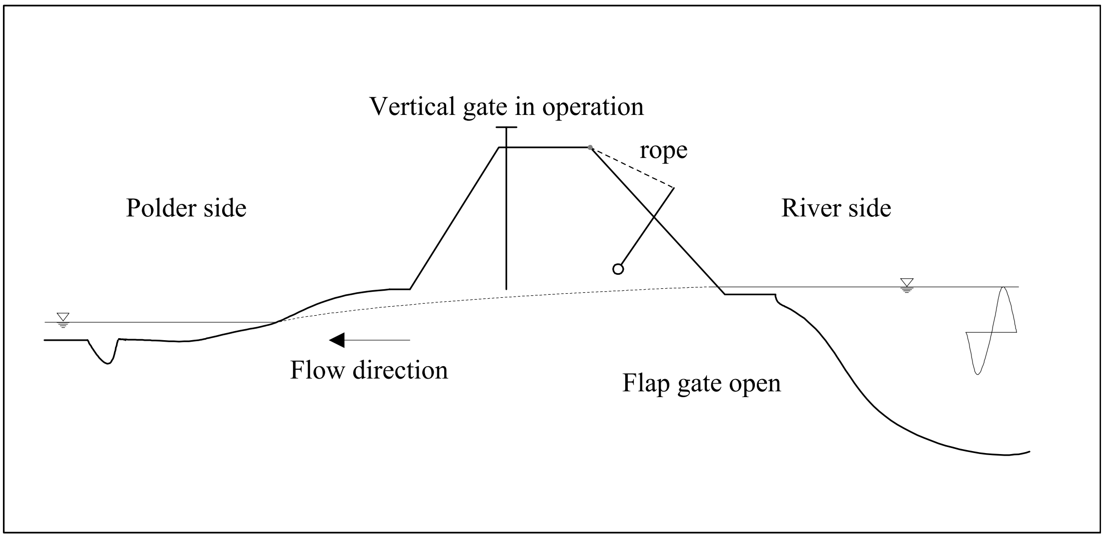

Figure 8.5 Flushing option of a polder (by gravity)

8.6 WATER MANAGEMENT STRATEGY AND LAND SUITABILITY ZONING

The identification of hydro-topographical categories is the first step in delineating land suitability zones. In order to answer the question what kind of agricultural development would be feasible in different parts of the area, several factors must be taken into account i.e. the saline intrusion, land surface, soil properties, and the tidal range. In conjunction with the development of a water management strategy, a land suitability zoning should be identified which requires a systematic and comprehensive analysis. The land suitability zoning is finally the results of the hydro-topography, the surface levels, the soil types and the water management strategy.

Tidal Irrigation Depth

Water storing inside the polder can continue for 10 - 14 days depending on tidal conditions (spring tide). Based on the achieved water level the tidal irrigation depth can be calculated. For Rice cultivation the hydraulic structure will have to be operated to lower the water level between 0 - 0.3 m during the low tides in the concerned area. This process of gradual lowering will continue upto a preferred level is achieved for fisheries in the canals. For this practice farmers should be informed beforehand so that they can only cultivate Rabi crops in the higher area to avoid damage during flushing.

Based on the hydro-topographical classification and the hydraulic condition of the schemes (hydraulic losses in the systems) the tidal irrigation possibilities of an area can be determined. Tidal irrigation is only possible within the hydro-topographical categories A and B. For agricultural development purposes the tidal irrigation depth is defined as the water layer when there is tidal irrigation. To calculate these tidal irrigation possibilities in relation to the present agricultural practices the criteria as given in Table 8.2 are used. It has, however to be realized that the tidal irrigation depth classification is not the only factor for deriving the land suitability zoning of the area.

Table 8.2 Irrigation depth classification

Class	Tidal irrigation depth in m	Cultivation
1	> 0.3	not suitable
2	0.0 - 0.3	Rice crops
3	< 0.0 (dry land)	Marginally suitable for Rice and nearly suitable for Rabi crop

Drainage Depth

The drainage criteria of the FCD schemes should be developed on the basis of inundation depth that may occur in the extreme wet season during excessive rain. A water depth greater than 0.3 m for three days or more is not suitable for any Rice crop. So lowering of the water level by operating the structures must depend on the 0.3 m depth within 3 three days. Based on this a preferred water level for the polder can be achieved. Drainage is intended to control the water level at the field for Rice cultivation only during the wet season. It varies with the topography, tidal level and structures operation. However, the drainage condition plays an important role in defining agricultural and water management practices available to the farmers. Lowering of the high water level by drainage should be realized in such a way that fish culture and environmental issues are also properly taken into account.

The suitable drainage depth for the preferred water level or normal year water level is also the same as irrigation (0 – 0.3 m).

Saline Intrusion

The open water and the groundwater system might be influenced by saline intrusion. In the coastal region of Bangladesh the ground water is not suitable for irrigation. One of the important factors for agricultural development is the salinity of the water and its distribution in space and time. Different crops have a different tolerance for salinity. This means for planning activities that acceptable saline conditions related to particular crops should be clearly defined. For example for Rice a saline concentration of 1,500 mg/1 is considered as the maximum (Rhoades et al., 1992).

Saline intrusion (during one hydrologic year) is also defined as one of the important factors for determining land suitability zones. Based on saline intrusion problems, four categories are defined as follows (Boissevain, 1995):

1: 0.0 - 2.0 months;
2: 2.0 - 3.0 months;
3: 3.0 - 4.0 months;

4: 4.0 - 5.0 months.

In polder 43/2A the saline intrusion is not a problem and will therefore not come into consideration.

Based on this classification, the water management strategy and components which are presented in Table 8.3 a land suitability zoning can be derived as shown in Table 8.4. This land suitability zoning can be derived for present and potential conditions. For land suitability zoning a water management strategy having a preferred water level for drainage and flushing conditions is very much essential. It is mainly focusing to improve the present conditions in the area by utilizing the existing infrastructural facilities. The water management strategy has take into account the present agricultural practices and problems of the farmers. The maximum flushing level, which will bring more area under irrigation during the early wet season, and the preferred drainage level that will be maintained will safe a large area from damage during the wet season have to be established. All other aspects of water management should have to be incorporated during finalizing the preferred water levels in the strategy (Figure 9.10). A proper statistical analyses of extreme events of flushing and drainage will also have to be done. All the factors of land suitability zoning have spatial characteristics, which makes it complicated to determine the overall land suitability zoning in a classical way. Fortunately use can be made of a GIS (described in detail in Chapter 9) to solve this type of problems. By determining the spatial distribution of land suitability a systematic map of the present situation, or the potential situation can be made.

Table 8.3 Soil and water management components in relation to water management options

Season, water management option and recommended crops	Components for water management	Components for soil management	On farm development
Wet season (drainage) Rice and fish	Prevent stagnant water Supply tidal water during dry spells Low lift pumping or traditional lifting from the canals Flood protection for home yards Sufficient tidal water level in canals for fish and domestic uses	Land preparation by tractor or animal draught Ample fertiliser application (urea, phosphate and potassium)	Field bund construction
Pre wet season (flushing) Rice and fish	Rise water level as much as possible Lowering of water level for suitable depth Low lift pumping or traditional lifting from the canals Sufficient tidal water level in canals for fish and domestic uses	Land preparation by tractor or animal draught; Ample fertiliser application (urea, phosphate and potassium)	Field bund construction
Dry season (flushing) Rabi crops, Boro and fish	Tidal irrigation Low lift pumping or traditional lifting from the canals Prevent saline intrusion Sufficient tidal water level in canals for fish and domestic uses	Land preparation by tractor or animal draught; Ample fertiliser application (urea, phosphate and potassium)	Field bund construction

For hydro-topographical category A and B areas a gravity flow can be expected to maintain a certain water level in polder 43/2A but for category C and D this is almost impossible. So, in the latter categories other measures should be applied like provision of irrigation inlets (small pipes) or additional structures in the embankment, which are applied now all over in Bangladesh. Irrigation in highland requires a different practice and operation. Simple systems should be considered where water is entered into the network of canal systems and after that farmers may pump the water into their field using low lift pumps or traditional ways.

Table 8.4 Land suitability zoning in polder 43/2A

Criterion	Category		Rice				Other crops	
	Irrigation or drainage depth in m	Lowering of water level for land suitability in m+PWD	Tidal irrigation		Rainfed		Rabi crops	
			Pr	Po	Pr	Po	Pr	Po
Tidal irrigation depth	< 0		S3	S2	S2	S1	S2	S1
	0 to 0.3	Maximum stored level (1.40 – 1.10)	S1	S1	NA	NA	S3*	S2
	0 to 0.3	Lowering the level from 1.10 - 0.80	S1	S1	NA	NA	NA	S3
	0 to 0.3	Lowering the level from 0.8 - 0.60	S2	S1	NA	NA	NA	NA
	0 to 0.3		S2	S1	NA	NA	NA	NA
	0 to 1.41		F	F	F	F	F	F
Drainage depth	< 0		S2	S1	S2	S1	NA	NA
	0 to 0.3	Max. drainage congestion level 1.50	S1	S1	S1	S1	NA	NA
	0.3 to 0.6	Lowering within 3 days from 1.50 – preferred water level	S1	S1	S1	S1	NA	NA
	0 to 0.3		S3	S2	S3	S2	NA	NA
	0.3 to 0.6		NS	S3	NS	S3	NA	NA
	above		F	F	F	F	F	F

Pr = improvement of the present condition; Po = potential condition; S1 = suitable; S2 = nearly suitable; S3 = marginally suitable; NA = not applicable; NS = not suitable; F = fish; * = for Rabi crops the preferred stored water level of 1.1 m+PWD has to be considered during irrigation only and the remaining procedure will be the same

9 MODEL DEVELOPMENT AND APPLICATION

9.1 GENERAL

A model is an essential tool to gain overall understanding of a complex system. It enables to predict the effects of critical decisions. Advances in computer technology, in the technology of communication and mathematical modelling of hydraulic and hydrological cycles have improved the potential to mitigate the damages of floods and inadequate drainage. Hydrologic or hydraulic models, based on a mathematical formulation of the flow of water under certain topography and boundary conditions, have proven to be effective tools in land and water development and management projects. The output of such models is in the form of water levels and discharges at various locations in space and time. These results can be used by various interest groups. It is quite natural that a designer or a planner wishes to see some of the changes of the design and their possible effects after rerunning the model.

A modelling approach will consist of several modules, related to drainage and flushing conditions. An analytical hierarchy model could be used for analyzing and impact assessment of different aspects of the schemes (hydrological, environmental, agricultural, social and economical). A mathematical model is fitted to the real system (reality) by means of model identification (what type of model) and parameter estimation. The most important points in the modelling study are to:
- define the problems clearly;
- realize the applicability and limitations of the models;
- schematize the real systems in a correct and proper way in line with the model application;
- consider the key data (parameters and properties) of the real system;
- analyze and evaluate the modelling results.

Models should be calibrated when it is possible, otherwise a sensitivity analysis should be carried out in order to judge the importance of each phenomenon on each parameter.

The models should be able to provide information for the:
- evaluation of physical and chemical processes in relation to land and water management strategies;
- development of water management strategies for the long term and operational rules and guidelines;
- research on drainage and flushing systems in tidal reclamation schemes.

Development of tidal lowlands can be characterized as interventions in a natural ecological system to change it into another ecological system with a higher economic value for human society. In case of a delta development programme, if the development is not attained or if substantial negative side effects occur, a negative impact will be the result. The main interventions might be changing the hydrological, morphological and ecological environment, e.g. (Luijendijk, 1988):
- lowering of the groundwater table;
- reduction of the river floodplain;
- increase of saline intrusion into the river;
- water level changes along the river;
- land subsidence;

- prevention of sediment deposition in swampy areas.

To forecast negative impacts as much as reasonably possible, the following activities may be considered before a development plan is realized:
- systematic collection, monitoring and evaluation of hydrological, morphological and ecological data;
- protection of environmental assets.

The analysis at the delta level or region has to be based on the following principles:
- the result of the analysis would have to be used for supporting the decision maker to take proper decisions regarding a delta development plan;
- in the pre-feasibility phase, as much as possible, using limited data;
- a modelling system to describe the main parameters in the delta level or region.

In this study the analysis at the delta level or region will be limited to water quantity (water level). In the equilibrium condition the upstream discharge from the river and the tidal influence from the sea will result in a certain balance. Due to the developments in the lower part, a new equilibrium condition will develop where, among others, the water surface profile along the river may also change. In case the new situation will be quite different from the previous situation, it will affect the systems upstream.

9.2 MODEL FOR THE SYSTEM

9.2.1 Water Management Components

The main components of water management systems of a polder are the following:
- polder area;
- canal network;
- capacity of the hydraulic structures for flushing and drainage;
- tidal characteristics of the surrounding rivers;
- rainfall intensity for the area;
- water bodies, like beels.

In case of a gravity drainage system these components should be evaluated based on certain criteria, i.e.:
- preferred and extreme water levels related to the land use and water management strategy;
- flow velocity in the hydraulic structures for fish migration to the polder area.

9.2.2 Open Water Flow Modelling

To develop an appropriate methodology for polder 43/2A, a combination of a GIS and a hydrodynamic model was used. The computational framework covers the main aspects of water quantity. It means that mathematical modelling at this level should be able to simulate the water movement.

For unsteady open water flow modelling an ample quantity of literature is available. Internationally well known standard books are Mahmood (1975), Abbott (1979), Cunge (1980) and Vreugdenhil (1989). The basic equations for unsteady open water flow are the Saint Venant equations which describe the conservation of mass and the conservation of momentum. This Saint Venant equation can be written as follows (Mahmood et al., 1975).

$$B\frac{\partial H}{\partial t}+\frac{\partial Q}{\partial x}=0$$

where:

t	time (s)
x	distance as measured along the channel axis (m)
H (x, t)	water level with respect to the reference level (m)
Q (x, t)	discharge at location x and at time t (m^3/s), (v *A)
B (x, H)	cross-sectional storage width (m)

and

$$\frac{\partial Q}{\partial t}+\frac{\partial(\alpha Q v)}{\partial x}+gA\frac{\partial H}{\partial x}+\frac{g|Q|Q}{C^2AR}=b\gamma w^2\cos(\Phi-\phi)$$

where:

v (x, t)	mean velocity (averaged over the cross-section area) (m/s)
R (x, H)	hydraulic radius of cross-section (m)
A (x, H)	cross-sectional flow area (m^2)
b (x, H)	cross-sectional flow width (m)
g	acceleration due to gravity (m/s^2)
C (x, H)	Chezy coefficient ($m^{1/2}$/s)
w(t)	wind velocity (m/s)
Φ(t)	wind direction (°)
ϕ (x)	direction of channel axis, measured clockwise from the North (°)
γ(x)	wind conversion coefficient
α	Coriolis coefficient, correction factor for non-uniformity of the velocity distribution in the advection term, defined as: $\alpha=\frac{A}{Q^2}*\int v(y,z)^2\,dydz$ where the integral is taken over the cross-section A

These equations are generally solved numerically by using an implicit finite difference scheme. In this study the DUFLOW computer program has been used. Summarized information about DUFLOW can be found in Appendix D. An open water management scheme (canals and hydraulic structures) has to be defined in the DUFLOW model as nodes and branches. A branch represents a conveyance element with a cross-section, resistance and bed slope. Nodes are used to link branches or hydraulic structures in order to form the schematization of the prototype.

In this study the DUFLOW version 2.05 program has been used for simulating open water flow in the system. DUFLOW is used because of its favourable computational, input and output characteristics and while it is easy to handle (Clemmens et al., 1991, Loof, 1991 and Schuurmans, 1991). DUFLOW has good application facilities with respect to propagation of tidal waves in estuaries and the operation of irrigation and drainage structures, like in polder 43/2A. Non availability of tidal time series data in this area was overcome by generating a sinusoidal curve with the help of DUFLOW using observed daily tidal high and low water levels. An additional advantage of the model is that the simulation of the runoff from an area a simple and effective rainfall-runoff relation is available.

Finally the effect of water management strategies on crop yield can be evaluated, drainage and flushing processes can be simulated and a sustainable agricultural development can be supported. Based on the model results the drainage and flushing capacity of the scheme can be determined. The models can be used for different purposes, i.e.:

- as a tool for designing water management schemes in tidal lowlands based on the land suitability zoning which has been derived previously, including the design of the protection of the area against floods with a certain frequency;
- as a tool for checking the performance of the reclamation scheme under a certain water management strategy;
- to check the drainage capacity of the scheme in order to be able to drain excess water, mainly during the rainy season;
- in case of tidal irrigation, to be able to control the soil moisture content in relation to agricultural development;
- to check the flushing capacity for providing water with reasonable quantity for agricultural purposes.

9.2.3 Geographical Information System (GIS)

A Geographical Information System (GIS) is a computer-based system for capturing and processing spatially distributed data of geographic nature (Mohan, 1991). According to Aronoff (1991) a GIS is designed for collection, storage and analysis of objects and phenomena where geographic location is an important characteristic or critical to the analysis. According to Eastman (1997) a GIS is a computer-assisted system for the acquisition, storage, analysis and display of geographic data (topography, climatology, land-use, soil type, etc.). The core of the system is the database, a collection of maps and associated information in digital format. Since the database is concerned with earth surface features, two elements can be distinguished i.e. the coordinates and the attribute of each point. GIS has provided an infrastructure for the analysis and evaluation of complex spatial problems in new and exciting ways. Today's GIS trends are directly influenced by two main driving forces i.e.,:

- the computer evolution which drives development of GIS towards an increasing degree of integration of different aspects;
- the increased demand for management of spatially distributed data and the need to solve the complex natural resources problems through spatial modelling techniques.

GIS is rapidly becoming a standard tool for the management of natural resources. It is used to assist decision makers by indicating various alternative development plans in real life situation and it has a capability to model the potential outcome for a series of development scenarios (Meijerink, 1985 and Brouwer, 1993). GIS is already well applied in the field of land use planning and management and also in non-engineering fields, for example economic growth (Despotakis, 1991 and Mather, 1994). In this Chapter GIS modelling in relation to land suitability of tidal lowlands will be presented. This modelling will be used especially to support planning activities in relation to a sustainable development of tidal lowlands. As stated by Plate (1997) planning of sustainable water management schemes includes provision to cope with change - which may be caused either by changes in land use and other physical conditions, or by changes in climate (Huising, 1993). In this study special attention will be paid to land and water development in lowland areas. The modelling principles with a GIS are presented in Figure 9.1. From Figure 9.1 it will be clear that a GIS should be supported by a proper database.

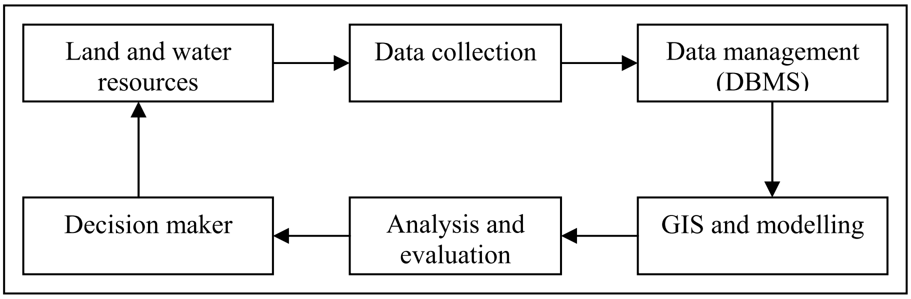

Figure 9.1 GIS and modelling in a planning process of land and water management

In addition to a GIS, a Geographic Analysis System (GAS) is needed in order to extend the capabilities of classical data base query to include the ability to analyze the database on spatial location. For this study IDRISI (Eastman, 1997) has been applied and a Geographic Analysis System has been developed for deriving land suitability zoning in tidal lowlands. A summarized information about the GIS model and its errors is presented in Appendix E.

9.3 LAND SUITABILITY ZONING WITH GIS AND GAS

The land suitability zoning is one of the thematic informations related to the agricultural potential (Kucera, 1993). It is based on information with spatial distribution characteristics which have to be taken into account i.e., topography (digital elevation), hydraulics, soil, salinity intrusion and cropping patterns. By using this information and the developed water management strategy, the risk of misuse in land utilization can be minimized and sustainable development of the area can be promoted.

Once the land suitability zoning is available, it will be very useful for the decision makers in their consideration on the development of the area. The information is dynamic in terms of space and time and can be defined as development itself (Despotakis, 1991). The land suitability zoning modelling with a GIS is illustrated in Figure 9.2. The main parameters for this application are:

- topography (digital elevation);
- (potential) open water level (irritability and drainability);
- soil types;
- saline intrusion.

In relation to the possible errors with the application of a GIS, it is clear that the accuracy of the data and their variations should be considered carefully. In this respect the main modules which have been applied are:

- images for each particular parameter which influences the land suitability zoning, i.e. tidal irrigation, drainability, soil and salinity intrusion maps;
- reclassification operation which involves the (re)assignment of thematic values to the categories of an exiting definition e.g. creating the hydro-topographical map based on the topographical map and (potential) hydraulic conditions of the area;
- overlaying technique which is based on the relationship among the parameters (adding, multiplication, dividing, maximizing and minimizing) based on their analytical relationship;
- cross-tabling calculation (combination) based on the result of the overlaying technique.

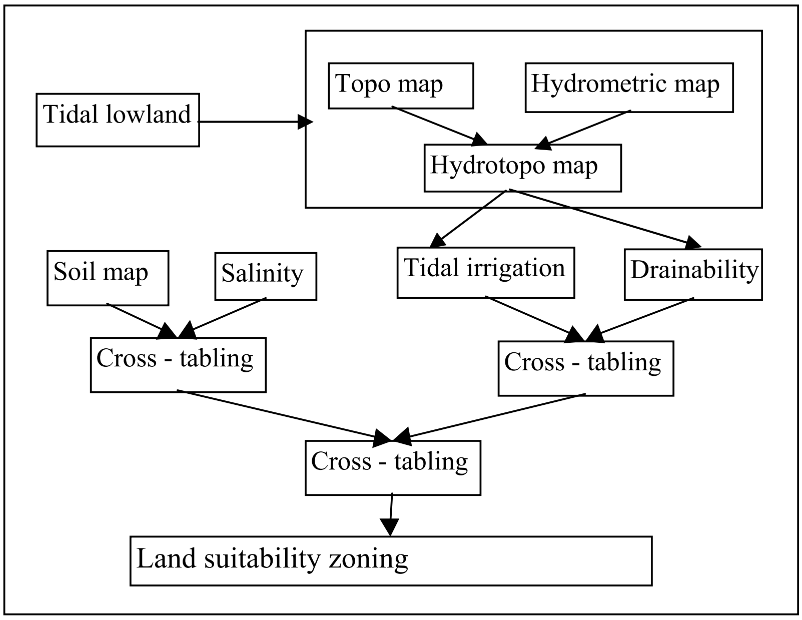

Figure 9.2 Land suitability zoning modelling with GIS (after Suryadi, 1996)

Hydro-topographical Map

To prepare a hydro-topographical map, two different images are needed i.e., a topographical (digital elevation) map and water level map based on the water management strategy. The water levels from flushing and drainage simulation are also needed. Based on this hydro-topographical image, a tidal irrigation depth image and drainage depth image can be created.

Drainability Map

To prepare a drainability map two different images are needed, i.e., a topographical map and a drainage water level map. When these two images are available, the drainability map can be created by the overlaying technique based on the criteria, which have been presented in Chapter 8.

Tidal Irrigation Map

For the creation of a tidal irrigation map two different images are needed, i.e. a topo map and a flushing level map. The main differences with the drainability map are the preferred water levels and the direction of flow in the system.

9.4 MODEL APPLICATION IN THE POLDER 43/2A AREA

9.4.1 Hydrodynamic Simulation

The polder has a saucer shape. It is crisscrossed by many canals, few of them are very large and the rest is smaller in size (length and width). The surrounding embankment makes this area almost like a small reservoir. Considering the environmental issues, it was preferred that the canals within the area would remain almost full. The potential hydraulic losses due to friction from the canals to the floodplain area are very small, since velocities of internal flows are very limited. Therefore the assumption has been made that a change in water level would be the same all over the area. Another assumption is that there are no obstructions (cross bunds) in the canal network. While hydraulic gradients in the polder are marginal for the DUFLOW network schematization, the polder area has been simplified and became equivalent to a reservoir. The cross-sections of the arbitrary sections were taken from the contourwise area, which was determined with the IDRISI Area module (to avoid huge cross sectional data collection). The total length of an arbitrary section is used for calculating the width of the section by using the equation:

$$B = A/L$$

where:
A cumulative contourwise area (m^2)
L total length of the chosen section taken from the schematization (m)

The remaining part of the schematization (structure control, initial condition, boundary condition, etc.) is carried out as a normal DUFLOW simulation. The network schematization of the DUFLOW model for the polder area is presented in Figure 9.3.

Based on the most critical situation prevailing in the polder area, which was already discussed in the previous Chapters two scenarios have been considered in order to develop a suitable water management strategy. The flushing situation refers to the storing of water inside the polder area, which is used for irrigation. The drainage or flood situation is investigated to determine the preferred water level during the wet season and the drainage capacity to remove surplus water from heavy rain. The latter is required to determine the damage under the present cropping pattern and to develop a possible strategy for improvement. For both cases only the existing structures and the embankment have been considered in the simulations.

The simulation is not done for the whole year. Time series tidal data were not available for this purpose. The Bangladesh Water Development Board collected data only during the daytime and for a three hours interval. There is no data collection in the night.

The storing possibility in the dry season (April-May) completely depends upon the tidal water levels in the river. Data of the station Mirjagonj show that water in the dry season can be stored only during spring tide. Normally two spring tide situations will be available in a month. Based on the collected data a sinusoidal curve was developed as a boundary condition. As per requirement of the farmers and considering the existing problems, the simulation was done monthwise to find out the maximum possible water level that can be attained in the dry season, especially in April.

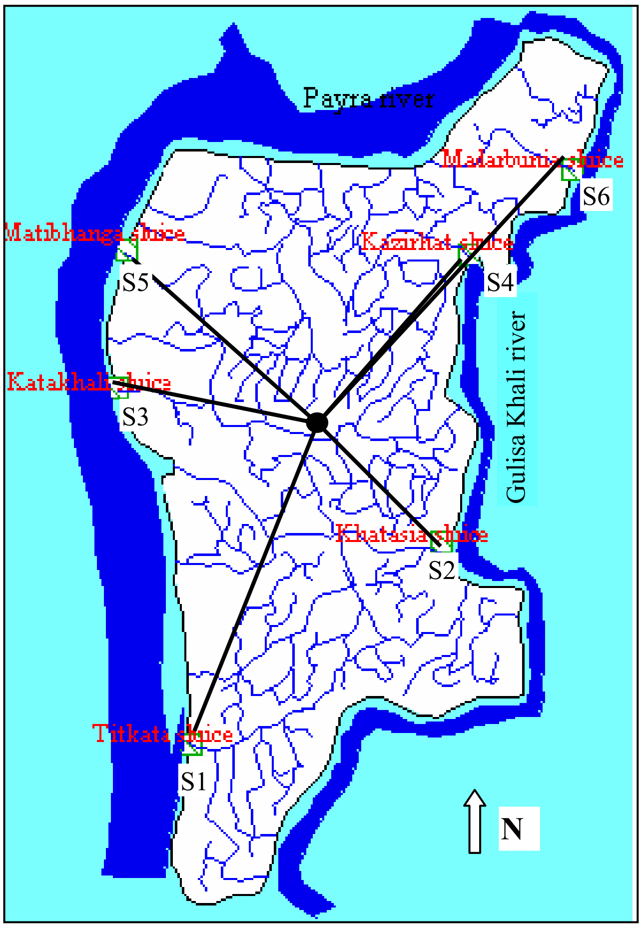

Figure 9.3 DUFLOW network schematization

During the wet season the simulation was done for the month of August while this is the critical month from the drainage point of view. The highest spring tidal values occur in this month. So results for this month will be more representative for other months. Also the drainage capacity of the hydraulic structures could be verified. From the DUFLOW simulation results in different months and from the requirements of the field a water management strategy could be developed. The simulated water level data could also be used in the GIS to prepare a land suitability zoning based on the criteria that have already been developed in Chapter 8.

Initial Conditions

The initial water level for the simulations was taken different for the flushing and drainage situation. The sill levels for the structures are not the same. A suitable water level in the canal network will also have to be maintained based on environmental considerations. The initial level for both drainage and flushing conditions should be fixed in such a way that in any case it should give results on the safe side. The initial levels used in the simulation for the months of April (flushing) and August (drainage) were respectively 0.8 and 0.5 m+PWD.

Boundary Conditions
From the statistical analysis of the collected data the 80% dependable tidal water level for high and low values has been determined. From this a sinusoidal tidal boundary condition is generated for all the external nodes of the schematization (end nodes of the hydraulic structures). In the case of flushing only evaporation is applied for the center nodes of the schematization.

In the flood and drainage situation the same 80% dependable spring low and high tidal water level values have been calculated and applied for preparing the simulations. A statistical analysis from the available rainfall data was also made and presented in Figure 6.3. From the rainfall depth duration frequency curve the 3-day consecutive rainfall was derived and 1:5 or 1:10 years return period values were chosen for the water balance simulation of DUFLOW to test the existing drainage capacity of the structures. From that value a representative year (from the collected data) was chosen to determine the rainfall - evaporation as boundary condition. The additional inflow in terms of rain in mm/day has been calculated with the formula given below.

$$q_{add} = (R - E) * 0.001 * A * 10000 * C / (24 * 3600)$$

where:

q_{add}	additional inflow to the node (m^3/s)
R	rainfall intensity (mm/day)
E	evaporation (mm/day)
A	catchment area (ha)
C	runoff factor

A high return period has not been chosen because this type of polder is designed for a lifetime of 20 or 25 years only. The drainage situation simulation is run for both the with and without structure operation condition. In Table 9.1 the 80% dependable tidal water level (high and low) for different months has been presented.

Drainage sluices
The polder has 6 sluices, sill level and size of which were shown in Table 6.1. The structures have been included in the simulation as weirs. In the simulation the discharge coefficient is selected in such a way that it represents the real situation of flow direction during flushing and drainage.

The discharge over a weir depends on the water level at both sides, the level of the sill, types of structures and the flow condition (free flow or submerged flow). The discharge coefficient (μ) is a correction factor for hydraulic effects of structures like contraction, internal friction, etc. The simulation developed in this study includes both types of flow because of the tidal fluctuation in the river and heavy rainfall in the polder area during the wet season. In DUFLOW simulations the same values of μ

have been used for flow towards the river and for flow towards the polder. For free flow a μ value of 1 has been used and for submerged flow a value of 0.83. The researcher has also made simulations by slightly varying these values to check the reliability of the model and found no significant changes in the results.

Table 9.1 80% dependable tidal water level calculated from the available data (1982 – 1997 for Mirjagonj station)

Month	Water level	In m+PWD
January	High	1.28
	Low	-0.36
February	High	1.38
	Low	-0.42
March	High	1.72
	Low	-0.38
April	High	1.92
	Low	-0.38
August	High	2.38
	Low	0.37
November	High	1.68
	Low	-0.01
December	High	1.35
	Low	-0.16

Gate Operation

All the sluices in this polder have two gates. One is a flap gate and the other is a vertical lift gate. During flushing, the flap gate at the riverside should be kept open. This is presently done by the farmers with a rope and tied with the upper portion of the sluice. During high tide the vertical lift gate will be open and let water to enter into the polder. During low tide the gate will be closed (sluice having a flap gate at the polder side too, does not need manual operation in this case). This operation would be done with a gap for a few days in between the two highest spring tides. During the research the operational device (closing or opening) in the sluice was not working. Farmers were doing this job in the traditional way, which is very laborious and difficult. During drainage the vertical lift gate will remain open and the flap gate will be in operation and let water discharge from the polder area. It is closed during high tide. The flap gates were built of iron and very heavy to operate manually. Due to overweight they can not drain sufficient water, as would be the case when they would have been lighter. Farmers cannot operate these gates properly when required because of the overweight. This is a common situation in Bangladesh. Leakage through the gates is also alarming. To overcome these situations testing with new light materials would have to be done. Hoisting devices of the vertical lift gates need modification for better operation.

9.4.2 Results

The drainage situation results from the hydrodynamic simulation for the month of August are presented in Figure 9.4 and 9.5. These graphs show the benefit of gate operation in the present condition. The result also shows the present drainage congestion level inside the polder area if there is no proper gate operation. The simulated results found for two probable conditions (1:5 and 1:10 years of return period) are on the safe side compared to the real situation. The maximum dry season

(April) storing water level that could be attained by 14 days of operation is shown in Figure 9.6. The water level for the different dry months is also shown in Figure 9.6. For storing there will be a gap of 7 to 8 days in the gate operation due to the (spring) tidal water level in the river.

The simulated discharge results for the six structures of the polder during the flushing and the drainage situation are presented in Figure 9.7, 9.8 and 9.9. For the drainage situation, the discharge with and without structure control has been simulated and presented. As per schematization in the model the negative discharge means water flows from the river to the polder area and the positive discharge means the reverse.

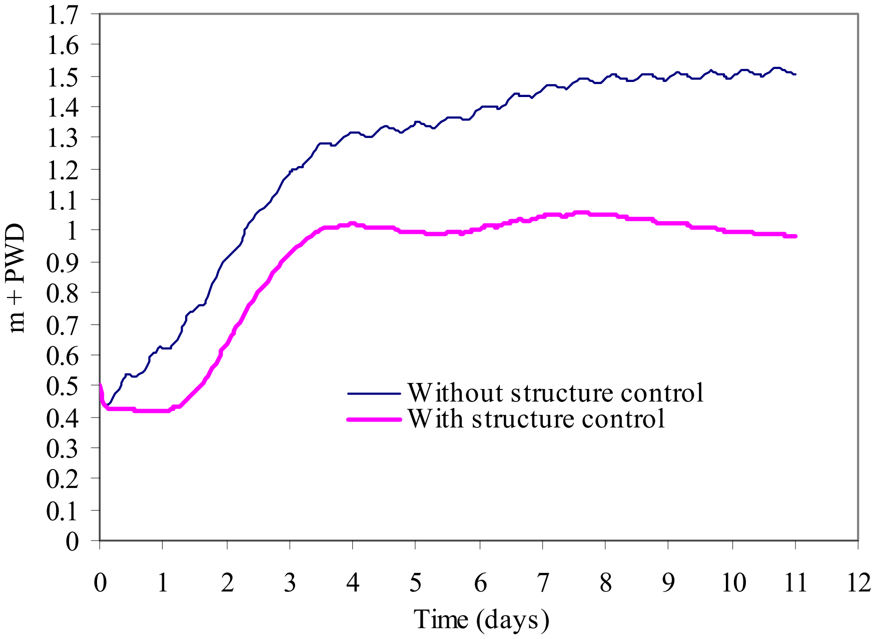

Figure 9.4 Drainage results with or without structure control (1:10 years return period and with 3 days consecutive rain)

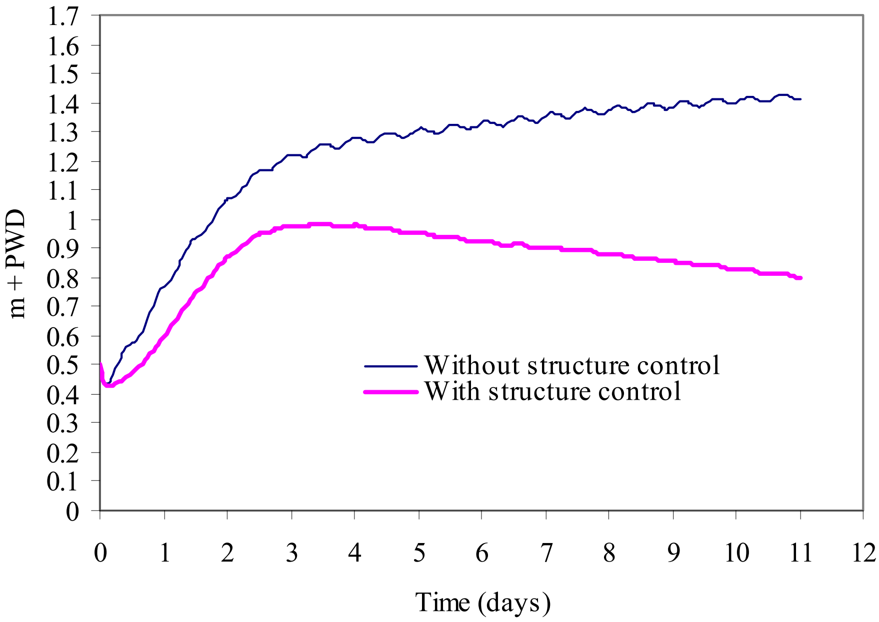

Figure 9.5 Drainage results with or without structure control (1:5 years return period and with 3 days consecutive rain)

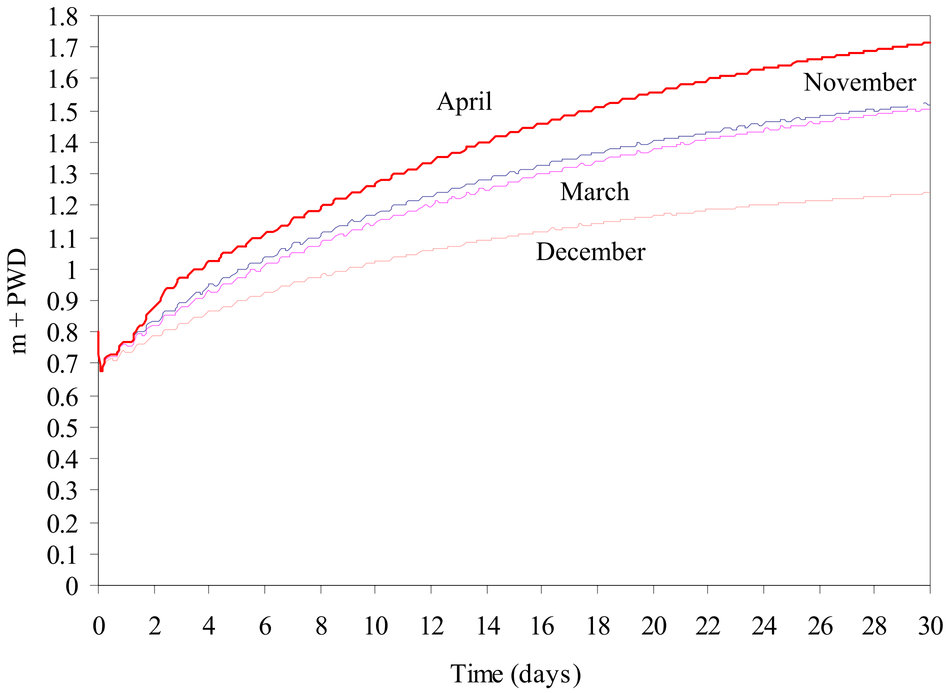

Figure 9.6 Storing water levels for the different dry months of the year

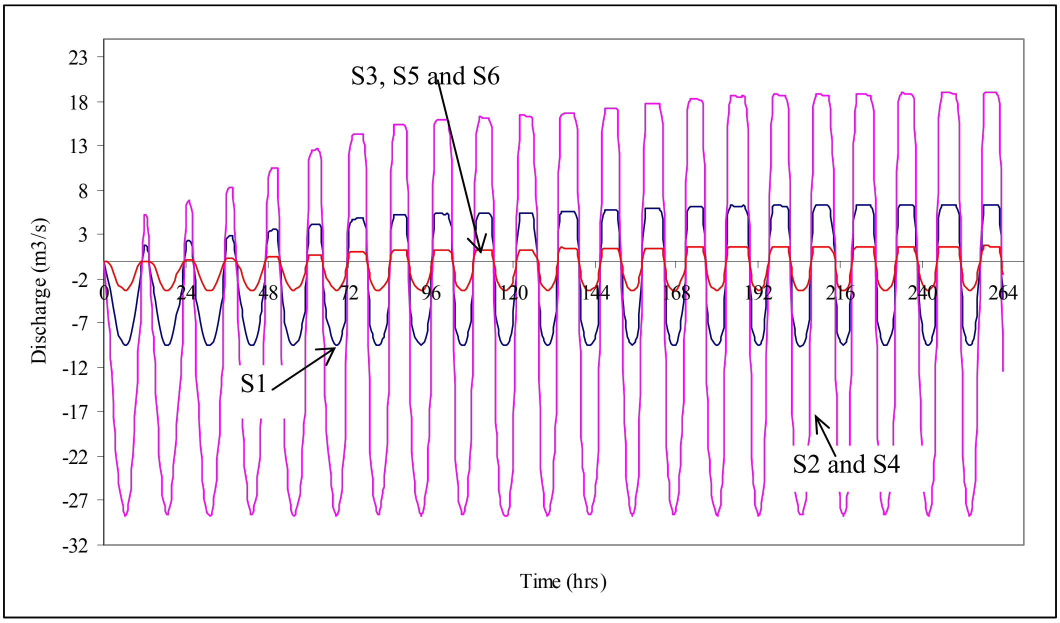

Figure 9.7 Drainage discharge results without structure control (1:10 years return period and with 3 days consecutive rain)

As per requirement in the field and considering the results of the simulations, an annual water management strategy has been proposed for the improvement of the area (Figure 9.10). The strategy has been prepared to match the normal practice of the farmers, to save the present cropping pattern and also to maintain the best environment.

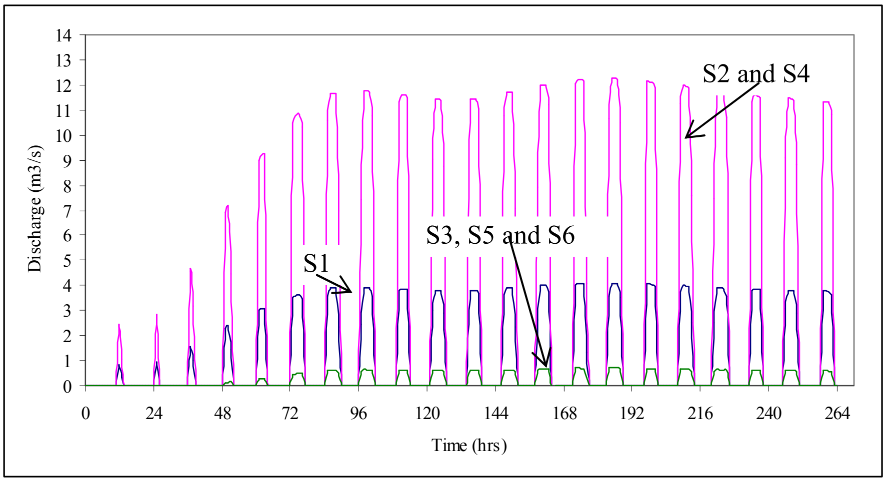

Figure 9.8 Drainage discharge results with structure control (1:10 years return period and with 3 days consecutive rain)

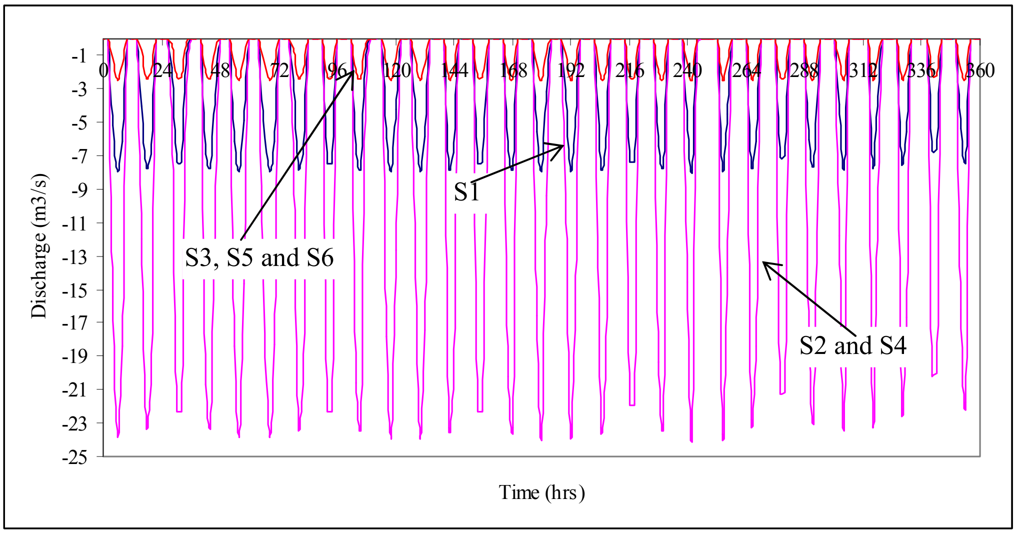

Figure 9.9 Drainage discharge results for the flushing situation in April

At the beginning of the year there will be a continuous water level of 1.10 m+PWD. This level has to be maintained until the middle of April. This level will be appropriate for sufficient soil moisture and water level in the polder for Rabi and Boro cultivation. This level is also chosen because of domestic uses of water within the area and fish culture. If the outside water level permits the stored water can be cleaned once during this period for quality reasons. During the period from mid April – until mid May water will be stored to the maximum level (1.40 m+PWD) within 14 days according to the outside river level for Aus transplantation. By considering the field requirements that level could be lowered within 3 - 7 days as per convenience of the farmers and transplanting time of the next crop. This lowered level would have to be maintained, based on the internal navigation and fish culture considerations. After that Aus can be grown in rainfed conditions. Thereafter the farmers can be ready to operate the sluice further to reduce the water level during heavy rains in the polder area when river low water levels remain higher. Aman crops need flood protection, which they already have by the embankment. Sometimes Aman needs supplementary irrigation which is also possible by this strategy. At maturity stage of Aman the water level inside the polder can be raised again to provide sufficient soil moisture in the land where the farmers will grow Rabi crops. During the harvesting time of Aman the water level can be lowered again for a safe harvesting.

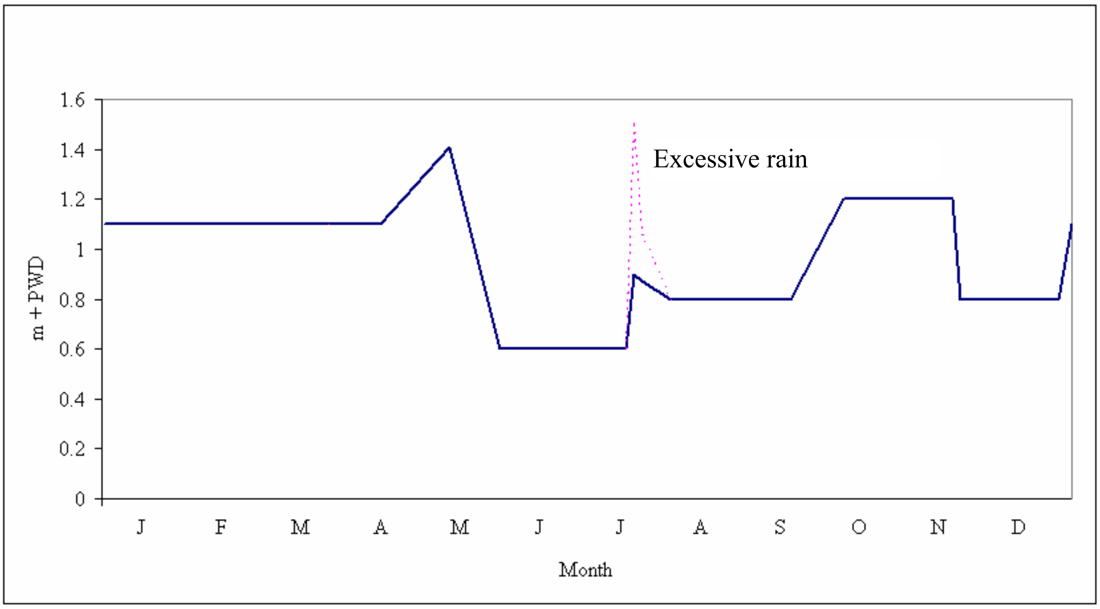

Figure 9.10 Proposed water management strategy for the area

We may not expect that initially people will follow the strategy exactly as the model shows. Therefore for conflict resolution and starting of the new practice, further discussion will have to be held to investigate whether some modifications in the proposed strategy would have to be made.

9.4.3 Risk Considerations

Embankment
Polder 43/2A is surrounded by an earthen embankment, which was designed based on a return period of 20 years. This is the present practice in Bangladesh. When a flooding will occur damage to crops, homestead and other infrastructures of the area may be expected. A return period of 20 years, basically means in this case a change of 5% for the loss of the wet season crop and a damage to homestead and infrastructure which is difficult to quantify, but which is not expected to be very significant.

Since the researcher is not proposing new interventions, any redesign consideration for the embankment is not applicable. The frequent breaching phenomenon of the embankment because of less maintenance and cuts made by the people for irrigation water is, however, a more significant concern. For obtaining the benefits of the proposed water management strategy it is of importance that the maintenance of the embankment will be done in an adequate way.

Drainage
At present the area suffers from serious drainage problems. In order to solve these problems the proposed strategy has to be followed. In absence of time series data, the simulation considered 80% dependable (happening) extreme tidal water levels (high and low) from wet months of the different years. This means 80% of the time the

water level will be available and only 20% of the time it will not be available. This is quite reasonable for a strategy. These tidal water levels govern the duration of drainage and amount of flow. Water levels having higher than 80% dependable values mean better drainage (relatively low water levels in the river) and lesser means poor drainage (relatively high water levels in the river). In future a detailed economic analysis could be done to reassess the suitable percentage of dependable water levels as a basis for the simulations.

By observing the rainfall data, it was found that practically the situation of three days consecutive rain is rare, but two consecutive days is very common. That is why 3-day consecutive rainfall values (1:10 and 1:5 years of return period) have been used in the simulations. For any higher values than the 3-day consecutive rainfall, the drainage problem will be more severe. Higher return periods mean lower risk, but the real data show that the 3-day consecutive rainfall is sufficiently safe.

Flushing
For flushing the tidal water levels in the river are the governing factor to determine how much the water level can be raised inside the polder area. 80% dependable extreme water levels (high and low) have been chosen to simulate the flushing conditions (from the dry months). A lower percentage is more safe for flushing while in practice higher water levels will be available in the river. During flushing irrigation area coverage and environmental issues are the major concerns. A higher percentage means that lower water levels in the river lead to less flushing and less irrigation area coverage. In addition people will face problems of domestic water supply.

9.4.4 IDRISI Modelling

Using the map collected from the field office of the Bangladesh Water Development Board, an index map in IDRISI has been produced by applying the Lineras and Polyras module of the model. This map has already been shown in Figure 6.1. The XY co-ordinate method was used to make the map. On screen digitizing technique has been used to develop the canal network of the polder area.

To include the elevation of the area, a spot elevation map of the Bangladesh Water Development Board was used. From that map, the spot elevation was calculated as required in the model. To represent the canal bottom that was not shown in the map, some measurements were done in the field and from the results the spot elevation of the canal bottom was determined. By the use of the Interpol module, the digital elevation model (DEM) for the polder 43/2A was developed. By use of the Reclassification module, a contourwise area map was produced from the DEM and presented in Figure 9.11. The contourwise area was calculated with the help of the Area module and to prepare an area elevation curve as presented in Figure 9.12. The flushing (irrigation) and drainage simulation results (levels) from the hydrodynamic simulation were displayed in the DEM (Figure 9.13, 9.14 and 9.15). The Figures show how much area can be brought under gravity irrigation, the problematic areas of drainage and how much area can saved from the present drainage problems by sluice operation. The hydro-topo maps were then produced combining the levels obtained from flushing and drainage simulation with the DEM by GIS (by the help of the Reclassification module). From the hydrotopo map flushing (irrigation) and drainage depth maps were also produced. For that Overlay and Assign modules have been applied between the respective hydrotopo map and the DEM of the area. From the irrigation and drainage depth maps, by applying the Reclassification module and according to the land suitability criteria developed in Table 8.4 respective irrigation and drainage suitability maps have been produced.

The rainfed and irrigated situation was considered during the analysis. The Cross-tab module has been used between the irrigation and the drainage suitability map to calculate the present land suitability under the proposed water management strategy. To determine the final land suitability, again the Cross-tab module is used between the present land suitability map and the rainfed suitability map. Finally the land suitability zoning map was produced showing where improvement is needed for polder 43/2A (Figure 9.16). The land suitability zoning was determined for the potential conditions by similar procedures. From the land suitability zoning map future planning can be carried out for proper water management and agricultural exploitation. The land suitability zoning for the potential condition is presented in Figure 9.17. The area calculation of different land suitability analysis can reflect the benefit of water management by showing the change of land suitability types (e.g. conversion of nearly suitable land to suitable land and so on). All the maps that are described above in this Geographical Analysis System modelling for the land suitability analysis and not presented in this Chapter are shown in Appendix F.

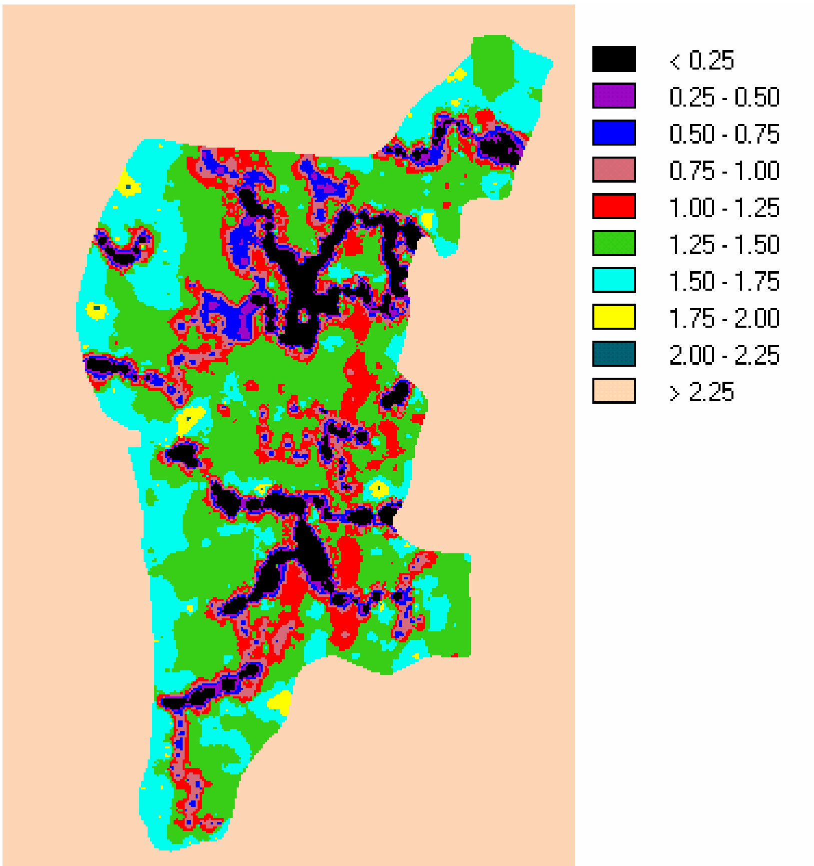

Figure 9.11 Topographical map in m+PWD

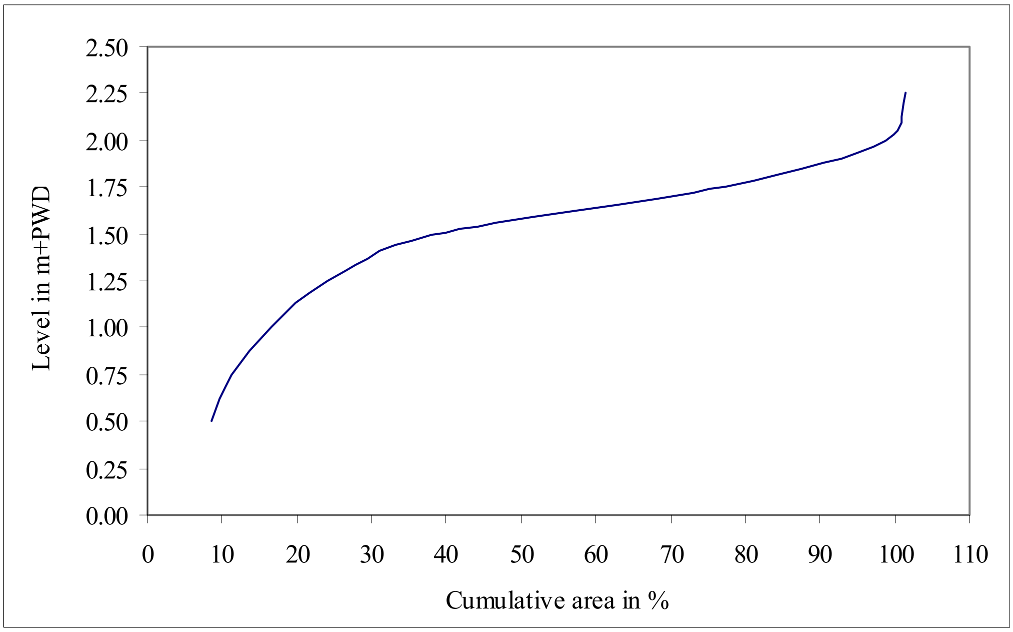

Figure 9.12 Area elevation curve of polder 43/2A

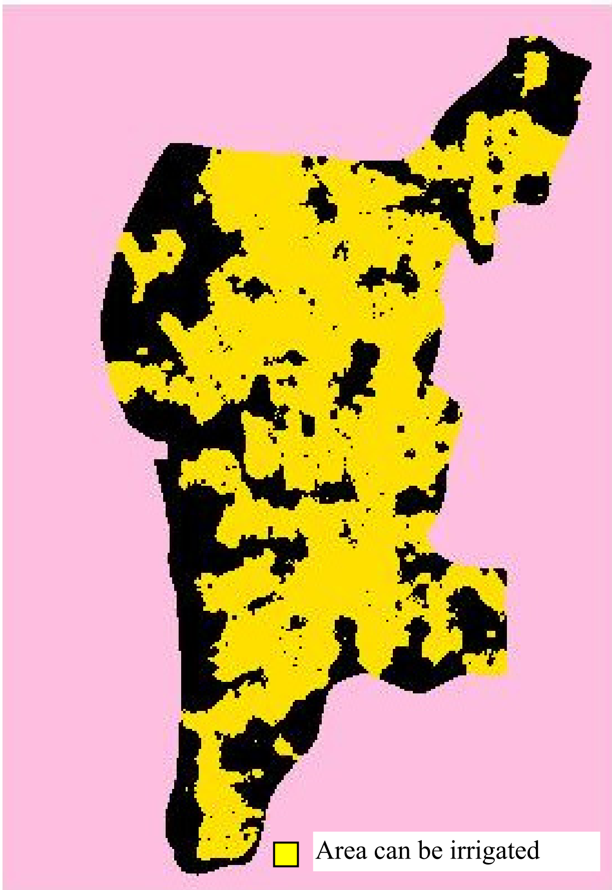

Figure 9.13 Irrigation possibility in April

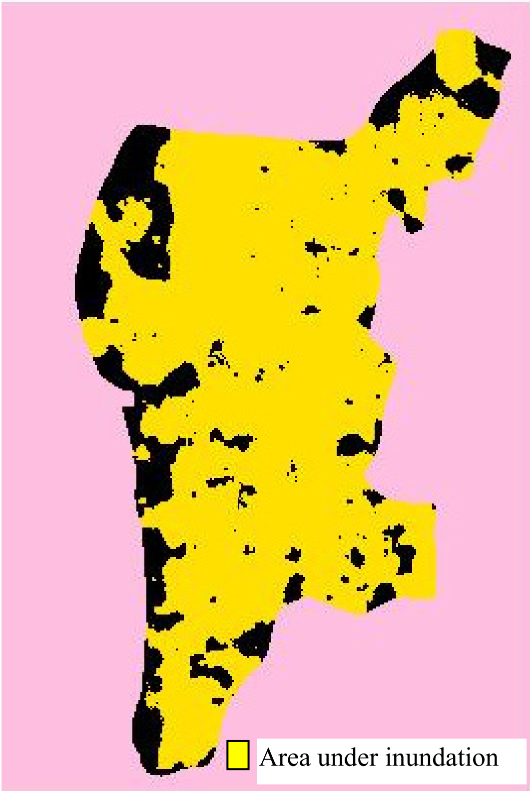

Figure 9.14 Drainage inundation without structure control (1:10 year return period with 3 days consecutive rain)

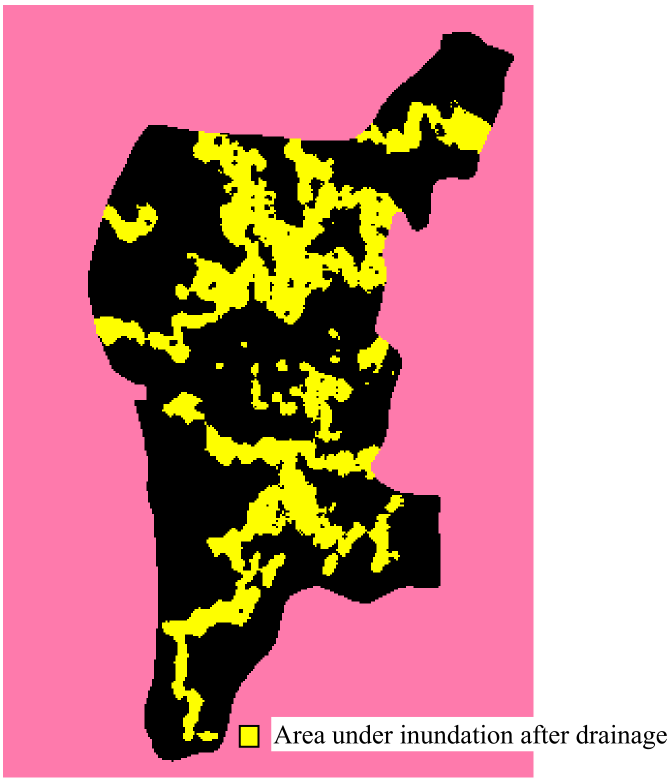

Figure 9.15 Drainage improvement possibility with existing structure control (1:10 year return period with 3 days consecutive rain)

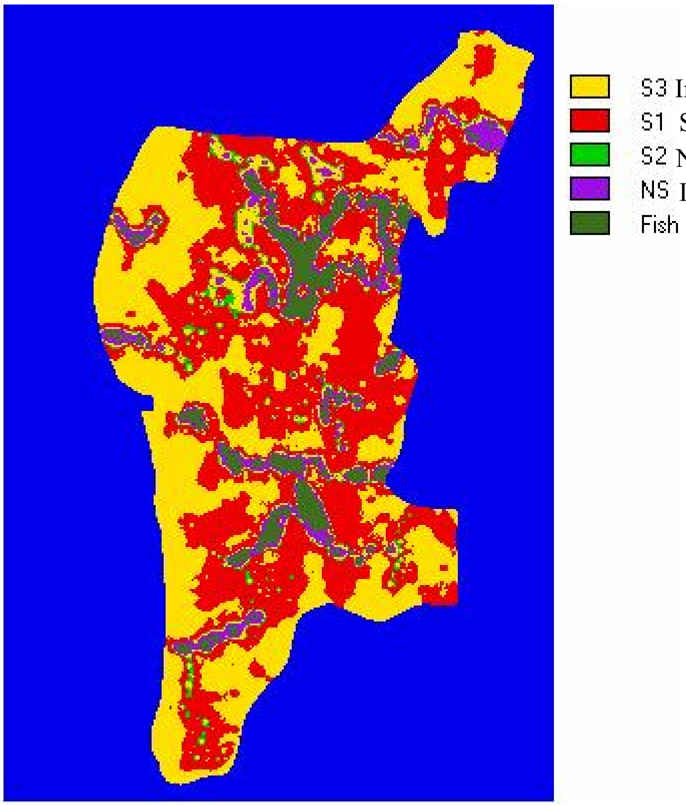

Figure 9. 16 Final land suitability zoning in the present condition

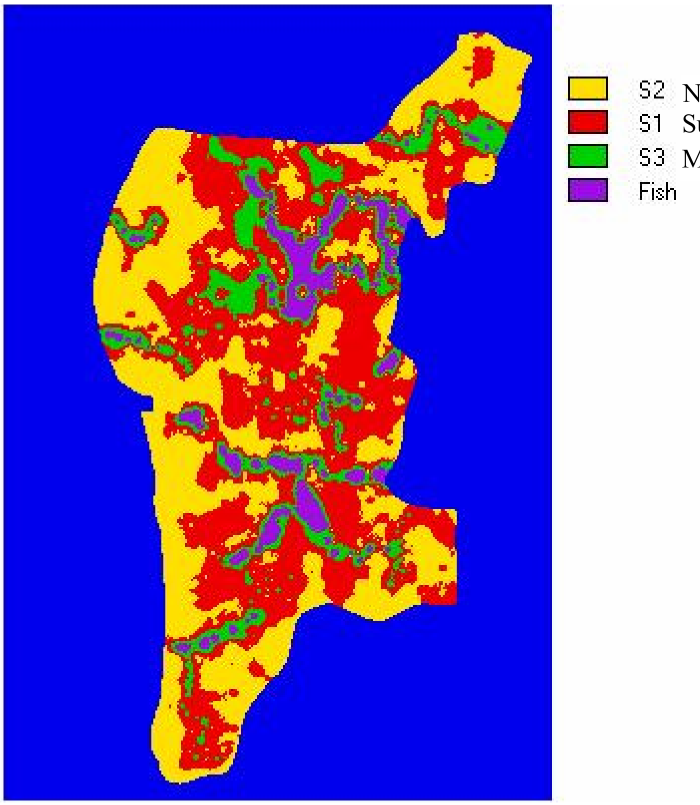

Figure 9.17 Final land suitability in the potential situation

9.5 FIELD MEASUREMENTS

In order to collect the required information for calibration and verification of the models the water levels within the polder area and surrounding rivers were measured at different times during the study. Several temporary gauges were installed for that purpose. The locations of the gauges are shown in Figure 9.18.

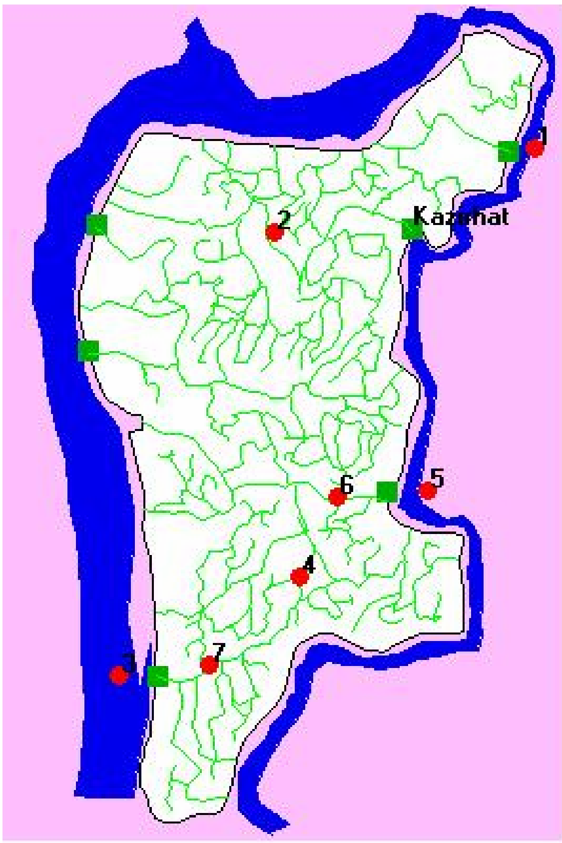

Figure 9.18 Temporary gauge locations

The main purposes of the measurements were to observe the possible drainage congestion in June – August in the present situation and water levels during the dry season in December – January inside the polder area. Water levels in the surrounding rivers were also measured. Gauge 1, 2, 3 and 4 were installed by the planning team of IPSWAM. The measurements were done for 12 hours only in the daytime (6 am to 6 pm). Gauge 2 and 4 are located within polder area. The drainage and flushing conditions of the polder area were measured for a particular year. The gauge within the polder area also represents the water management effort of the people (if any) by observing the water levels. The field measurements were carried out in the dry and wet seasons of 1998 - 1999. The water levels for the permanent station Mirjagonj were statistically analyzed (80% and 50% dependable high and low tide) and are also shown in the same Figure to verify the reliability of the measured data. During the fieldwork the researcher did an experiment to show the possible internal water storage capacity associated with sluice operation. For that purpose he choose the sluice in Kazirhat (3 vents). The results of that experiment were measured in gauge 2, which was inside the polder area. Figures 9.19, 9.20, 9.21, 9.22, 9.23, 9.24 and 9.25 present the measured water level data described above.

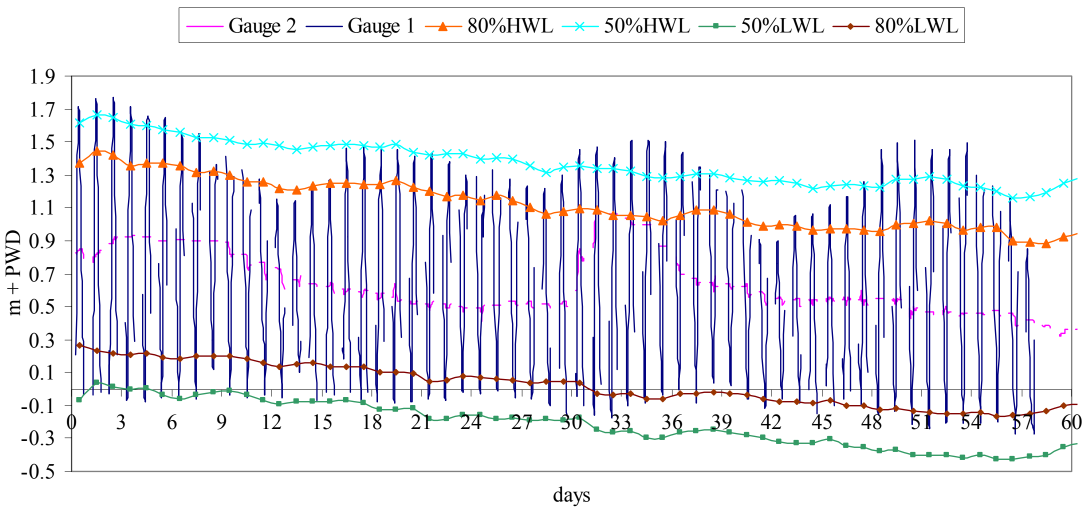

Figure 9.19 Water levels at gauge 1 and 2 in December - January 1998 – 1999, without proper gate operation

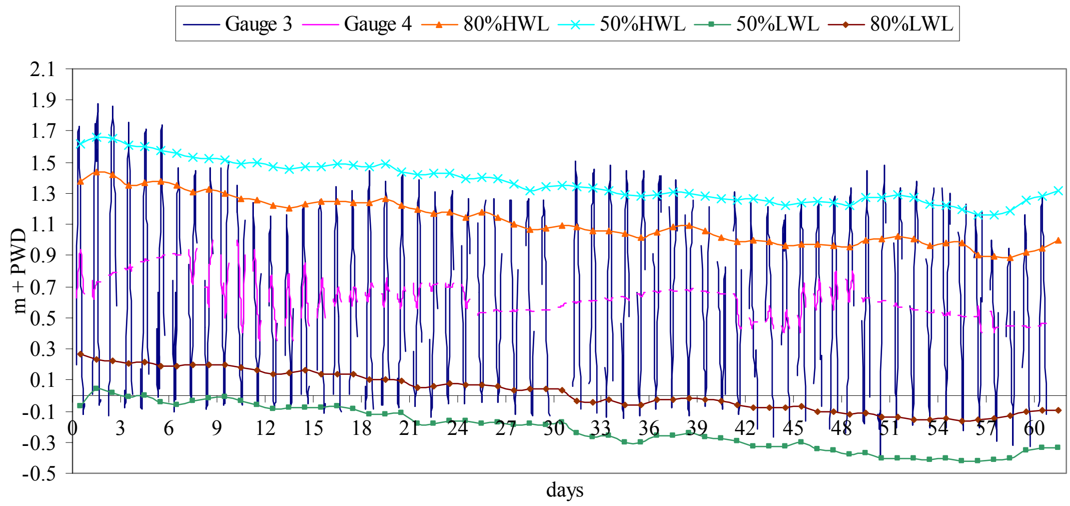

Figure 9.20 Water levels at gauge 3 and 4 in December – January 1998 – 1999, without proper gate operation

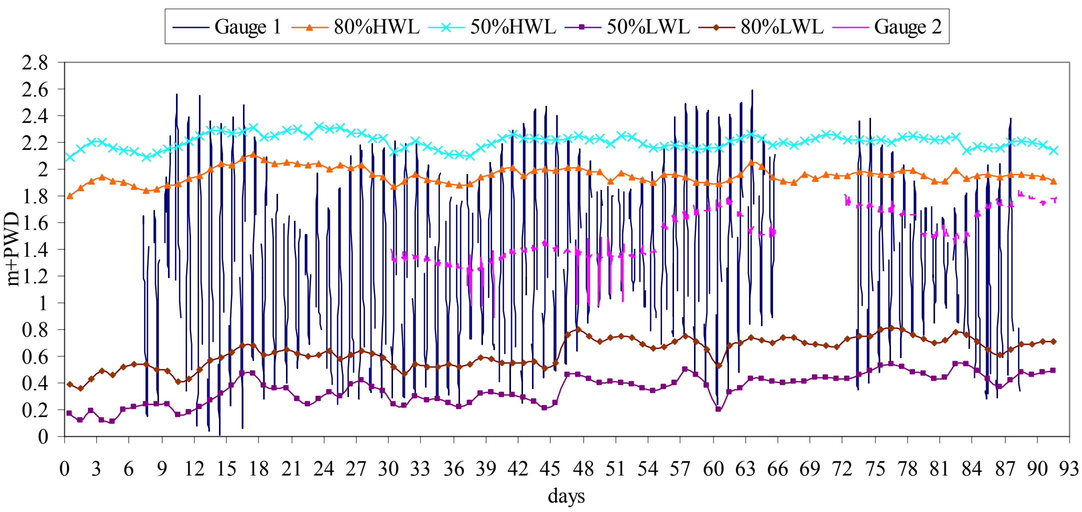

Figure 9.21 Water levels at gauge 1 and 2 in of June - August 1999, without proper gate operation

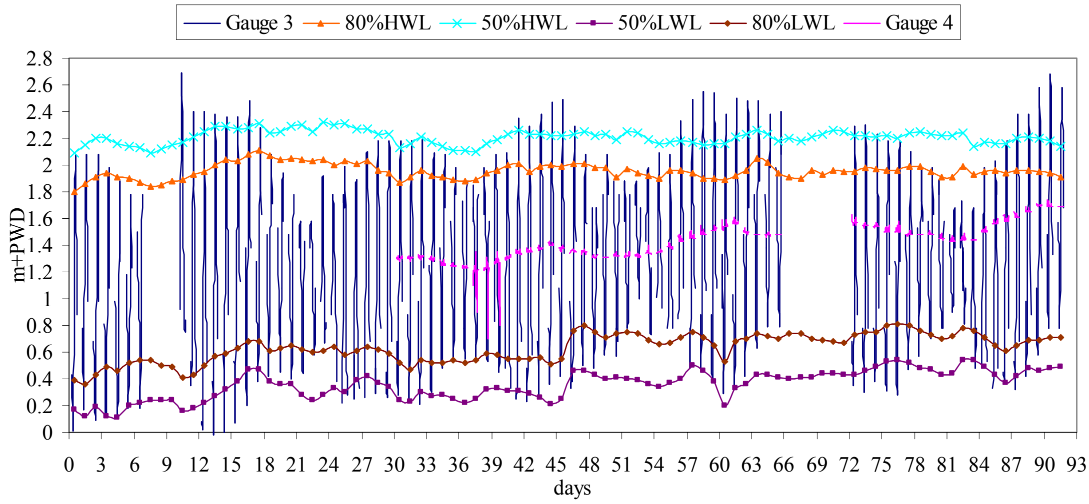

Figure 9.22 Water level at gauge 3 and 4 in June - August 1999, without proper gate operation

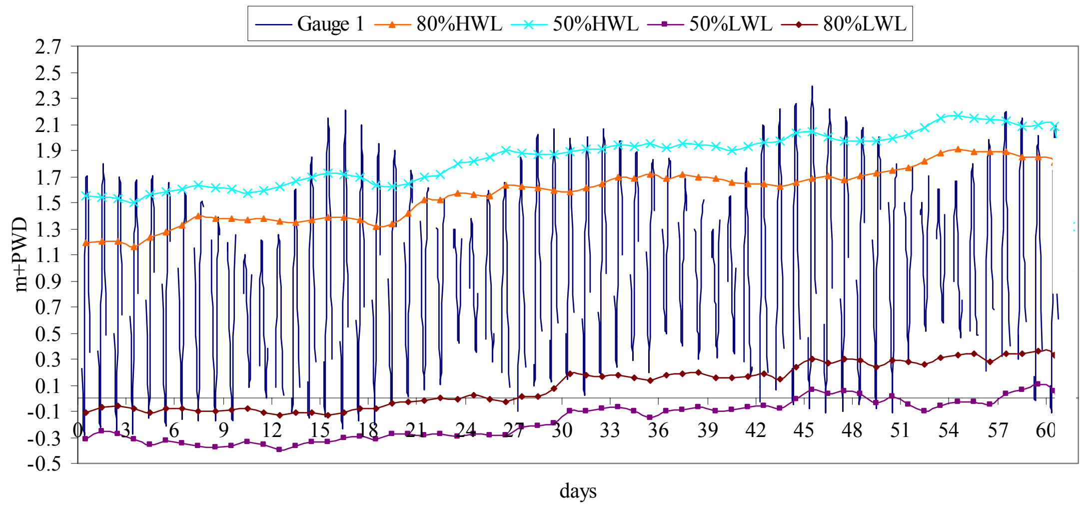

Figure 9.23 Water levels at gauge 1 in April - May 1999

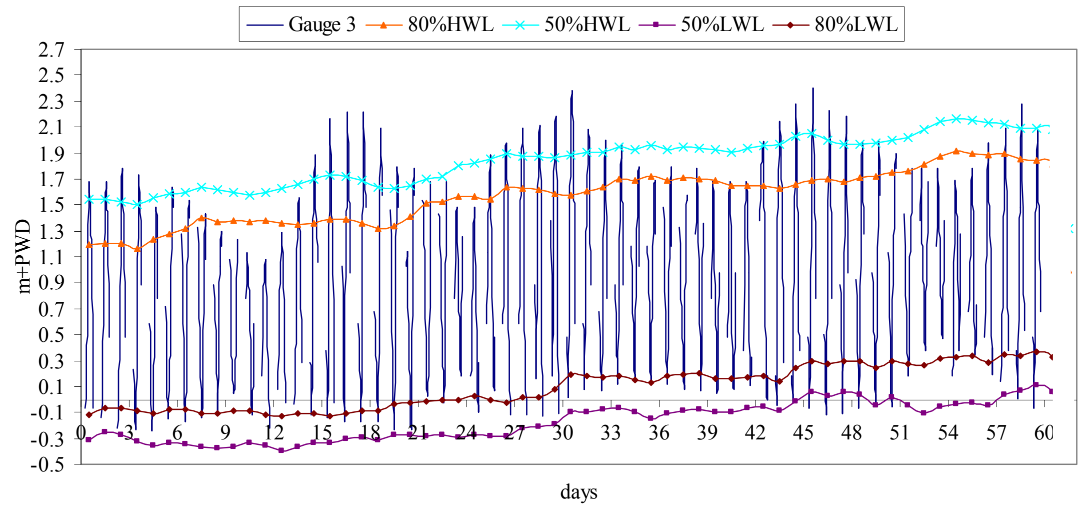

Figure 9.24 Water levels at gauge 3 in April - May 1999

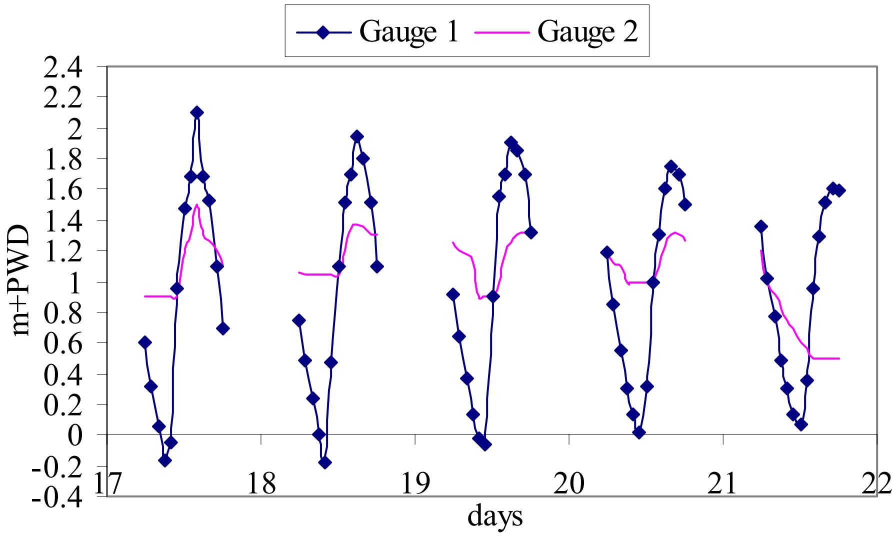

Figure 9.25 Water level measurements for gauge 1 and 2 by gate operation for storage at Kazirhat in April 1999

From the Figures presented above the problems of water shortage during dry seasons and drainage congestion in wet seasons may be clearly observed. Even though the gates of the sluices are not in a position for operation but still some operational trend is visible in these Figures.

The experimental results in April show that water can be stored in the polder area during spring tides for irrigation by sluice gate operation (Figure 9.25). The sluice gate operation was done only for one high tide (daytime) and for one sluice. The measurement in the gauge 2 (inside polder) was taken nearer to the sluice. The propagation time of internal water level rises and the partial obstruction of canals cause delay. For that reason the water level measurements show fall (after one rising) of the water level when there was no storing even in the high tide at night. It could have been much more uniform if the water level measurements could be taken continuously.

To verify the hydrodynamic simulation results and realize the change in water management practice for the area another set of temporary gauges were installed by the researcher. They are at location 3, 5, 6 and 7. In this case 24 hours water levels were measured.

The researcher took initiative to repair all the gates of the sluices for better water management practices and to show their consequences to the farmers, but due to lack of money this was not possible. Therefore he choose two sluices, which needed fewer repairs. The researcher repaired the sluice gates and the connecting canal network was re-excavated by the Union Parishad. The measurement was carried out in this region. The measured water level data for the wet season are presented in Figure 9.26 and 9.27. The water level data for the permanent station nearby Mirjagonj were statistically analyzed and also presented in the same figure to judge the measured water levels.

The probability distribution curve for the station Mirjagonj as presented in Figure 9.26 and 9.27 shows that the water levels for the year 2001 are not representative.

Practically this year spring tide comes with a high frequency value. The road in the Patuakhali district town was under water, which was reported in all the daily newspapers in Bangladesh. With this high situation the sluice operation shows much better results (gauge 6 and 7) with sluices operation explained in the approach. It was possible to maintain a maximum water level inside the polder area at 1.3 m+PWD (the maximum level was for less than 3 days), while the outside river water level was reached maximum at 3.0 m+PWD along with the high rainfall. The results might be even better if the year of data collection would be a representative one. Water levels could be lower as the model result shows. The hydrodynamic simulation results for the drainage and flushing situation was found to be quite good compared to the measured values.

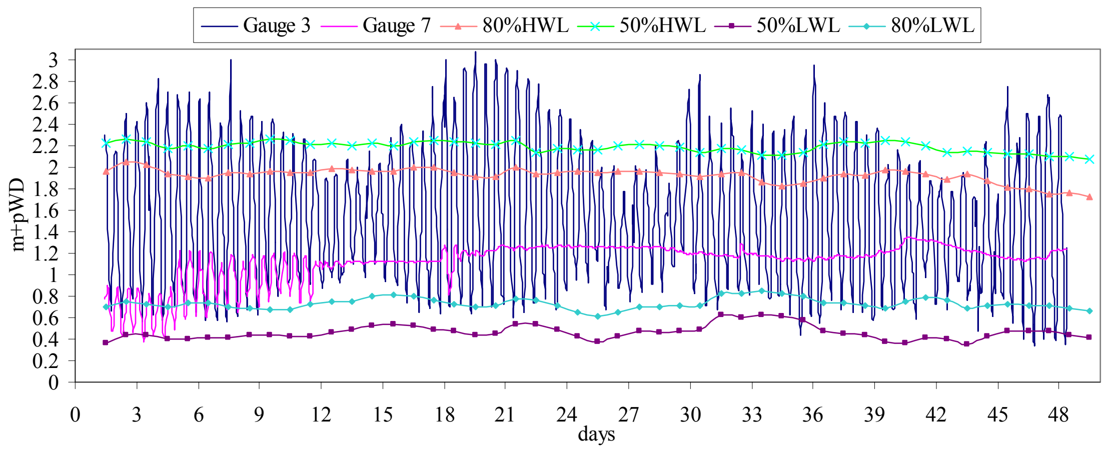

Figure 9.26 Water levels at gauge 3 and 7 in the months August - September 2001 with structure operation

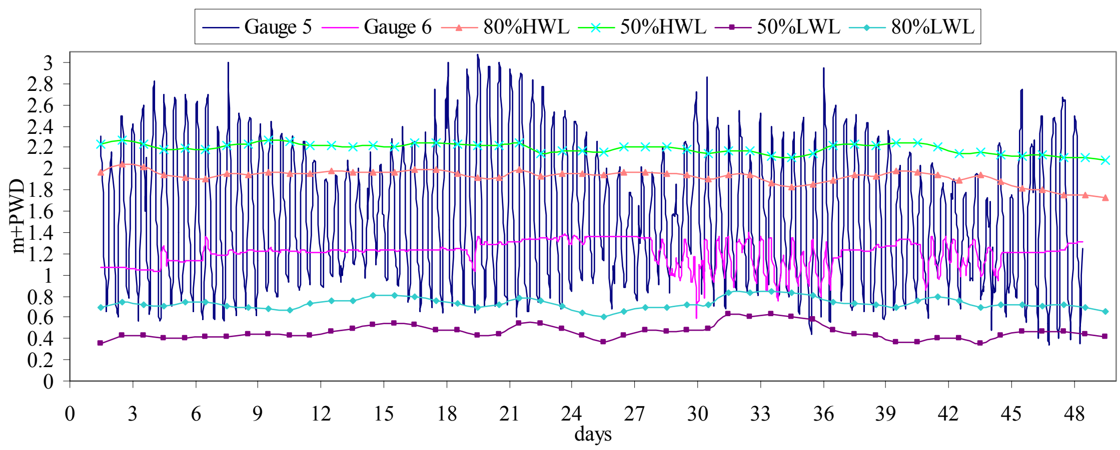

Figure 9.27 Water levels at gauge 5 and 6 in the months August - September 2001 with structure operation

10 ENVIRONMENTAL IMPACT ASSESSMENT OF THE WATER MANAGEMENT STATEGY

In the following a preliminary assessment of main environmental impacts due to a possible implementation of the proposed water management strategy in polder 43/2A is presented. Undoubtedly this matter will have to be considered in more detail at a later stage preceding implementation. In general the impact assessment data have been used from the survey on selected areas by the researcher. The survey data of the Integrated Planning for Sustainable Water Management (IPSWAM) programme on environmental assessment (related one only) have also been used as a criterion of qualitative judgement. The discussion and interviews between the Agency professionals and different stakeholders in polder 43/2A have been used to judge the weights of the impacts.

10.1 SOCIAL IMPACT ASSESSMENT

The purpose of social impact assessment (SIA) as a part of general environmental evaluation is to assess the likely impact of a measure on the structure and functioning of social orderings. Social impact assessment provides data on social impacts in a form that can be used in the overall decision making process. The social impact assessment will therefore involve an assessment of the impact of the interventions or related organizations on the livelihoods of different categories of people and on the distribution of benefits among different social groups.

10.1.1 Stakeholders in Polder 43/2A

The groups of people or individuals whose livelihoods are affected by an intervention, whether positively or negatively are often known as stakeholders. In polder 43/2A majority of the people are directly or indirectly affected either positively or negatively. The stakeholders of the area under consideration are highland farmers, lowland farmers, sharecroppers, lessees, fishermen, boatmen, labourers, businessmen and water users especially women at domestic level.

10.1.2 Social Impact Assessment of the Water Management Strategy

Possible interventions in polder 43/2A were examined in this study. Social Impact Assessment has been done for the proposed water management strategy. The interventions suggested in this strategy include repair of all infrastructures for better operation. Construction of small pipe inlets for irrigation in higher area, which can not be covered by flushing. Small bunds have to be constructed by the farmers in their croplands to hold water. Formation of some institutional arrangement is also proposed in this strategy. Impact of the interventions, which was constructed during reclamation for flood control and drainage improvement, will also, be discussed here.

Framework for Analysis
The impact assessment done here is based on some assumptions, which are as follows:
- polder 43/2A is not new. The proposed strategy basically seeks to improve upon an existing polder. Therefore it is difficult to measure the extent of actual impact

of the strategy. However, while discussing the impact of the proposed strategy and related organizations, reference will be made, where possible to the impact of previous interventions;
- all changes and improvements in polder 43/2A were not only achieved due to the previous interventions. There were other Government and non-government Agencies contributing to the developments in this polder. The Bangladesh Water Development Board had made the major interventions, creating an environment for other Agencies to start their development;
- proper people's participation will help to improve water management and livelihoods for the people of the area;
- the water management strategy as proposed in this study will help to reduce the negative impacts of the previous interventions.

10.1.3 Assessment of Impact on the Livelihoods of the Stakeholders

The people of polder 43/2A in general admit that their livelihoods have changed significantly since the completion of the polder. The general feeling is that the overall impact of the previous interventions has been positive. Some negative impacts on the livelihoods of the people were also present. The proposed water management strategy and related organizations are expected to have a very positive impact on the life and living of the people. It is expected to give new benefits that were not thought of earlier. Impacts of the proposed strategy and related organizations on different resources of livelihood and on different social groups are presented in Table 10.1, which have been already presented in Chapter 6 and 7.

Table 10.1 Summary of impact assessment

Stakeholders and issues	After the reclamation	Proposed strategy and related organization
Stakeholders		
Highland farmers	+/– –	+ +
Lowland farmers	+	+ +
Sharecroppers	+	–
Lessees	+	+/–
On-farm labourers	+	+ +
Off-farm labourers	(+)	+
Businessmen	+/–	+ +
Boatmen	–	(+)
Fishermen	+/– –	+
Women	+/–	+
Issues		
Navigation	– –	(+)
Road Communication	+	+
Health & Sanitation	+/–	+

(+) = Slightly positive; + = Positive; + + = Highly positive; +/– = Positive for some stakeholders while negative for others; – = Negative; – – = Highly negative;

10.2 ENVIRONMENTAL SITUATION AND IMPACTS

In an Environmental Impact Assessment (EIA) an attempt is made to identify, predict and assess the likely consequences of proposed development activities. Execution of an Environmental Impact Assessment in an early phase of the planning process will contribute to an optimisation of scheme design, from both economic and environmental point of view.

Schemes should be screened during the identification stage to determine the appropriate type of environmental analysis based on the nature, potential magnitude and sensitivity of the issues. As per World Bank indications the scheme has to be assigned to one of the following categories:

- Environmental Impact Assessment is normally required as the proposed measures may have diverse and significant environmental impacts (large scale schemes);
- a limited environmental analysis is appropriate, when the proposed measures may have specific environmental impacts (small scale schemes);
- environmental analysis is normally less necessary for measures in the field of education, health, nutrition, institutional development, etc..

The aim of the environmental study in polder 43/2A was to examine the environmental soundness during practicing the proposed strategy. The criterion for the environmental assessment of polder 43/2A was framed on the basis of the data and information being collected during the study. The scope for the environmental analysis in polder 43/2A is limited. The environmental situation and issues that have already been presented in Chapter 6 and 7 will be considered for impact assessment.

10.2.1 Scoping and Area of Influence

Scoping

Scoping is the process of identifying the Important Environmental Components (IEC) and key issues for the assessment. In polder 43/2A which was performed in consultation with Government Agencies, non-government organisations and different stakeholders. The Important Environmental Components selected for polder 43/2A were: surface water quality, salinity, groundwater quality, wildlife species, wetlands, agricultural production, soil fertility, capture fisheries production, culture fisheries production, navigation, health, nutritional state, way of life, property ownership and employment.

Area of Influence

Considering polder 43/2A, bounding is aiming at how far the environmental effects can be measurable. Qualitative assessments might sometime have to be made. The level of effort needed for data acquisition, analysis and assessment is not necessarily uniform for all environmental components. Important Environmental Components for the Environmental Impact Analysis in polder 43/2A are selected mainly within the boundary of the area.

10.2.2 Impact Prediction and Assessment

The natural physical environment for the present situation and for the proposed water management strategy in polder 43/2A is given in Table 10.2, where the positive and negative impacts on selected environmental components are shown.

The natural biological environment for the present situation and for the proposed water management strategy in polder 43/2A is given in Table 10.3.

Table 10.2 Impacts on the natural physical environment for polder 43/2A

Environmental component	No significant impact	Impact with present situation (positive(+) and negative(-))			Impact with proposed strategy (positive(+) and negative(-))		
		Small	Medium	High	Small	Medium	High
Movement of wildlife	√						
Conflicts of irrigation with other water use			√(-)			√(+)	
Flooding and drainage problem				√(-)			√(+)
Land		√(+)				√(+)	
Soil		√(-)				√(+)	
Agriculture			√(+)				√(+)
Surface water				√(-)			√(+)
Ground water		√(+)				√(+)	
Drinking water			√(-)			√(+)	
Water quality							
Surface water			√(-)			√(+)	
Ground water		√(-)			√(+)		
Salinity		√(-)			√(+)		

√ = Showing impact

Table 10.3 Impacts on the natural biological environment for polder 43/2A

Environmental component	No significant impact	Impact with present situation (positive(+) and negative(-))			Impact with proposed strategy (positive(+) and negative(-))		
		Small	Medium	High	Small	Medium	High
Capture fisheries			√(-)				√(+)
Culture fisheries		√(+)					√(+)
Forest		√(+)				√(+)	
Homestead vegetation			√(+)				√(+)
Wildlife		√(-)			√(+)		

As a result of the proposed water management strategy the present land utilisation is expected to increase resulting in an incremental Rice crop production of 6,200 ton/year (from Table 10.9 and Table 10.10). This will increase the number of farm families who will get farm benefits from the polder. The employment opportunities especially the farm labour utilization are expected to increase to 260,000 man-days by intensive agriculture. The changed cropped area was calculated from Table 10.9 and 10.10 and from there the agriculture labour utilisation has been calculated as per normal procedure of the Bangladesh Water Development Board.

The increased scope that would be created for fish culture by the proposed water management strategy is expected to further improve the fish production by 140 ton/year (from Table 10.9 and Table 10.10) which will increase the fish consumption of the people.

The water management strategy as proposed in this study, is expected to enhance the socio-economic conditions in polder 43/2A such as:

- stakeholders representation in Water Management Groups and the Water Management Association can reduce conflicts especially conflicts related to water use;

- people's participation at lowest level can be ensured;
- women's participation will be improved;
- improvement of surface water quality;
- homestead forest and vegetation can be increased.

From the results of the qualitative Environmental Impact Assessment it may be concluded that the existing environment would be improved by implementing the proposed water management strategy. It would increase the irrigated area and reduce the drainage congestion problems. The water management strategy will, therefore, improve the quality of life of the people socially, environmentally and economically.

10.2.3 Environmental Management Plan

Polder 43/2A is aiming to improve the existing conditions of the stakeholders with participatory water management. As regards to environment, the environmental impacts on the components with effects and mitigation measures for sustainable management is shown in Table 10.4. The mitigation measures proposed in this plan need little financial support from the Agency. Most of the measures can be dealt easily by the institutional organizations proposed in this study.

10.2.4 Impacts of the Proposed Water Management Strategy on Coastal Polders

The comparative impacts of the proposed water management strategy on the coastal polders related to agricultural practices and the ecosystem are presented in Table 10.5. The benefit that could be achieved by practicing of the proposed water management strategy and related organization along with the modification needed for the strategy are also shown in Table 10.5.

10.3 AGRICULTURAL COST AND BENEFITS ASSESSMENT OF POLDER 43/2A

10.3.1 Before and after the Reclamation

The agricultural production cost and benefits for polder 43/2A have been analysed and presented for before and after the reclamation. T. Aman, T. Aus and Rabi were the three major crops grown in this area. The higher lands were mostly double cropped, while the medium and low lands were single cropped. The yield was very low due to tidal inundation almost every year together with wet season rains. Crop damage was a common problem in polder 43/2A and hence there was no crop security. Aman was the main crop, which grows in rainfed conditions under tidal flooding. Rabi was grown in a limited area. The pre and post polder agricultural assessment of the polder are shown in Table 10.6 and 10.7. Environmental aspects were not considered during the reclamation. Fisheries aspects were also not included at that time. Future water management and beneficiaries involvement for operation and maintenance was also not considered. The assessment was done based on the available reports and documents of that time for polder 43/2A and surrounding polders.

Table 10.4 Environmental management plan for polder 43/2A

Environmental component	Environmental effects	Proposed mitigation measures
Land	Land is not fully used for agriculture, fisheries, forestry and livestock	Ensure water for: - Increase number of crops; - Preparation of appropriate cropping calendar; - Appropriate plan for fish culture; - Tree plantation in possible areas; - Care for livestock.
Soil	Degradation of soil quality due to excess use of fertilisers and soil salinity Reduction of soil fertility due to less flushing	Use of natural fertilizer Flushing through structures
Agriculture	Reduction of agricultural production and crop damage	Preparation of best-suited cropping calendar Increase of irrigation and drainage facilities
Surface water	Bad quality, growth of water hyacinths	Cleaning of water hyacinths Re-excavation of silted up khals Maintain flowing condition in the khals Development of planned sanitary system
Ground water (Drinking)	Not well known (some evidence of being adequate) Shortage of drinking water	Needs detail analysis for quality aspects Installation of more hand tube well for drinking
Capture and culture fish	Reduced in khals People are not familiar with fish culture Scarcity of fingerlings	Arrangement for fish to enter through the structures Control of excessive fishing Motivation of people for fish culture Limitation of unwise use of pesticides Fisheries management and stocking Provision of financial support (if possible)
Forest, homestead and vegetation	Deforestation	Plantation of trees at suitable places
Wildlife species	No significant adverse impact	Safe breeding environment of both terrestrial and aquatic wildlife Prevent hunting
Social environment	Social conflicts, social and economic imbalances, gender discrimination	Proper representation of all water management activities Promotion of women's representation in users group
Economic environment	Living standard of the people	Intensive agricultural programme to increase employment opportunity Programme for culture fisheries in ponds and capture fisheries in open water bodies Arrangement of interest free loan for the poorer people
Health and sanitation	Water borne diseases Poor sanitation and open latrine causes health hazards	Installation of hand tube wells for drinking Use of boiled water or water purification tablets in case when surface water is used for drinking Education of students in schools and madrashas Awareness among the people regarding health and sanitation through institutional development

Table 10.5 Comparative impacts of the proposed water management strategy on the coastal polders

	Before reclamation	Immediately after reclamation	Proposed water management strategy	Modification needed
Agriculture	Damages of Aman Low yield Tidal flooding Saline intrusion	Tidal flooding stopped Aman damage protected Yield increased HYV introduced LV dominates due to insufficient supplementary irrigation	Flood control and drainage management improved Supplementary irrigation possible (Boro - Aus - Aman) or (Rabi - Aus - Aman) cropping pattern is possible Crop diversification is possible	Design of the hydraulic structures has to be modified to reduce the velocity of water so that the fish fry can easily enter into the area through the structures Light flap gate has to be designed for easy operation Hoisting device of the vertical lift gate has to be modified for easy operation Khals obstruction has to be removed Small irrigation inlet could be provided in the embankment for relatively high area irrigation All obstructions made in the khals opposing flushing and drainage have to be removed
Ecosystem	Wetland, beels and khals are full of fish, crab and shrimp Aquatic wild life abundance	Wetland area reduced No connection between river and inside khals Natural stocking process of fish stopped Yield reduction of fish in the floodplain area Navigation stopped	Natural stocking process will persist Limited navigation will be possible inside the area Domestic uses of water will be ensured Localized drainage congestion will be removed	

Table 10.6 Condition of polder 43/2A before reclamation (Bangladesh Water Development Board, 1983, 1988 and 1989)

Crop	Area in ha	Yield in ton/ha	Total annual production in ton	Price in Tk/ton	Gross market value in 10^6 Tk	Annual unit cost of production in Tk/ha	Total annual cost of production in 10^6 Tk	Net annual benefit in 10^6 Tk
T. Aus	1,249	1.2	1,499	5,360	8	2,700	3	5
T. Aman	3,398	1.8	6,116	5,360	33	2,800	10	23
Rabi	1,653	0.4	661	8,040	5	1,800	3	2
Total	6,300		8,276		46		16	30

Table 10.7 Condition of the polder 43/2A after reclamation (Bangladesh Water Development Board, 1983, 1988 and 1989)

Crop	Area in ha	Yield in ton/ha	Total annual production in ton	Price in Tk/ton	Gross market value in 10^6 Tk	Annual unit cost of production in Tk/ha	Total annual cost of production in 10^6 Tk	Net annual benefit in 10^6 Tk
T. Aus	1,650	1.5	2,475	5,360	13.0	2,900	5.0	8.0
T. Aman	3,500	2.0	7,000	5,360	38.0	3,000	11.0	27.0
Rabi	2,308	0.8	1,846	8,040	15.0	2,000	5.0	10.0
Boro (L)	67	1.8	121	5,360	0.7	3,100	0.2	0.5
Total	7,525		11,442		67.0		21.0	46

10.3.2 Present and Future Condition

At present the water management practice in polder 43/2A is very limited. Farmers are not utilising the infrastructure of the polder and suffer from drainage congestion and flooding. In addition to that no water is available for land preparation during T. Aus planting. This situation is becoming more critical day by day. Three agricultural assessment situations of polder 43/2A are presented in Table 10.8, 10.9 and 10.10. In this assessment environmental aspects are considered along with the fisheries situation of the area. The cropped area for the present situation was calculated from Figure 7.1. The market price of the produced crops and cost of production was chosen from the investigation and Government of Bangladesh prices. The production cost of the crops includes several input cost like seeds, fertiliser, labour, bullock, irrigation, pesticide and equipment.

Table 10.8 Present situation of polder 43/2A (after Bangladesh Water Development Board, 2000)

Crop	Area in ha	Yield in ton/ha	Total annual production in ton	Price in Tk/ton	Gross market value in 10^6Tk	Annual unit cost of production in Tk/ha	Total annual cost of production in 10^6Tk	Net annual benefit in 10^6Tk
T. Aus (LV)	1,880	1.7	3,196	6,075	19	9,043	17	2
T. Aus (HYV)	570	2.7	1,539	6,075	9	14,081	8	1
T. Aman (LV)	2,505	1.8	4,509	7,425	33	11,415	29	4
T. Aman (HYV)	995	2.6	2,587	6,075	16	12,140	12	4
Khesari	900	1.1	990	9,640	10	3,564	3	7
Chili and S. patatoes	70	0.6	42	37,000	2	17,904	1	1
Fish	110	0.9	99	50,000	5	6,972	1	4
Mughbean, etc.	275	0.5	138	23,000	3	5,750	2	1
Boro (HYV)								
Total	7,305				97		73	24

No investment was made by the farmers to improve the present faulty water management practice in polder 43/2A. In this study the researcher was not suggesting options for the future implementation which include major technical interventions. He has developed a water management strategy for polder 43/2A which is, among others, based on the operation with the repaired existing infrastructure and involving all users of the polder. Expected assessment in polder 43/2A with the proposed strategy is shown in Table 10.10, which includes the operation and maintenance cost as production cost (khals re-excavation and removal of obstructions in khals). Practicing with the proposed water management strategy, the cropped area is expected to increase due to improved drainage and a large area will be covered by flushing (irrigation). The crop damage will reduce due to less inundation. The crop yield will also be further increased along with the fisheries in polder 43/2A. The assessment values in Table 10.10 have been chosen from the limited survey on a selected area by the researcher. The survey of the Integrated Planning for Sustainable Water Management (IPSWAM) programme covers three alternative options and huge agricultural assessment data has been gathered. As because the researcher was a member of the survey team during the Integrated Planning for Sustainable Water

Management (IPSWAM) programme, the required data that can be fit with the proposed water management strategy have also been chosen from that survey.

Table 10.9 Expected future situation for polder 43/2A doing nothing further (after Bangladesh Water development Board, 2000)

Crop	Area in ha	Yield in ton/ha	Total annual production in ton	Price in Tk/ton	Gross market value in 10^6Tk	Annual unit cost of production in Tk/ha	Total annual cost of production in 10^6Tk	Net annual benefit in 10^6Tk
T. Aus (LV)	1,950	1.8	3,510	6,075	21	9,550	19	2
T. Aus (HYV)	590	2.9	1,711	6,075	10	14,312	8	2
T. Aman (LV)	2,405	1.9	4,570	7,425	34	11,535	28	6
T. Aman (HYV)	1,095	2.9	3,176	6,075	19	12,297	13	6
Khesari	510	1.3	663	9,640	6	3,564	2	4
Chili and S. patatoes	335	0.8	268	37,000	10	18,086	6	4
Fish	110	1.0	110	50,000	6	11,620	1	5
Mughbean, etc.	420	0.6	252	23,000	6	5,750	2	4
Boro (HYV)								
Total	7,415				112		79	33

Table 10.10 Expected future situation with the proposed water management strategy

Crop	Area in ha	Yield in ton/ha	Total annual production in ton	Price in Tk/ton	Gross market value in 10^6Tk	Annual unit cost of production in Tk/ha	Total annual cost of production in 10^6Tk	Net annual benefit in 10^6Tk
T. Aus (LV)	1,185	2.8	3,318	6,075	20.0	14,000	17.0	3.0
T. Aus (HYV)	1,255	3.8	4,769	6,075	29.0	16,000	20.0	9.0
T. Aman (LV)	2,475	2.8	6,930	7,425	51.0	12,500	31.0	20.0
T. Aman (HYV)	1,025	4.0	4,100	6,075	25.0	14,500	15.0	10.0
Khesari	375	1.4	525	9,640	5.0	3,864	1.0	4.0
Chili and S. patatoes	625	1.1	688	37,000	25.0	19,810	12.0	13.0
Fish	110	2.3	253	50,000	13.0	38,636	4.0	9.0
Mughbean, etc.	800	0.8	640	23,000	15.0	7,330	6.0	9.0
Boro (HYV)	10	4.5	45	6,075	0.3	16,000	0.2	0.1
Total	7,860				183.0		106.0	77.0

From Table 10.9 and 10.10 the expected agricultural incremental net benefit and crop production changes with the proposed water management strategy can be assessed. According to Table 10.8 the agricultural net benefit for the present situation is Tk 24 million. The expected net benefit under continuation of the present conditions shows Tk 33 million (Table 10.9). This increment is expected to occur because of the other development activities in the surrounding area and in the polder. The proposed water management strategy is expected to result in a net benefit of Tk 77 million (Table 10.10). This implies an incremental net benefit of Tk 44 million (77 - 33), which is very much encouraging.

11 EVALUATION

11.1 GENERAL

Water management in FCD schemes is an interactive process. Any development in the field influences the performance of the water management in the polder. Subsequently developments in the water management in the polder influence the surrounding river. Therefore the assessment of the impact of a development plan for a polder, should be based on a macro-to-micro approach. For design purposes, a micro-to-macro approach should be followed.

In the past, the planning processes of FCD schemes have largely ignored linkages between water users, river basin and some other important aspects such as health, income, equity and ecology. Policies and plans in the near future will have to consider the increasing interest of many stakeholders. Presently most of the FCD schemes have operation and maintenance problems and lack integration between different aspects of water management. Several attempts were made by the Bangladesh Government to improve the water management of the schemes to attain sustainability. But so far they have not been very successful. Water development and management will have to be based on a participatory approach involving users, planners and policy makers at all levels. Public supports for policy actions need to be generated through awareness and education campaigns. Turnover of FCD schemes from the public to the private sector, and the important role of water user organizations and participatory management at farm level should be ensured.

Water management can be improved by integrating western oriented technocratic and administrative models with local traditional indigenous management practice prevailing in the polder area. Water management schemes cannot be planned or designed in isolation either from a spatial or a sectoral point of view. Water sector development needs to be conceptualized and defined within the broader framework of a national and regional development plan. In future, schemes will have to be designed in such a way as to encourage cooperation between Government, associations and farmers. Moreover, proper attention has to be paid to the long-term impacts. In concrete operational terms, this would entail integrated water management and institutional arrangement modifications.

The most important parameters of water management in FCD polders are the tidal irrigability (flushing) and drainability (drainage). For that reason agricultural land use should be linked with these two important aspects in order to maximise the utilization of land and water. For example, a proper operation (drainage and flushing) in the area very much depends on the availability of water (quantity in space and time) which is expressed by the hydro-topographical conditions of the area. Due to the fact that the hydro-topographical conditions are not constant in time and space, it is recommended that for every FCD scheme, a systematic monitoring and evaluation programme will be established. This programme should help to assess the sustainable development concept in order to improve the water management of the polder. Based on the monitoring data, the land suitability zoning of the area which is based on the hydro-topography and the developed water management strategy should be evaluated and modified from time to time.

FCD schemes and irrigation systems should be treated differently. Stakeholders' demand and management requirements are completely different in FCD schemes compared to irrigation systems. Some good examples from the irrigation systems might be taken, but not copied as was done earlier.

Many of the FCD schemes in Bangladesh have positive impacts and increased agricultural production but some of them had negative impacts too. Some of these schemes created significant environmental problems like reduction of different fish species and reduction of the floodplain. Fisheries and FCD development are generally in conflict with each other. The sweet water capture fisheries resources are dependent on inland water bodies. The annual flooding and post-flood standing water in the floodplain has a significant role in fish production. In the wet season floodplains play the primary role for re-population and increase of biomass in open water fishery production systems. With regard to the fisheries, the essential impact of FCD schemes is the change in water regime inside the protected area from a natural uncontrolled to a controlled regime. Other factors which were perceived to have been responsible for the decrease in capture fisheries concerned the expansion of agrochemical pollution, increased incidence and severity of fish disease and over-fishing.

Injudicious planning of roads, canals and other infrastructure blocking the natural drainage ways cause many of the drainage problems, especially in low lying irrigation and drainage schemes. There is considerable scope for preventing and alleviating drainage problems by more integrated planning and water management.

Efforts should have to be taken to mobilize operation and maintenance funds from stakeholders through Water Users Associations (WMA) and Water Management Groups (WMG). Initially, contribution amounts are not as important, as the willingness and commitment to participate. Investigations have shown that people are willing to pay, provided there is a guarantee that they will have a say in the use of the money. Taking this into account, water rates or service fees could be agreed upon and through the proposed institutional arrangements, people could be given the opportunity to participate in the planning and decision making process. Involvement of the people in operation and maintenance of the FCD schemes, the crucial requirement for progress in this context includes as well a strong political will of the Government.

Modelling and Application

By considering the results of the GIS for polder 43/2A it can be concluded that a GIS is a useful tool for assessing the land suitability zoning, which is based on many variables with complicated inter-relationships. For polder areas topographical data are the most sensitive.

Especially for decision makers, GIS may be an appropriate tool for comparing the effects of different land use or water management strategies in FCD schemes. A GIS is not only a presentation tool, but together with a Geographical Analysis System it has a modelling capability. The modelling with a GIS should be kept simple, but it can still give useful results.

One dimentional hydrodynamic simulation of flushing and drainage for polder 43/2A has been very effective to verify the present situation and capacity of the existing sluices. The reservoir concept of simulation is a useful technic to present the consequences of water management strategies in FCD schemes and to assess the future development posibilities. The modelling for polder 43/2A has been done based on statistical criteria in order to get a representative result.

Based on the field ivestigations, measurments, the modelling results for polder 43/2A and by considering the present practices of the farmers, a strategy has been recommended for future water management in the polder area. This strategy will contribute to the improvement of the agricultural performance. It also gives the possibility to improve the water management without considering any new technical interventions. The negative impacts that are prevailing due to bad operational practices and improper planning in the past will come to an acceptable level with the application of this strategy.

The approach and models developed in this study have been tested in polder 43/2A. The models can be used to formulate suitable future water management strategies for similar areas. The approach and models can also be used for salinity control (with modification) or for environmental impact assessments. When a large area will be reclaimed, the impact of the development on the adjacent areas needs to be evaluated in order to determine a ‘safe’ development of the latter.

11.2 EVALUATION RELATED TO PILOT POLDER 43/2A

Like other FCD schemes in Bangladesh, polder 43/2A is suffering from drainage congestion, lack of reliable irrigation practices and ultimately from improper water management. Waterlogging has been identified as a key problem faced by a significant proportion of the farmers. Poor khal excavation and maintenance are key issues for many farmers in the operation and maintenance of the water management system of the polder.

Unplanned human interference in the existing canal network blocks the flushing and drainage possibilities and creates additional problems to the area. Influential farmers use the canals for making ponds in front of their homestead and converting them into fishing area. This practice should be stopped in this polder and also in other FCD schemes in Bangladesh.

Some critical moments for Rice cultivation that were identified by the researcher are:

- for T. Aus (LV and HYV):
  - seedbed preparation and transplantation are not possible if insufficient rainfall occurs in April and May;
  - yields reduce when there is insufficient rainfall during the vegetative growth stage in the months of May and June;
  - sometimes the crops are severely damaged in the matured or ripening stage when there is excessive rainfall in the months of July and August;
- for T. Aman (LV and HYV):
  - it can not be planted in time in some years due to drainage congestion caused by excessive rainfall in the months of July and August;

- it is sometimes damaged in the mature or flowering stages when there is no or limited rainfall in the month of October.

Land suitability zoning based on hydro-topographical categories and a water management strategy is an important factor for developing a polder area. Before making a detailed land suitability zoning map for a certain polder area, a simple survey is advised in order to derive a hydro-topographical map. This map will be useful to develop a preliminary idea about what type of water management strategy should be applied in the area. It should be realized that the hydro-topographical conditions of areas are dynamic and change due to the natural phenomena or man made measures (sea level rise, land subsidence, obstruction in the drainage and flushing network). Land suitability zoning shows the possibility of future development for present and potential conditions. This analysis might be applied to other FCD areas to resolve water management conflicts between people from different land types and profession. The potential condition might need new interventions.

To address the present operational and management problems of the FCD schemes several steps have to be followed. The operation and maintenance approach has to be developed based on the different aspects of water management along with the existing problems and the possible contribution of each party. The proposed planning steps would have to be followed to improve the water management in completed FCD schemes. Considering all the problems, the agreed water management strategy should be demonstrated to the local people to show them the consequences of water management.

The FCD schemes will be improved, modified and rehabilitated if required, only when the stakeholders agree to take over the responsibility and share the cost of operation and maintenance. The stakeholders will have to be involved right from the beginning of the planning exercise. They will have to be involved in planning, design and implementation of the modernization of the FCD schemes and have to commit themselves for their future share in those activities. After showing the results of the new approach, the schemes will be handed over to them for operation and maintenance.

In the past, the efforts in forming the different groups did not sufficiently take sociological aspect into consideration. The best approach is when the stakeholders through discussion in meetings develop the institutional arrangements. Agency staff should communicate with the stakeholders to assure that the combined roles and responsibilities of Agency and stakeholders guarantee a sustainable water management. Institutional arrangements should not have too many tiers and should be as simple as can be comprehended by the stakeholders. Guidelines for institutional arrangements should not be rigid guidelines, there should be some flexibility. A simple two tiers institutional arrangement has been suggested in this study.

For hydro-topographical category A and B areas a gravity flow can be expected to maintain a certain water level in polder 43/2A but for category C and D this is almost impossible. So, in the latter categories other measures should be applied like provision of irrigation inlets (small pipes) or additional structures in the embankment, which are applied now all over in Bangladesh. Irrigation in highland requires a different practice and operation. Simple systems should be considered where water is entered into the network of canal systems and after that farmers may pump the water into their field using low lift pumps or traditional ways.

The hydrodynamic simulation results were found very good during field measurements and verification. The strategy for water management and institutional arrangements as proposed for polder 43/2A would have to be followed in other FCD polders. This will lead local people to unify for better water management. This strategy includes all the related issues they are facing now. The newly developed strategy includes the construction of small bunds surrounding the fields of the farmers. These bunds will help to store water during rainfall and flushing for a few days in their field, which has been the practice all over in Bangladesh except in this region.

The operation and maintenance strategy is not a fixed one, it can be modified or changed as per requirement of the farmers in the polder area. The water level shown in the proposed water management strategy is based on normal situations and certain probable conditions. Users might find little deviation when following the strategy. For sure the water levels would be within allowable limits. For adapting this newly developed strategy time has to be allowed, because integrated water management involving local people needs time to cope.

The approach developed in this study is at first instance only considering the existing sluices of the polder. After several years of experience with this strategy, new intervention possibilities can be considered in consultation with the stakeholders. Supplementary irrigation for Aman during dry spells in the wet season is also possible in this strategy. A sufficiently high water level for internal navigation and fishing is maintained too. Based on the rainfall conditions adequate irrigation after April-May and drainage after July-August is also possible.

The gates of the sluices should be remodelled with lighter materials so that the farmers can easily operate the sluices and the sluices can properly drain as it was expected. The existing leakage problems in the gates should be addressed in a proper way. The hoisting devices of the sluices have to be re-designed so that the farmers can lift or lower the gates easily.

The proposed strategy has to be explained to the farmers at the beginning of the cropping seasons for their needed adjustment on changing of cropland especially Rabi. The present land utilisation is expected to increase resulting in an incremental Rice crop production of 6,200 ton/year. This will increase the number of farm families who will get farm benefits from the polder. The employment opportunities, especially the farm labour utilization are expected to increase to 260,000 man-days.

The proposed strategy is further expected to improve the fish production by 140 ton/year and the fish consumption of the people. Only water management in the FCD schemes will not assure equal distribution of benefits to all categories of people in the area, other socio-economic parameters have to be included for that purpose.

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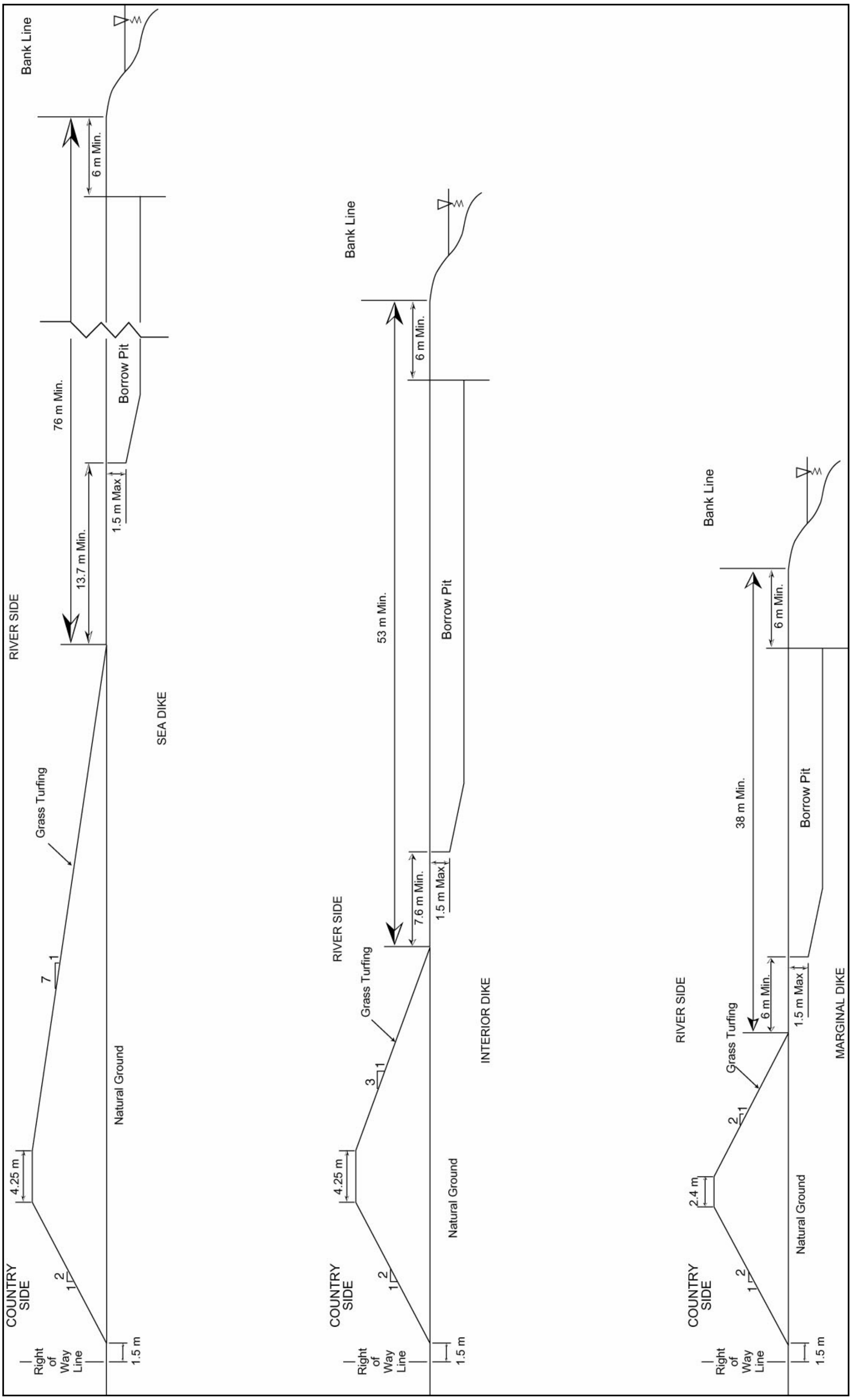
APPENDIX A. Typical Cross Sections of the Different Types of Coastal Embankments



APPENDIX B. Stakeholder Participation, Institutional Arrangements and Cost Recovery Attempts in Bangladesh

Policy Level

By early 1990s, the necessity of stakeholders participation and water management of FCD schemes has been materialised in Bangladesh. In August 1994 the Ministry of Water Resources issued Guidelines for Peoples Participation in Water Development Projects. Through the approval of these guidelines in June 1995 the Government of Bangladesh expressed its commitment to participatory water management in FCD schemes. This marked a major advancement in water management policies, and envisaged building up of institutions of local people and representatives of local associations along with officials of different agencies.

After the introduction of the Guidelines of People's Participation (1994) in water development and management, it was realised that provision for people to participate in it is not sufficient to ensure sustainability. Unless the rights, duties, and responsibilities of all parties involved are clearly defined. It was further recognised that decentralisation of decision-making powers, transparent procedures and lateral accountability are fundamental to effective participation.

In September 1996 the Bangladesh Water Development Board was requested by some of its funding agencies to revise the Guidelines for People's Participation. A working group was formed for this purpose and the consultants of the System Rehabilitation Project (SRP) were charged to assist the Bangladesh Water Development Board to revise the guidelines (1994).

In April 1998 the Bangladesh Water Development Board came out with the revised guidelines, institutionalising local participation: Proposal for guidelines for participatory water management (Bangladesh Water Development Board, 1998). This report presented the synthesis of the outcome of a great number of studies, surveys workshops and seminars on the subject of participatory water management. This was culminated at the national conference on participatory water management, where policy makers, leaders, professionals and academics formulated a number of crucial resolutions on fundamental issues in participatory water management. These guidelines in particular address the rights, duties and responsibilities of all those involved in the processes for water development and management rather than only the procedures to involve the people in the processes.

Updating of the guidelines was again needed to keep pace with the overall reform in the water sector. So, the guidelines as published by the Bangladesh Water Development Board were still considered incomplete. A procedure (task force) was initiated to combine key features of the original (1994 guidelines) and the newly proposed guidelines and to include many other points on which consensus was developing. It was also decided that the new guidelines should be short - outlining key features, simple and flexible to be easily applicable at field-level, to facilitate creative development of institutions for efficient water management. The Ministry of Water Resources directed the Bangladesh Water Development Board to do this job. In September 1998, Dr. Clarence Maloney, an expatriate social specialist under the

Water Sector Improvement Project (WSIP) prepared a modified matrix summarising guidelines for participatory water management in water development projects.

Dr. Y. A. Choudhury presented the Guidelines for Participatory Water Management in (Draft-1) in December 1998, which was to rationalise the System Rehabilitation Project Guidelines. The taskforce submitted the new guidelines for participatory management in water development projects, in January 1999.

In the meantime, several other guidelines were developed by different projects for their own use.

The Local Government Engineering Department in March 1986 prepared the guidelines under the heading ‘Operation and maintenance of small scale flood control and drainage scheme’ for Integrated Rural Works Program. In June 1994, prepared a guidelines and manual for operation and maintenance of small scale water resources schemes for use in Rural Development Program - 4 project. The Compartmentalisation Pilot Project (CPP) of Bangladesh Water Development Board formulated the guidelines under the heading ‘Briefing Notes on the People’s Participation Approach’, December 1998. The Local Government Engineering Department also developed guidelines for participatory process of Small Scale Water Resources Development Sector Project (Revised Draft) in April 1999.

In view of too many guidelines already formulated and more than one Agency being involved in the process, in May 1999, an inter-agency taskforce committee was constituted to integrate all approaches in this regard for developing the guidelines for participatory water management. The Committee finalised these guidelines in 2001.

Legal framework and Institutional Arrangements

The Water Users Organisations that have been proposed in the various guidelines are mostly registered with the concerned water management Agencies (Bangladesh Water Development Board and Local Government Engineering Department) but do not have the provision (except in one or two cases) of registration under any law. The legal status of the Water Users Groups, as proposed in various guidelines is presented in Table B.1.

The institutional arrangements at the field level, as they have been proposed in different guidelines are summarised in Table B.2.

Cost Sharing by Stakeholders

Reference to cost sharing of operation and maintenance activities by the stakeholders, as have been addressed in different guidelines are summarised in Table B.3.

Table B.1 Legal status of different water users organisations (after Quaseem, 2000)

Guidelines	Legal status
LGED (Integrated Rural Works Program), 1986	O&M committees are formed under LGED projects but don't have any legal status
LGED (Rural Development Program - 4), 1994	O&M committees are formed under LGED projects but don't have any legal status
Guideline for Peoples Participation, 1994	WUGs, WUCs, WUAs and FWUAs are not registered under any law and have no legal status, except those that are formed under BWDB projects
System Rehabilitation Project, 1998	Did not address legal status issue
Maloney, 1998	Registration of the WMCs under Societies Act
Compartmentalisation Pilot Project, 1998	The WMCs at different levels are formed under BWDB projects but don't have any legal status
Chowdhury, 1998	Did not address legal status issues
Ministry of Water Resources, 1999	WMGs, WMAs and FWMAs shall be legally registered and shall have their own by-laws
LGED (Small Scale Water Resources Development Sector Project), 1999	WMAs are registered under the Cooperative Societies Act of 1986 and for that purpose some changes in the Co-operative Societies Rules 1987 have been accepted.

BWDB = Bangladesh Water Development Board; LGED = Local Government Engineering Department; WUG = Water Users Group; WUC = Water Users Committee; WUA = Water Users Association; FWUA = Federation of Water Users Association; WMC = Water Management Committee; WMG = Water Management Group; WMA = Water Management Association; FWMA = Federation of Water Management Association; O&M = Operation and Maintenance;

Table B.2 Institutional arrangement of different water users organisations (after Quaseem, 2000)

Guidelines	Institutional arrangement
LGED(Integrated Rural Works Program), 1986	One-tier O&M Committee - composed of the farmers, fishermen and boatmen within the area. The Executive Committee is composed of the beneficiaries, ex officio members (Block Supervisor of DAE and Sub-Assistant Engineer of LGED), and special representation from landless small farmer and fishermen.
LGED(Rural Development Program - 4), 1994	One-tier O&M committee – farmer's representatives representing villages, lowlands, medium highlands and highlands, various classes. UP member, Sub-assistant Engineer and Block Supervisor are ex-officio members. Community organiser assists beneficiaries to get access to Government resources and agencies.
Guideline for Peoples Participation, 1994	Project Council will be formed at the planning and implementation stages, with representatives from the stakeholders, agencies, local administration and Non Government Organisations 4-tier water users organisations for O&M activities WUG with farmers at common irrigation outlet or low lift pump level WUC at branch canal or command structure level WUA composed of representatives from WUCs FWUA composed of representatives from WUAs Executive Committee at each tier called "Board" to manage the activities entrusted at the corresponding tier
System Rehabilitation Project, 1998	3-tier institutional arrangement: WMBC at the level of the stakeholders is the lowest tier; WMSC, with stakeholders' representatives at the system level; Project Committee with stakeholders' representatives from all positively or negatively affected areas. Project Committee will include UP Chairmen and co-opted members.
Maloney, 1998	3-tier stakeholders organisations (a 7 - 9 member Executive Committee at each tier for doing the day-to-day activities): WMG is the lowest tier; WMA consisting of representatives from WMGs;

Guidelines	Institutional arrangement
	Apex WMA composed of representatives from all sections of people within the project boundaries. (For large complex projects, JWMC under the BWDB with representatives from WMAs, agencies like DAE, LGED, Co-operative Bank, Fishery and Non Government Organisations)
Compartmentalisation Pilot Project, 1998	3-tier stakeholders organisations: ChWMC formed with representatives from different categories of stakeholders, farmers, landless households and fishery households of water management units; ScWMCs consisting of representatives from the ChWMCs and representatives from the UPs; Compartment Water Management Committee or Project Council, but its formation has not yet been finalised. At present, a forum consisting of President and vice-president of the ScWMCs is advising the head of Compartmentalisation Pilot Project. (Besides these tiers, there is another committee called the Adjacent Area Representative Committee (AARC) headed by UP Chairman and other stakeholders)
Chowdhury, 1998	4-tier stakeholders organisations: WMG with representatives of the stakeholders is the lowest tier; WMA composed of office bearers from WMGs; JWMC composed of office-bearers from WMAs; JWM Council composed of office bearers from JWMCs.
Ministry of Water Resources, 1999	3-tier stakeholders organisations (a 9 - 11 member managing committee will be formed at each tier): WMG composed exclusively of the stakeholders irrespective of the system facility - is the 1st tier. The elected woman UP member will be an ex-officio member of the Group and the BWDB, DAE block supervisor and the UP Chairman shall be an advisory member without voting power; WMA is composed of all the WMGs within a Thana. If the project spreads over a number of Thanas or districts, the WMAs may join together to form a Federation of WMAs (FWMA). The concerned UP Chairman will be the ex-office member of the Association and the BWDB's Sub-divisional Engineer shall act as an advisory member; Water Management Council will be formed at the Thana level, which covers the area of the water management projects within a particular Thana. In case the area of a water management project encompasses the jurisdiction of more than one Thana, the Water Management Council may be constituted at the district level with the participation of district level officers including bankers, concerned Local Government office holders, Non Government Organisations, representatives from different occupational groups (farmer, boatmen, fishermen, rickshaw-puller, landless destitute and women) and the users group.
LGED (Small Scale Water Resources Development Sector Project), 1999	One-Tier Water Management Co-operatives Associations (WMCA), which includes all stakeholders and the membership is non-homogeneous Executive Committee includes representatives from the WMCA members, and representatives from LGED, other GOB agencies, UP and Thana development committee

BWDB = Bangladesh Water Development Board; LGED = Local Government Engineering Department; WUG = Water Users Group; WUC = Water Users Committee; WUA = Water Users Association; FWUA = Federation of Water User's Association; WMC = Water Management Committee; WMG = Water Management Group; WMA = Water Management Association; FWMA = Federation of Water Management Association; WMBC = Water Management Block Committee; WMSC = Water Management System Committee; JWMC = Joint Water Management Committee; ChWMC = Chawk Water Management Committee; ScWMC = Sub- compartment Water Management Committee; DAE = Department of Agricultural Extension; GOB = Government of Bangladesh; UP = Union Parishad; O&M = Operation and Maintenance

Table B.3 Cost sharing activities of different water users organisations (after Quaseem, 2000)

Guideline title	Cost sharing of operation and maintenance by the beneficiaries
Local Government Engineering Department (Integrated Rural Works Program), 1986	There is provision for contribution of general members for operation and maintenance of projects
Local Government Engineering Department (Rural Development Program - 4), 1994	Cost of regular and preventative operation and maintenance are to be borne by the beneficiaries. The Agency will take care of major works such as re-excavation of khals
Guideline for Peoples Participation, 1994	Water User Groups will be fully responsible for operation and maintenance below turn out and tertiary level. They will share costs for operation and maintenance for primary and secondary level in the form of water rate or irrigation service fee
System Rehabilitation Project, 1998	Mention has been made of contribution by the stakeholders in cash and kind, or in the form of labour, but it has not been elaborated
Dr. Maloney, 1998	Stakeholders' contribution in cash, labour and local material for the annual and emergency maintenance and efficient operation of the water management system has been emphasised
Compartmentalisation Pilot Project, 1998	Nothing has been mentioned on this issue
Chowdhury, 1998	Need for stakeholders' contribution in cash, kind or in the form of labour has been mentioned but not detailed
Ministry of Water Resources, 1999	The idea of cost sharing is accepted but not stressed
Local Government Engineering Department (Small Scale Water Resources Development Sector Project), 1999	100% of the operation and maintenance costs are to be born by the beneficiaries except in the cases of natural calamities

APPENDIX C. Results of Soil Salinity Analysis in Samples from 0 - 0.10 m-surface for Different Places in Polder 43/2A

Sample number	Location, Village and Union	Salts in dS/m	Classification	Remarks
1	Nandipara, Choto Bighai	2.31	Very slightly saline	Safe
2	Nandipara, Choto Bighai	3.88	Very slightly saline	Safe
3	Bhajna, Choto Bighai	0.85	Non-saline	Safe
4	East Matibhanga, Choto Bighai	4.44	Slightly saline	Harmful
5	Hartokibaria, Choto Bighai	1.41	Non-saline	Safe
6	East Matibhanga, Choto Bighai	1.61	Non-saline	Safe
7	Matibhanga, Choto Bighai	2.45	Very slightly saline	Safe
8	Chaltabunia, Choto Bighai	0.88	Non-saline	Safe
9	South Bighai, Boro Bighai.	3.80	Very slightly saline	Safe
10	Patukhali, Boro Bighai	1.45	Non-saline	Safe
11	Patukhali, Boro Bighai	1.65	Non-saline	Safe
12	Titkata, Boro Bighai	1.29	Non-saline	Safe
13	Titkata, Boro Bighai	8.30	Moderately saline	Harmful
14	Keorabunia, Boro Bighai	1.30	Non-saline	Safe
15	Keorabunia, Boro Bighai	1.21	Non-saline	Safe
16	Keorabunia, Boro Bighai	1.30	Non-saline	Safe
17	Boro Bigha	0.72	Non-saline	Safe
18	Choto Bighai,	0.63	Non-saline	Safe

Analysis conducted by the Soil Resource Development Institute (Soil Samples were collected on 10 February, 1999)

APPENDIX D. Summarized Information about the DUFLOW Package

General Information

DUFLOW is a micro-computer package for the simulation of one-dimensional unsteady flow in channel systems. It was developed by the International Institute for Infrastructure, Hydraulic and Environmental Engineering (IHE, Delft), The Rijkswaterstaat (Public Works Department), Tidal Water Division, The Hague and Delft University of Technology, Faculty of Civil Engineering.

The mathematical characteristics are:
- Saint-Venant equations for unsteady non-uniform one layer flow;
- mass transport equation for water quality modelling;
- water quality modelling, the process description (function) can be supplied by the user in relation to his or her problem;
- implicit four-point Preissmann finite difference scheme;
- Gauss elimination or conjugate gradient method (optional) for solving the set of equations.

The physical characteristics are:
- one-dimensional, one layer, unsteady flow;
- branched systems with variable cross-sections;
- control structures, like weirs, culverts, siphons and pumps;
- structure operation functions can be defined with an individual specification;
- rainfall run-off relations for lateral flow;
- operation of structures related to hydraulic conditions;
- wind stress and storage;
- boundary conditions to be specified as levels, discharges or rating curves, constant or as time series.

The input - output characteristics are:
- fully menu driven and interactive;
- numerical and graphical output in time and space;
- file access with standard editors (ASCII);
- various options for presentation.

The DUFLOW package can be applied in the following cases:
- tidal and flood waves;
- irrigation and drainage schemes;
- oscillations in harbours and lagoons.

Before applying the DUFLOW package, one should realise the limitations of the software, i.e.:
- maximum number of sections;
- maximum number of boundary conditions;
- maximum number of output steps.

The numerical solution method does not support super critical flow, except inside some structures. In this version a total capacity is limited, it means there is no fixed limitation for each input e.g. number of nodes and sections or number of boundary conditions. The user should arrange his/her schematization in such a way that all the requirements are accommodated in a balanced way.

Basic Equations and Linerization

This mass equation (presented in Chapter 9) states that if the water level changes at some location this will be the net result of local inflow minus outflow. The momentum equation (presented in Chapter 9) expresses that the net change of momentum is the result of interior and exterior forces like friction, wind and gravity.

For the derivation of these equations it has been assumed that the fluid is well-mixed and hence the density is considered constant.

The advection term in the momentum equation:

$$\frac{\partial(\alpha Q v)}{\partial x}$$

where:

v	=	mean velocity
α	=	coriolis coefficient

Can be broken into:

$$\alpha\left(2\frac{Q}{A}\frac{\partial Q}{\partial x}-\frac{Q^2}{A^2}\frac{\partial A}{\partial x}\right)$$

where:

Q	=	discharge
A	=	cross-sectional flow area

The first term represents the impact of the spatial change in discharge. The second term that expresses the effect of spatial change in cross-sectional area is called the Froude term. In case of abrupt changes in cross-section this Froude term may lead to computational instabilities.

Discretization of the Unsteady Flow Equation

The basic equations are discretized in space and time using the four-point implicit Preissmann scheme.

Defining a section Δx_i from node x_i to node x_{i+1} and a time interval Δt from time $t = t^n$ to time $t = t^{n+1}$, then discretization of the water level H can be expressed as:

$$H_i^{\,n+\theta} = (1-\theta)\, H_i^{\,n} + \theta\, H_i^{\,n+1}$$

At node, x_i and time $t + \theta\Delta t$

and

$$H_{i+1/2}^{n} = \frac{H_{i+1}^{n} + H_{i}^{n}}{2}$$

in between nodes x_i and x_{i+1} at time t. In a similar way other dependent variables can be approached.

The transformed partial differential equations can be written as a system of algebraic equations by replacing the derivatives by finite difference expressions. These expressions approximate the derivatives at the point of references ($x_{i+1/2}$, $t^{n+\theta}$) as shown in Figure D.1

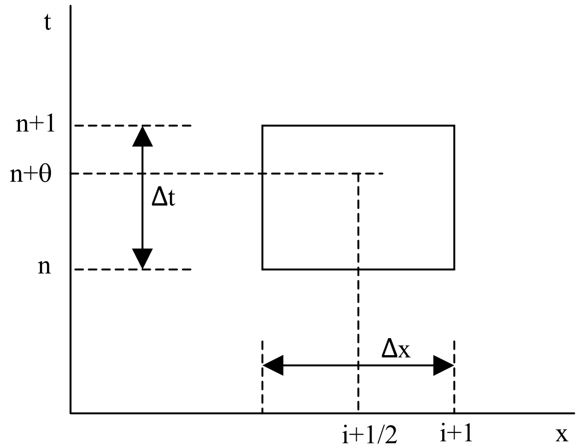


Figure D.1 Numerical schemes used in DUFLOW

Mass equation is discretized into:

$$B_{i+1/2}^{*}.\frac{H_{i+1/2}^{n+1} - H_{i+1/2}^{n}}{\Delta t} + \frac{Q_{i+1}^{n+\theta} - Q_{i}^{n+\theta}}{\Delta x_i} = 0$$

and momentum equation into:

$$\frac{Q_{i+1/2}^{n+1} - Q_{i+1/2}^{n}}{\Delta t} + gA_{i+1/2}^{*}\frac{\left(H_{i+1}^{n+\theta} - H_{i}^{n+\theta}\right)}{\Delta x_i} + \alpha\frac{\left(\frac{Q_{i+1}^{n}}{A^{*}_{i+1}}Q_{i+1}^{n+1} - \frac{Q_{i}^{n}}{A_{i}^{*}}Q_{i}^{n+1}\right)}{\Delta x_i} + g\frac{\left(Q_{i+1/2}^{n+1}\left|Q_{i+1/2}^{n}\right|\right)}{\left(C^{2}AR\right)_{i+1/2}^{*}}$$

$$= b^{n}\gamma(w_{i+1/2}^{n+1})\cos(\Phi^{n+1} - \phi)$$

The symbol (*) (like in $B^{*\,i+1/2}$) expresses that these values are approximated at time $t^{n+\theta}$.

This discretization is of second order in time and place if the value θ = 0.5 and it can be shown that in this case the discretized system is mass-conservative. In most applications, a somewhat larger θ-value, such as 0.55 is used in order to obtain a better stability (Roache, 1972).

The values indicated with (*) are computed using an iterative process. For example, a first approximate of B is

$B^{*} = B^{n}$

which is adjusted in subsequent iteration steps:

$$B^{*} = \frac{\left(B^{n} + B^{n+1,*}\right)}{2}$$

where B^{n+1*} is the new computed value of B^{n+1*}.

So finally, for all channel sections in the network to equations are formed which have Q and H as unknowns on the new time level $t^{n+1.}$.

$$Q_{i}^{n+1} = N_{11}H_{i}^{n+1} + N_{12}H_{i+1}^{n+1} + N_{13}$$

$$Q_{i+1}^{n+1} = N_{21}H_{i}^{n+1} + N_{22}H_{i+1}^{n+1} + N_{23}$$

Boundary and Initial Conditions

For a unique solution of the set of equations additional conditions have to be specified at the physical boundaries of the network and at the sections defined as hydraulic structures.

The user-defined conditions at the physical boundaries may be specified as levels, discharges or a relation between both. For instance a (tidal) elevation H, a discharge Q or a so-called Q-H relation.

At internal junctions the (implicit) condition states that the water level is continuous over such a junction node, and that the flows towards the junction are in balance since continuity is requires.

$$\sum_{j=1}^{jj} Q_{j,i} + q_{i} = 0$$

where:

i	=	indication for the junction node
$Q_{j,i}$	=	discharge from node j to node i
q_i	=	additional or lateral flow to node i

The above equations are solved at each time step.

Hydraulic Structures

An hydraulic structure is defined between two nodes. Various types of control structures can be defined such as weirs, flap gates, culverts, syphons and pumping station, which cover most of the control structures in real life systems.

Weirs

The discharge over a weir depends on the upstream and downstream water levels, the sill level and the flow condition (free or submerged flow). The general equation for the flow over a weir is:

$$Q = \mu * B * H\sqrt{2g\Delta H}$$

where:

Q	=	flow discharge through the weir (m^3/s);
μ	=	the discharge coefficient (-);
B	=	width of the weir (m);
H	=	depth above the sill (m);
ΔH	=	head difference between upstream and downstream of the weir (m).

The discharge equation is linearized and generalized as follows:

$$Q^{n+1} = N_1 * H_i^{n+1} + N_2 * H_j^{n+1} + N_3$$

Culverts

By considering the friction losses in a culvert based on the Chezy formula the flow equation for a culvert can be written as follows:

$$Q = A * C\sqrt{\frac{R * \Delta H}{L}}$$

where:

ΔH	=	friction losses (m);
L	=	length of the culvert (m);
A	=	cross-sectional area of the culvert (m^2);
R	=	hydraulic radius of the culvert (m).

This formula is linearized as follows:

$$Q^{n+1} = \frac{A^2 * C^2 * R * \Delta H}{L * \left|Q^n\right|} = F * \Delta H$$

Serial coupling means that a dummy node I is inserted between the nodes i and j.

$$Q^{n+1} = F * (H_i^{n+1} - H_I^{n+1})$$

This equation can be generalized in a similar way as the weir equation.

Solving Procedure for the Set of Linear Equations

Each branch and node in the network has a unique identification number, assigned by the user. The number of unknowns is in principle equal to 2*j+i, where j is the number of branches and i is the number of nodes. In each branch the unknowns are the discharge at the begin and at the end. At each node the water level is the unknown.

Appendix E. Summarized Information about the GIS Model and Errors

Main Features of a GIS

The GIS in fact is a computer-based system comparable to a variety of other expert system where a great number of data are stored in the central core of the model and which is used to make judgements based on digital image processing. GIS may comprise a spatial database describing the geography (shape and position) of earthen surface features and an attribute database describing the characteristics or qualities of these features. An analysis of the spatial distribution of all the features and phenomena which can be genetically related through a qualitative or quantitative model can lead to assessing the strength of a spatial pattern. Sometimes it is possible to predict the location of more of such features. It means that with a GIS the users should think about patterns, about space and the processes that act in space. These spatial and attribute databases are the core of a GIS which could be conceived as consisting of those components presented in Figure E.1.

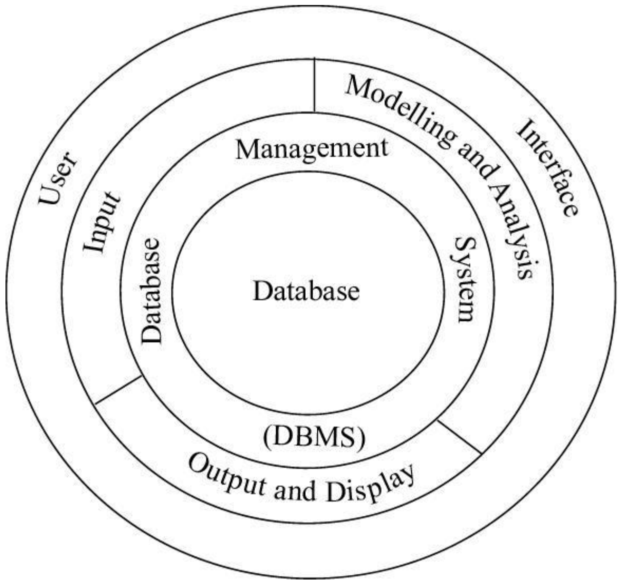


Figure E.1 The components of a GIS (after Mc Cloy, 1995)

With this spatial distribution character of a GIS, the identification of the areas that have a significant development potential, their limitations or constraints can be evaluated properly in a short time. For the land suitability zoning the basic information is:
- hydro-topographical map of the area;
- water levels due to the water management strategy;
- tidal characteristics (flushing and drainage);
- salinity intrusion.

For this several new image maps were created among others:
- tidal lowland classification which is based on the hydro-topographical conditions;
- land suitability which is based on soil, agriculture and preferred water levels;
- water management schemes which are based on hydro-topography, drainability, soil type, land suitability, flushing and salinity control.

Before presenting the modelling with GIS for the land suitability zoning based on the water management strategy concept, three main features of a GIS will be described i.e., spatial data bases, spatial modelling and the precision and accuracy of the systems. In addition, error propagation will be discussed briefly.

Spatial Data Base

Space is defined as a relationship between objects. It is a concept within which one can organize and locate objects. A spatial database is a collection of spatially referenced data that acts as a model of reality (Valenzuela, 1991). Spatial or geographic data have a set of characteristics that make them different from data used in the information systems which are developed for other sciences e.g. medical and business. Spatial data have three major components i.e:

- geographic position;
- attributes or properties;
- related time.

These three major components can be defined in other words: where and what it is and when did it exist.

Spatial Modelling

When GIS operations are used in a correct and systematic sequence, they perform a type of computational model. For example, to model land suitability zoning based on a water management strategy for a tidal lowland several variables will have to be taken into account in a systematic way. This type of activity can be defined as spatial modelling with GIS. In this spatial modelling there are three different classes of models, i.e, logical, empirical and conceptual (Heuvelink, 1993). A logical model simulates a new attribute by applying simple logical 'rules'. In this case for example modelling hydro-topographical conditions of an area is based on a logical relationship between the elevation map and the water level maps. Empirical models are based on an empirical understanding of the links between model input and model output. Regression and correlation techniques are often used to set up the relationship between several parameters.

Precision and Accuracy

All instruments used in a GIS, such as a digitizer or a plotter, can only be used with a certain level of precision. Precision is determined by the smallest unit of measurement to which data can be recorded. Making measurements with a high degree of precision does not mean that the results are necessarily correct. Precision is not the same as accuracy. Accuracy is a statistical concept which states the likelihood or probability that a particular set of data is within a certain range of the true value (Weir, 1991).

Errors in Geographic Information Systems

GIS provides a powerful set of tools for capturing, manipulating and modelling map information held in digital form. GIS is above all, an integrating technology that allows, encourages and expects users to bring together data form many different sources through the unifying medium of geography. The typical application of GIS is in a kind of spatial modelling which can be described simply as combining information from several different images to produce a single output image, for example in this study, a land suitability assessment.

An error in GIS can be defined as difference between reality and the representation of reality (Heuvelink, 1993). It includes not only mistakes or faults but also the statistical concept of variation. Errors can arise at any stage of using a GIS, from the collection of the original data to the output and use of the resulting information. Basically errors can be classified as follows (Weir, 1991):
- errors in the source data;
- errors occurring during data input;
- errors in data storage;
- errors in data analysis and manipulation;
- errors in data output and application.

Error Propagation
As soon as maps that are stored in a GIS are used as input to a GIS operation (modelling), the errors in the input maps may propagate to the output of the operation. Conclusions which are based on this output may be unreliable. To reduce the influence of these possible errors and their consequences, in the application of a GIS appropriate steps should be taken to keep those errors within an acceptable range. So far, in general there is no accepted theory to handle error and error propagation in GIS (Lanter and Veregin, 1992).

To eliminate possible errors, the following measures can be considered:
- improvement of the method of data collection;
- use of a proper resolution during the processing with GIS;
- use of a proper model for each particular problem;
- calibration and verification of the models.

Data Structures and Integrated Analysis Functions in a GIS

In a GIS there are two types of spatial data representations which are commonly used i.e.:
- *vector model*
  A vector is defined as a quantity with a starting coordinate and an associated displacement and direction. It consists of representations of objects by means of points, lines and polygons (formed by points and lines) in 2-D or 3-D, organized in chains or in sequences to form a data structure with explicit coordinates and pointers that connect objects in a hierarchic way. The spatial relationship of the points, lines and polygons, one to another is called topology (Lyon et al., 1995). Vector models have the line as the basic logical unit in a geographical context (Meijerink et al., 1994). A series of xy location pointers along the line are recorded as the components of a single data record. Points are recorded as line of zero length, polygons constitute lines with common beginning and ending points. The objects are precisely specified. The hierarchy must be known and has to be used to locate objects in a vector database;
- *raster model*
  As the basic data unit, raster models have a unit of space for which entity information is explicitly recorded. They consist of a rectangular array of picture elements or pixels which are in one-to-one correspondence with small rectangular areas on the original picture material that they represent. These pixels are the basic units at which information is explicitly recorded. Spatial data are organized in pixels and each pixel is only assigned one value. The size of a pixel is not

necessarily the same as the minimum mapping unit, a minimum mapping unit is formed by one or more pixels.

The representation of data in vector and raster models is presented in Figure E.2.

Attribute Data Management
In image representation one is concerned with characterization of the quantity that each pixel represents (Jain, 1989). Attribute data for raster images, Update and Reclass modules are the primary tools to be used for editing attribute values. In the systems there should also be a possibility to convert from one system to another.

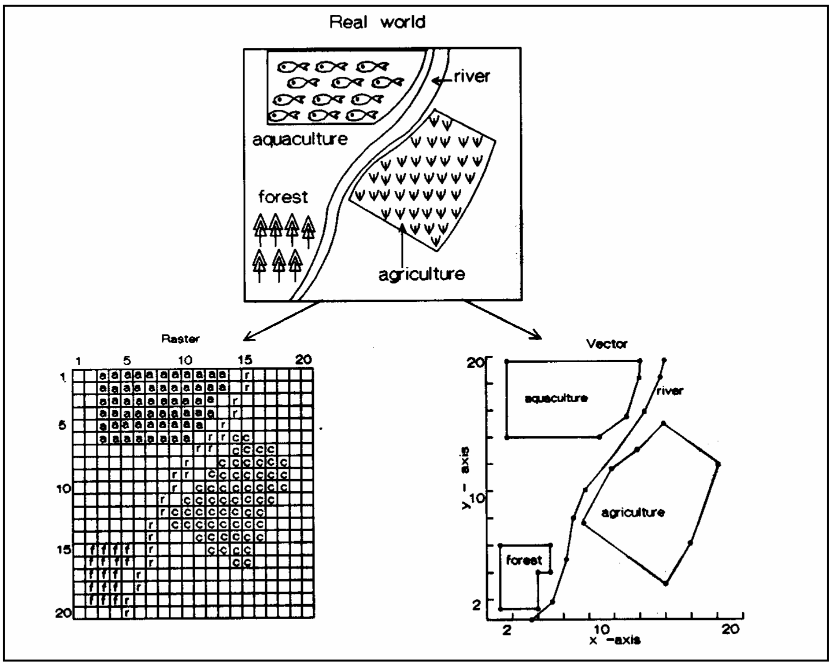


Figure E.2 Representation of data in vector and raster models (after Aronoff, 1989).

Map Algebra
Map algebra refers to the use of image files as variables in normal arithmetic operations. This is also an advantage of a GIS where full algebraic operations on a set of images are possible. In this case the main modules are:

- *Overlay*
  Overlaying of maps will result in the creation of new spatial entities, which undertake mathematical operations between two image files. The values assigned to a certain location are computed as a function in one or more of the existing maps. By overlaying, a new data set containing new areas is formed. Three types of overlay operations are available i.e., arithmetical, logical and conditional;
- *Scalar*
  scalar can be used to mathematically change every pixel in an image file by a constant (for example to change form feet to meters);
- Reclassification and transformation
  Used to reassignment and modify thematic values of every pixel in an existing image (for example to take the inverse for the whole image or to transform all pixel values into logarithmic values). The process involves looking at the attribute for a single data layer and assigning an additional attribute. Typical examples of

reclassification and transformation are classifying an elevation map with a certain interval (for example every 1 meter) and reclassifying a soil map;

- *cross-table calculation*
  which performs 'condition-implied action', in case combination plays an important role, this module will often be used in a modelling with GIS.

For these operations, both the usual Boolean operator which is based on the Boolean logical operator And and Or as well as a 'Fuzzy' set can be applied. In a Boolean image, there is only yes or no (zero or one) information (areas fulfilling a set of criteria) (Eastman 1997).

Spatial Interpolation
In a classical way it is clear how the contours on a topographical map can be constructed by following lines of equal height. The pattern can be seen and can be verified and corrected based on the real situation. But in case of point observations like soil type, salinity, and land subsidence, the actual pattern of variation can not be seen but can only be sampled at a set of points. To study the spatial patterns and to enable spatial combinations of various types of data, they have to be combined and converted within an image database. An interpolation procedure should be used. The value of a property between data points can be interpolated by fitting a plausible model of variation to the values at the data points and then calculate the value at the desired location (Burrough, 1986). The principle of interpolation is presented in Figure E.3. For example there are five data points with known x and y coordinates and the magnitude of the variable z at the related locations.

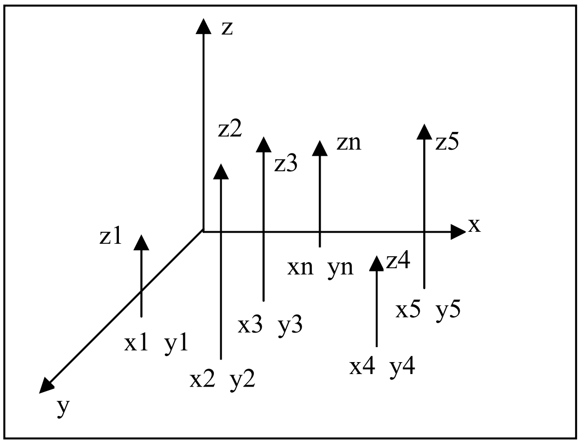


Figure E.3 The spatial interpolation based on known surrounding points

The general form of the equation for interpolation at a particular point is as follows:

$$z_n = \sum_{i=1}^{n} w_i z_i$$

where:

z_n	=	estimated value of the interpolation at any point with coordinates x_0, y_0
w_i	=	weight of the sampling point *i*
z_i	=	observed value of the attribute at point *i*, with coordinates x_1, y_1
n	=	number of considering points, *i* = 1 2,3,......n

To determine the weighting factor w, various techniques can be used. In this study, interpolation uses the principle that the known values in the locality, surrounding or neighbourhood are of more relevance than those further away and weights will be given to the surrounding points (e.g. four surrounding points).

APPENDIX F. Land Suitability Maps for Present and Potential Conditions under the Proposed Water Management Strategy

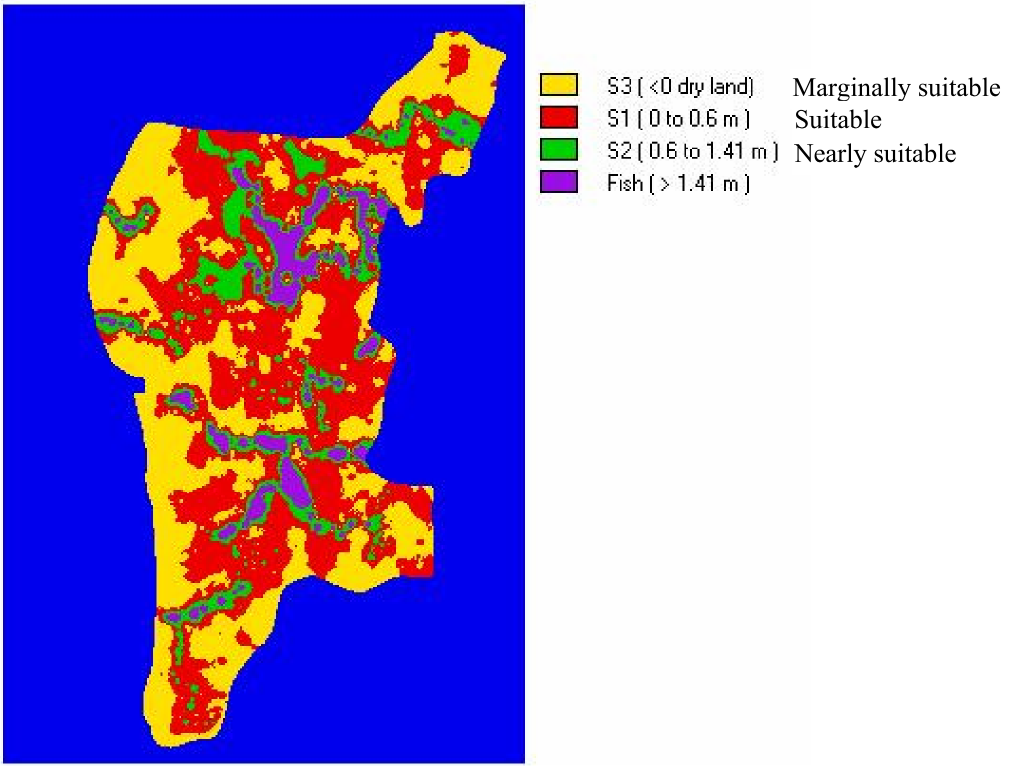


Figure F.1 Irrigation land suitability at present

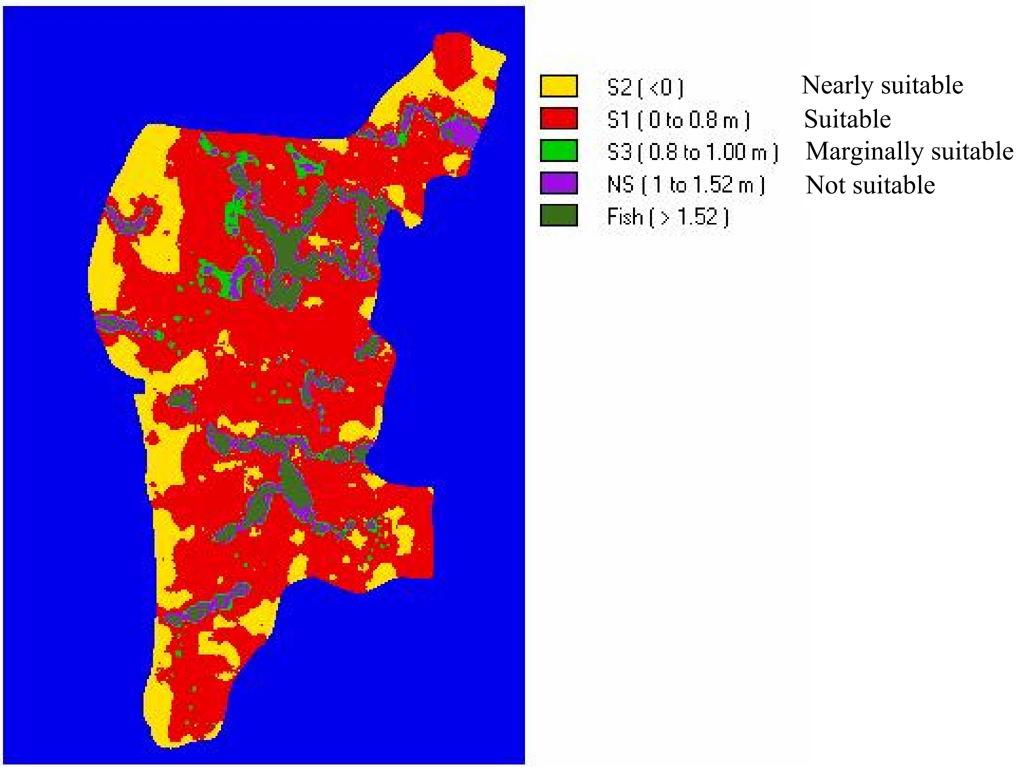


Figure F.2 Drainage land suitability at present

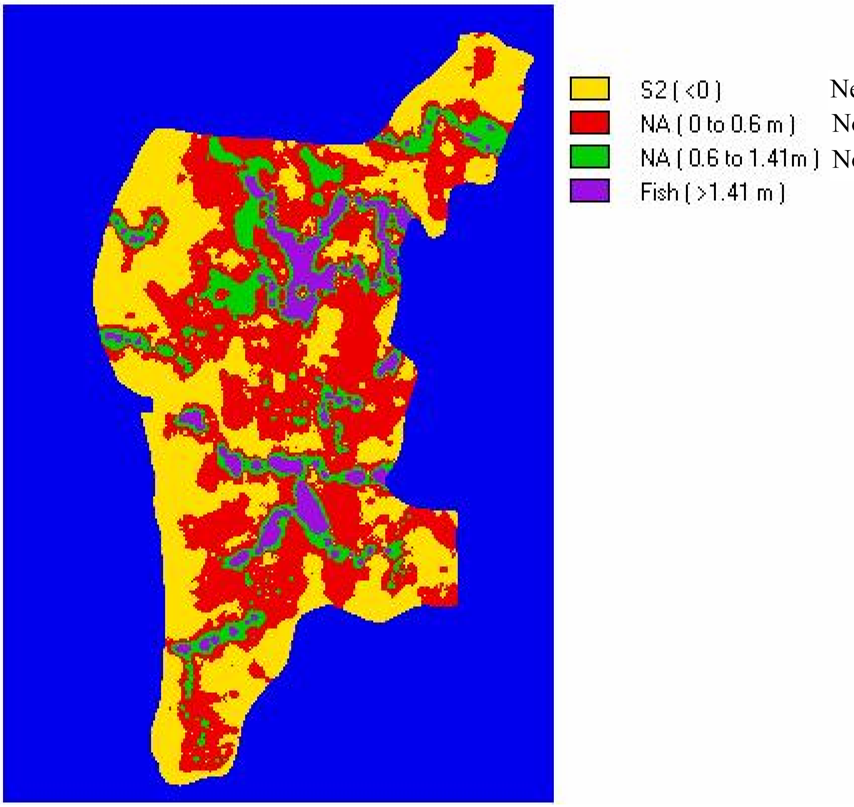


Figure F.3 Rainfed land suitability at present

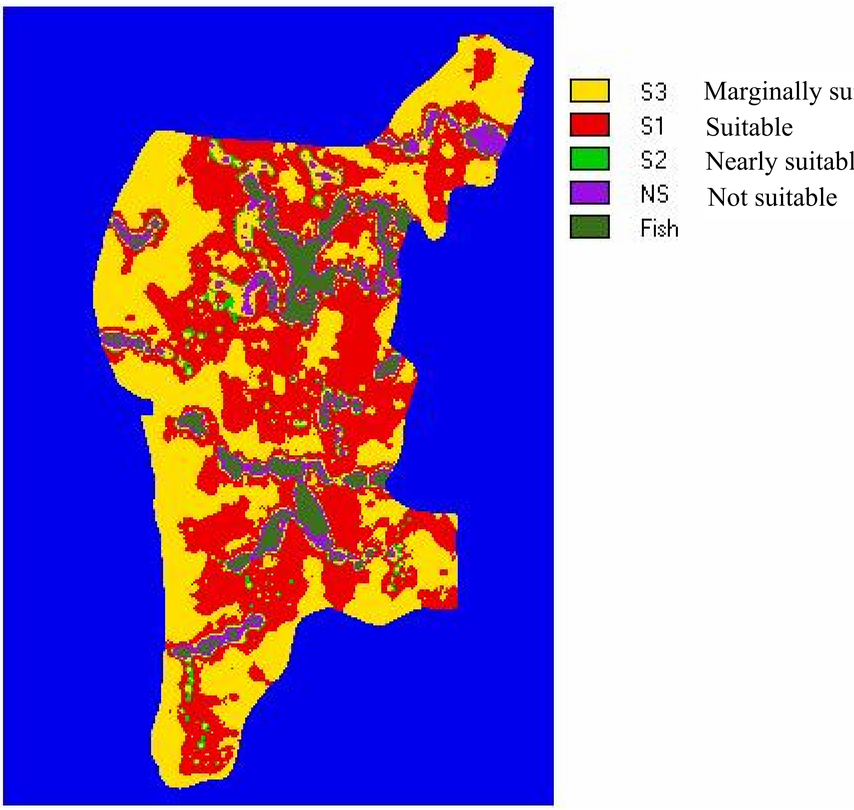


Figure F.4 Present land suitability with out rainfed situation

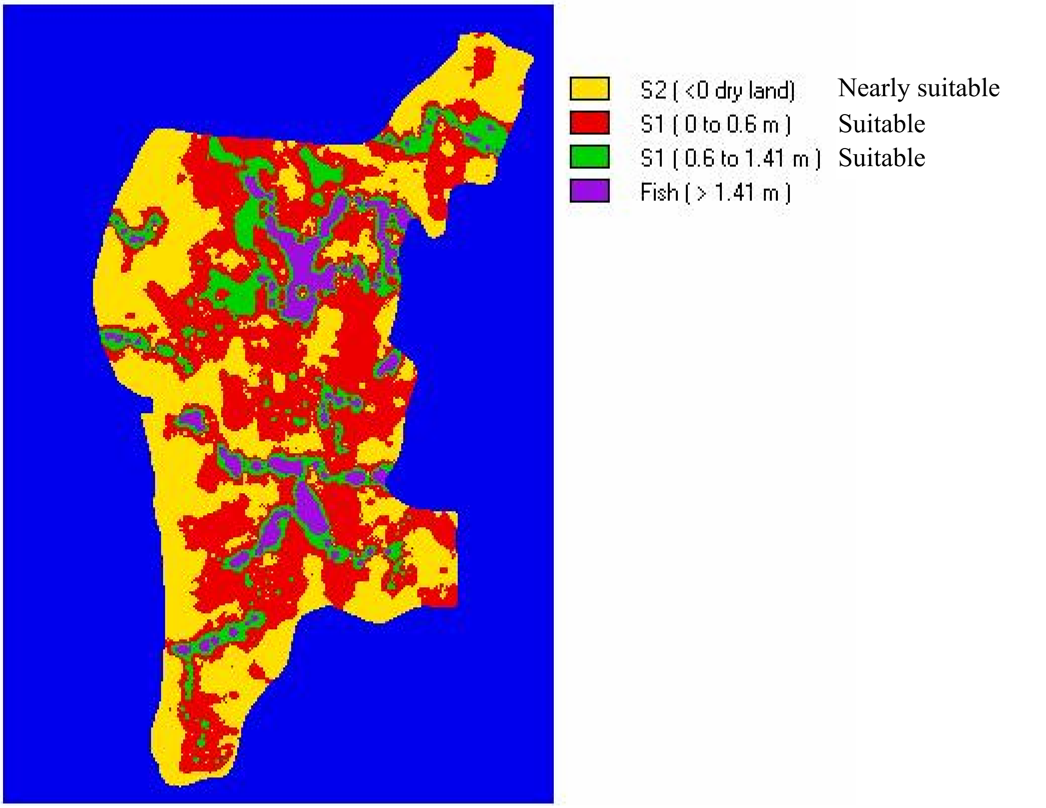


Figure F.5 Potential irrigation land suitability

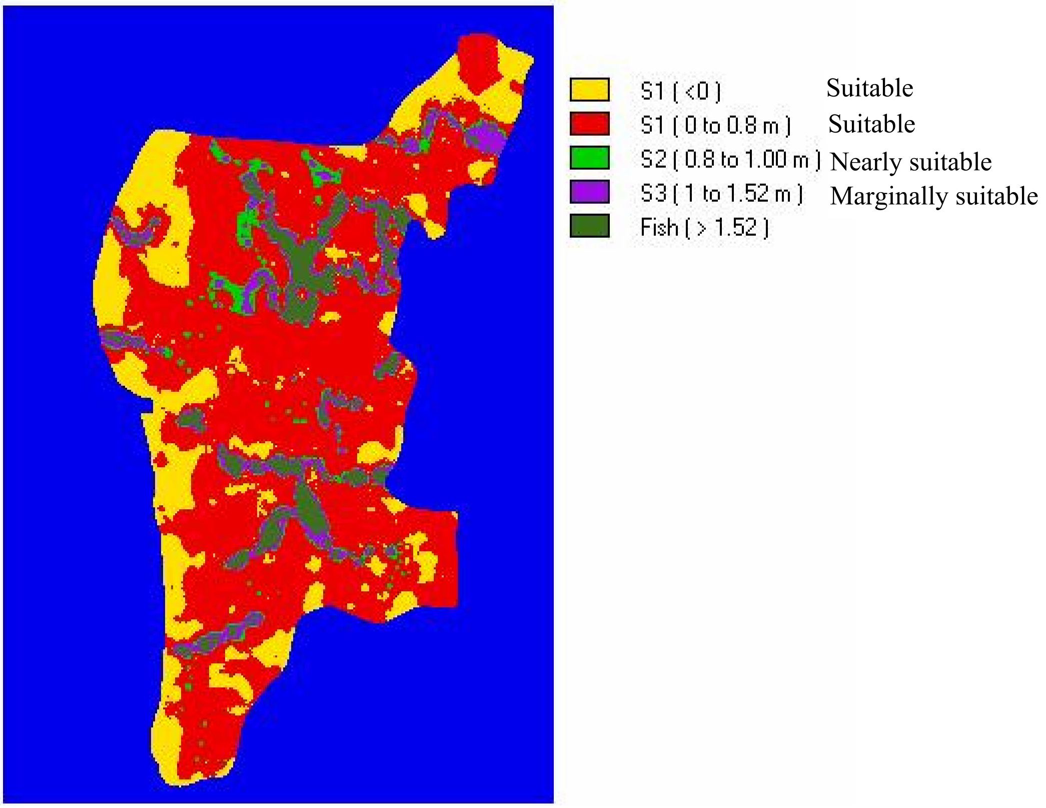


Figure F.6 Potential drainage land suitability

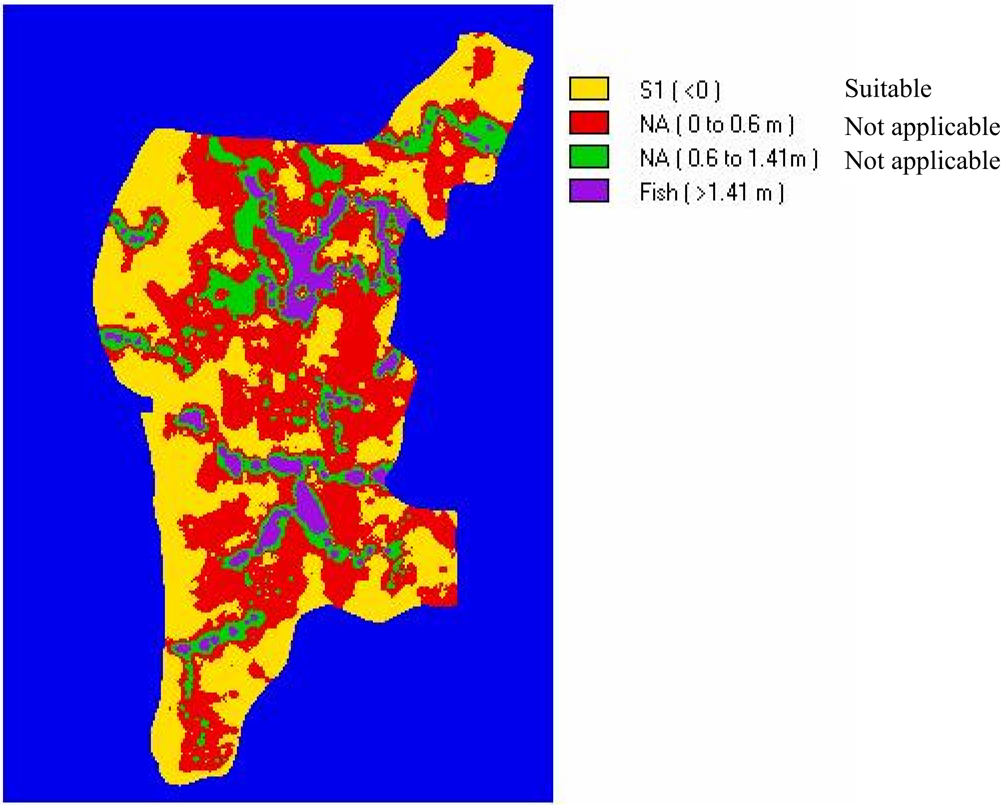


Figure F.7 Potential rainfed land suitability

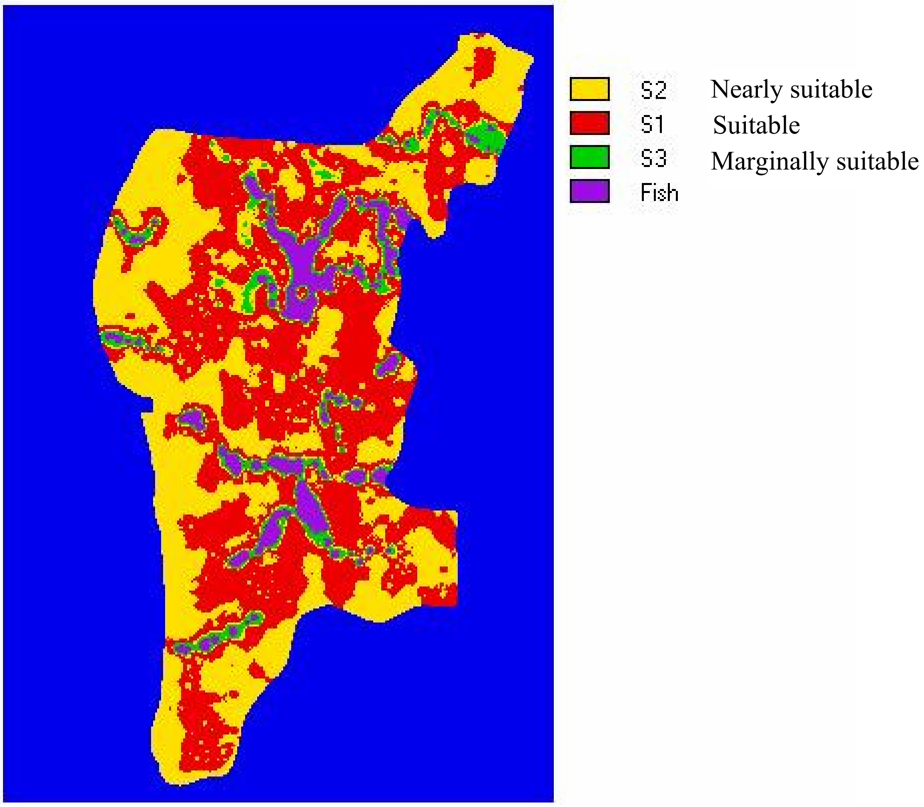


Figure F.8 Potential land suitability with out rainfed situation

APPENDIX G. Abbreviations and Acronyms

ADB	Asian Development Bank
B. Aman	Broadcasted Aman
B. Aus	Broadcated Aus
BADC	Bangladesh Agricultural Development Corporation
BPDB	Bangladesh Power Development Board
BWDB	Bangladesh Water Development Board
C/S	Country Side
CPP	Compartmentalisation Pilot Project
DAE	Department of Agricultural Extension
DDP	Delta Development Project
DEM	Digital Elevation Model
DO	Dissolved Oxygen
DOF	Department of Fisheries
DS	Drainage Sluice
DTW	Deep Tube Well
EIA	Environmental Impact Assessment
EIP	Early Implementation Project
EPADC	East Pakistan Agricultural Development Corporation
EPWAPDA	East Pakistan Water and Power Development Authority
ESCAP	Economic and Social Commission for Asia and the Pacific
FAP	Flood Action Plan
FCD	Flood Control and Drainage
FCDI	Flood Control Drainage and Irrigation
FFW	Food for Works
FPCO	Flood Plan Coordination Organisation
GAS	Geographic Analysis System
GDP	Gross Domestic Product
GIS	Geographical Information System
GoB	Government of Bangladesh
GoN	Government of The Netherlands
HH	House Hold
HWL	Highest Water Level
HYV	High Yielding Variety
ICID	International Commission on Irrigation and Drainage
IEC	Important Environmental Components
IECO	International Engineering Company Inc.
IPSWAM	Integrated Planning for Sustainable Water Management
IUCN	The World Conservation Union
JICA	Japan International Cooperation Agency
LGED	Local Government Engineering Department
LLP	Low Lift Pump
LRP	Land Reclamation Project
LV	Local Variety
LWL	Lowest Water Level
MLGRDC	Ministry of Local Government, Rural Development and Cooperatives
MoWR	Ministry of Water Resources
MPO	Master Plan Organization
MSL	Mean Sea Level

NGO	Non Government Organisation
NMWP	National Water Management Plan
O&M	Operation and Maintenance
PWD	Public Works Department
R/S	River Side
SDS	Surface Drainage Sluice
SIA	Social Impact Assessment
SRP	System Rehabilitation Project
STW	Shallow Tube Well
T. Aman	Transplanted Aman
T. Aus	Transplanted Aus
Tk	Currency of Bangladesh (58 Tk = 1 US $)
UN	United Nations
UNDP	United Nations Development Programme
UP	Union Parishad
WARPO	Water Resources Planning Organisation
WMA	Water Management Association
WMG	Water Management Group
WRM	Water Resources Management
WSIP	Water Sector Improvement Project
WUA	Water Users Association

APPENDIX H. Glossary of Terms

Aman	Wet season rice crop
Aus	Rice varieties grown during pre-wet season
Beel	Floodplain lake that may hold water perennially or dry up during the dry season
Boro	Dry season rice crop
Bund	Earthen dam, closure
Dighi	Water body larger than pond
Gram	Village
Hat	Big market
Hoar	Depression of floodplain located between two or more rivers, which is look like a saucer
Jele	Professional fisherman
Khal	Canal
Khas	Government unutilized land
Madrasa	Schools with emphasis on Islamic religious curriculum
Mahajan	Traditional money lenders
Matbar	Village leader
Mauza	Smallest revenue village
Panchayet	Group of village leaders
Sadar thana	The thana that has its headquarter at the district headquarter
Thana	Administrative units above union and below the district
Union	Local level administrative unit comprising of few villages
Upazila	Sub-district
Zamindars	Local level rulers

APPENDIX I. List of Symbols

Symbol	Definition	Unit
A (x, H)	Cross-sectional flow area	m^2
b (x, H)	Cross-sectional flow width	m
B (x, H)	Cross-sectional storage width	m
C (x, H)	Coefficient of Chezy	$m^{1/2}/s$
C	Run off factor	
C (x, t)	Concentration of solute material	mg/l
D (x, t)	Dispersion coefficient	m^2/s
E_c	Electric conductivity	mmhos/cm
E	Penman evaporation from a free surface	mm/day
g	Acceleration due to gravity	m/s^2
ΔH	Head difference between upstream and downstream of a weir	m
H (x, t)	Water level with respect to the reference level	m
L	Total length of the chosen section	m
m	Side slope of the canal cross-section	
n	Manning roughness coefficient	
q_{add}	Additional inflow to the node	mm/day
Q (x, t)	Discharge at location x and at time t (v * A)	m^3/s
R	Rainfall	mm/day
A	Catchment area	ha
R (x, H)	Hydraulic radius of cross-section	m
t	Time	s
v (x, t)	Mean velocity (average over the cross-section area)	m/s
w (t)	Wind velocity	m/s
x	Distance as measured along the channel axis	m
Δx	Grid size in x direction	m
Δy	Grid size in y direction	m
z	Vertical co-ordinates, positive upwards	m
ϕ (x)	Direction of channel axis, measured clockwise from the North	°
Φ (t)	Wind direction	°
γ (x)	Wind conversion coefficient	
α	Coriolis coefficient, correction factor for non-uniformity of the velocity distribution in the advection term, defined as: $\alpha = \frac{A}{Q^2} * \int_0 v(y,z)^2\, dydz$ where the integral is taken over the cross-section A	
θ	Weighting factor	
Δ	Small increment	
μ	Discharge coefficient	

SAMENVATTING

Algemeen

Bangladesh is een land met weinig natuurlijke hulpbronnen. Het aantal inwoners is op dit moment 130 miljoen. De oppervlakte beslaat 147,570 km^2. De bevolkingsdichtheid is met 849 mensen per km^2 nu reeds groter dan in enig ander land met uitzondering van de kleine stadstaten. Het land is in feite een delta, gevormd door de alluviale afzettingen van de grote rivieren: de Ganges, de Brahmaputra en de Meghna. Het heeft een complex netwerk van ongeveer 230 rivieren die ongeveer 6% van het landoppervlak beslaan. Een belangrijk kenmerk van de rivieren is dat 57 ervan uit de buurlanden India en Myanmar komen. Deze rivierensystemen draineren een stroomgebied van ongeveer 1.72 miljoen km^2, waarvan slechts 7% in Bangladesh ligt. De overige 93% van het stroomgebied is gelegen in China, India, Nepal, Bhutan en Myanmar. Bangladesh lijdt al eeuwen onder het dubbele probleem van ‘overstroming en droogte’.

Aanvankelijk maakten de Zamindars lage dijken en houten koker sluizen en onderhielden deze als bescherming tegen binnendringen van zout water en overstromingen. Onofficieel zijn de Zamindars doorgegaan met dit onderhoud zelfs nadat ze van die plicht ontheven werden toen de Britse overheerser het Zamindar systeem afschafte. Zonder de initiatieven van de Zamindars begonnen de lokale boeren in vele gevallen zelf dijken te maken die technisch gezien slecht en ontoereikend waren. Nadat de regering dit werk overgenomen had werd er meer aandacht besteed aan het maken van polders. Bij gebrek aan technische kennis en door financiële beperkingen stagneerde de inpoldering. Inpoldering heeft de productie doen toenemen en hoop op verdere ontwikkelingen gebracht.

De grootschalige landaanwinnings- en waterbeheersingsprojecten zijn in de vijftiger jaren begonnen. In die tijd, na verscheidene jaren van studie, stelde een team van experts van de Verenigde Naties het Ganges-Kobadak Project voor, dat in de districten Kushtia, Jessore en Kulna ligt. Nadat het land in 1954 en 1955 onder ongekende overstromingen had geleden stelde de regering een overstromingscommissie in om de problemen te analyseren en om te adviseren betreffende te nemen maatregelen. In 1956 verkreeg men vervolgens hulp van een Technische Assistentie Missie van de Verenigde Naties, een team van experts in waterbeheer, bekend als de Krug Missie. Na een gedetailleerde analyse van de enorme problemen die de overstromingen met zich meebrachten diende dit team in 1957 het Krug Missie Rapport in. In 1959 werd, gebaseerd op de aanbevelingen van de Krug Missie, de ‘East Pakistan Water and Power Development Authority (EPWARDA)’ opgericht voor een uniforme en gecoördineerde ontwikkeling van water- en energie voorraden in het huidige Bangladesh. In 1964 heeft deze Dienst met de hulp van de ‘International Engineering Company Inc. (IECO)’ een Masterplan voor de ontwikkeling van de watervoorraden opgesteld. In dit plan wordt een begin geschetst van een formulering van een geïntegreerd plan voor hoogwaterbeheersing en de ontwikkeling van de watervoorraden van het land. In het Masterplan staan de beperkt beschikbare hydrologische gegevens en de aanbevolen acties richtten zich op systematische en wetenschappelijke hydrologische gegevensverzameling en verwerking.

Het Masterplan behelsde een portefeuille met 58 landaanwinning- en waterbeheersingsprojecten, inclusief 3 stuwdammen in de belangrijke rivieren, verdeeld over 20 jaar uit te voeren, te beginnen in 1965. Deze projecten voorzagen in hoogwaterkeringen voor 5.8 miljoen ha land. Niet alle geïdentificeerde projecten zijn door gebrek aan geld ten uitvoer gebracht. Het voornemen was om in de gebieden met een hoogwaterkering irrigatiesystemen aan te leggen, maar de nadruk werd gelegd op hoogwaterbeheersing door een systeem van dijken en polders, daar in die tijd bescherming tegen hoogwater door grootschalige waterbeheersingsprojecten werd gezien als de oplossing voor het vergroten van de landbouwproductie. Drie alternatieve opties werden voorgesteld:

- bedijkingen met drainage door zwaartekracht;
- bedijkingen met drainage door uitwateringssluizen;
- bedijkingen met bemaling.

In het begin van de zestiger jaren werd het ‘Coastal Embankment Project’ ontworpen en opgezet door de ‘East Pakistan Water and Power Development Authority’. In 1967 werd vervolgens voorgesteld dat het ‘Coastal Embankment Project’ in twee fasen opgesplitst zou worden en dat de eerste fase uitgevoerd zou worden als onderdeel van het ‘Grow More Food Programme’. In april 1968 werd de eerste fase goedgekeurd. Deze fase bestond uit 92 polders met ongeveer 4,022 km bedijking en 780 sluizen. Het bruto polderoppervlak dat beschermd moest worden in fase I werd op iets meer dan 1 miljoen ha geschat. In juni 1971 was fase I klaar. Polders tijdens fase II werden geclassificeerd als opgeschort in het herziene programma en in de project evaluatie. Fase II omvatte drie categorieën gebieden:

- relatief zoete gebieden;
- eilanden in zee,die ongeschikt waren door erosie en sedimentafzetting;
- gedeeltelijk drooggelegde en niet drooggelegde gebieden als gevolg van de bouw van de Meghna Cross-dam.

Na de onafhankelijkheid van Bangladesh in december 1971 werd de ‘East Pakistan Water and Power Development Authority’ opgedeeld in twee afzonderlijke Diensten. Dit leidde tot de oprichting van de ‘Bangladesh Water Development Board (BWDB)’ en de ‘Bangladesh Power Development Board (BPDB)’. Dit deed men met het oog op uitgebreide water- en energie ontwikkelingsprogramma’s en om de uitvoering van projecten te versnellen.

De ‘Land and Water Resources Sector Study’ in 1972 van de Wereldbank leidde tot het laten vallen van de nadruk op grootschalige werken voor hoogwaterbeheersing. In plaats daarvan pleitte men voor de ontwikkeling van kleinschalige irrigatie met pompjes en diepe putten, in zekere mate ondersteund door aanvullende goedkope hoogwaterbeheersing en afwatering projecten (Flood Control and Drainage [FCD]).

In 1974 vond in Bangladesh een grote watersnoodramp plaats. Bij het opmaken van de schade die deze overstroming had aangericht werd de regering zich bewust van de noodzaak van snel uitvoerbare FCD projecten. FCD gebieden liggen overstromingsgebieden van de rivieren, of het zijn kustpolders. Ringdijken verschaffen bescherming tegen overstromingen vanuit de rivieren of de zee, of tegen het binnendringen van zout water. Waar nodig zijn uitwateringssluizen in de dijken geplaatst waardoor de khals (natuurlijke kanalen die laaggelegen gebieden en rivieren verbinden) kunnen afwateren. Veel landinwaarts gelegen FCD gebieden hebben depressies, die het hele jaar door of bijna het hele jaar water bevatten zogenaamde *beels*. Zij zijn vaak verbonden met rivieren door een netwerk van khals of handgegraven kanalen en kunnen alleen afwateren wanneer het waterpeil in de rivier dat toestaat. In de meeste FCD gebieden zijn tegenwoordig drie groeiseizoenen te onderscheiden, namelijk: Kharif-I, Kharif-II en Rabi. Vanuit het oogpunt van de landbouw zijn de FCD gebieden ontworpen om:

- de Aus te bescherming tegen vroege rivieroverstromingen;
- het gebied onder Aman uit te breiden door overstromingswater uit de gebieden te weren;
- om gedurende de periode na de moesson water in de gebieden te bergen.

Met in achtneming van de verschillende kenmerken van de FCD projecten - zoals bijvoorbeeld infrastructuur, topografie, belangrijke waterbeheer uitdagingen en de kenmerkende conflicten - kunnen de gebieden ingedeeld worden in:

- Haor gebieden;
- Chittagong polders;
- Khulna polders;
- Beel gebieden;
- Overstromings gebieden.

De vele opties voor waterbeheer in de FCD gebieden maken het waterbeheer in deze gebieden nogal complex. Internationaal gezien is er veel geschreven over het verbeteren van het waterbeheer in irrigatie systemen. Dit heeft geresulteerd in de ontwikkeling van adequate modellen voor het beheer van irrigatie systemen. Voor FCD gebieden is dit niet het geval geweest en het waterbeheer in de FCD gebieden blijft ver achter bij het beheer van irrigatie systemen.

Gedurende de afgelopen decennia zijn er enorme investeringen gedaan in hoogwaterkeringen, drainage en irrigatie systemen om land te winnen en om vele poldergebieden te ontwikkelen. In deze gebieden is een zorgvuldig waterbeheer vereist om optimale resultaten van de investeringen in de fysieke infrastructuur te verkrijgen en om de boeren in staat te stellen een redelijk bestaan te leiden. In veel gevallen is het huidige waterbeheer in de FCD gebieden echter beneden verwachting gebleven, met als resultaat lagere opbrengsten dan voorzien tijdens de voorbereiding, ontwerp- en bouwfase.

Ervaringen uit het verleden in de ontwikkeling van de watersector laten de noodzaak zien van een goed waterbeleid in Bangladesh. Na uitvoerige discussies heeft de regering van Bangladesh in 1999 de 'National Water Policy' gepubliceerd.

Hoogwaterbeheersing projecten zorgen voor algemene verbeteringen, door de reductie van de overstromingsdiepte om een veilige omgeving zowel voor wonen als voor landbouw te verzekeren. Ze kunnen echter ook leiden tot drastische veranderingen in het natuurlijke watersysteem, wat een onbalans in de aquatische milieus en ecosystemen ten gevolge kan hebben. Structurele interventies verstoren bijvoorbeeld de vrije stroming in de overstromingsgebieden. Bovendien, kan voortdurende verstopping of stagnatie de natuurlijke doorspoeling belemmeren en leiden tot de verspreiding van ziekten door vervuild water die de publieke gezondheid bedreigen. Totaal terugdringen van overstromingswater kan ook op de aanvulling van grondwatervoorraden een grote invloed hebben. FCD projecten veroorzaken in het algemeen een negatieve invloed op de visvangst; dit komt door de reductie van regelmatig overstroomde overstromingsgebieden en *beels* evenals het blokkeren van de vismigratie routes in het gebied van het project. Daarbij komt ook nog dat pesticiden, gebruikt in de rijstvelden,de vissoorten kunnen uitroeien. Veel vissers hebben hun middel van bestaan verloren of gingen in de rivier vissen. Dit leidde tot overbevissing in deze gebieden, die ook nog last hadden van de verandering in de vismigratie. Hoogwaterbeheersing van FCD gebieden heeft wel de mogelijkheden geboden voor het kweken van vis.

De hoogteligging binnen een polder is niet overal hetzelfde. Daarom ontstaan conflicten over het waterbeheer. De belanghebbenden in een polder hebben niet dezelfde belangen. Hierdoor treft men in bijna alle FCD gebieden conflicten aan. Het beheer en het onderhoud van de FCD gebieden zijn onvoldoende. Er moet nog veel gedaan worden om deze situatie te verbeteren.

De opzet van deze studie

Deze studie beschrijft de historische achtergrond van de ontwikkeling van het waterbeheer in Bangladesh en de huidige situatie in de FCD gebieden. De huidige situatie van het landgebruik en de hydrologische condities met betrekking tot de FCD gebieden worden gepresenteerd. Er wordt een overzicht gegeven van de ontwikkeling van laaglandgebieden langs de kusten in Zuidoost Azië. Op basis van een uitgevoerde analyse van het functioneren van de verschillende FCD gebieden en van de water sector in Bangladesh is een benadering ontwikkeld voor het verbeteren van de FCD gebieden in de kuststreek.

De meeste projecten die zijn uitgevoerd om de agrarische productie op te voeren voldoen niet aan de verwachting. Onoordeelkundige planning van wegen, kanalen en andere infrastructuur, die de natuurlijke afwatering verhinderen veroorzaken vele van de afwateringsproblemen, speciaal in laag gelegen irrigatie- en afwateringssystemen. Om de afwateringsproblemen te voorkomen en te verminderen is het vooral van belang een geïntegreerde planning en waterbeheer te hebben. Veel FCD gebieden zijn lang geleden ontwikkeld. Dientengevolge is het nodig de prakrijk van het waterbeheer te verbeteren en tot een zekere mate van modernisering over te gaan om tegemoet te komen aan de eisen van integraal waterbeheer. In de loop van de tijd zijn de omstandigheden en de hydrologische condities in de gebieden veranderd. De wensen van de gebruikers veranderen met de tijd mee. Het functioneren van de systemen gaat ook achteruit. Het beheer en onderhoud van de systemen zijn nogal verwaarloosd door de regering en de gebruikers. Betrokkenheid van de boeren en hun mening zijn niet meegenomen als een belangrijk onderdeel in de projectplanning. Nieuwe ontwikkelingsmogelijkheden in de watersector nemen af, maar zijn nog niet uitgeput. In de toekomst moet bij projectvoorbereiding ook rekening worden gehouden met genoemde aspecten bij het ontwikkeling van het waterbeheer en moet worden geprobeerd de negatieve gevolgen voor het milieu zo klein mogelijk te houden.

Met het oog op het hierboven genoemde was het dringend noodzakelijk een goede benadering voor de verbetering van het functioneren van de FCD systemen te ontwikkelen, onder andere door de plaatselijke bevolking erbij te betrekken, in het bijzonder bij beheer en onderhoud alsmede bij de voorbereiding van de verbetering van de systemen. Het was ook nodig te onderzoeken of deze FDC systemen werden beheerd en onderhouden zoals ze ontworpen waren en of er verbeteringen in de ontwerpen kunnen worden aangebracht.

De algemene doelstelling van het onderzoek was dus een benadering te ontwikkelen voor een duurzame ontwikkeling en waterbeheer in de FCD gebieden in Bangladesh. Op basis hiervan zijn effectieve technieken, hulpmiddelen en institutionele regels ontwikkeld om de uitvoering van dit concept te ondersteunen.

Overwegingen betreffende waterbeheer

De bodemcondities en de praktijk van het waterbeheer, gebaseerd op de verbanden tussen hydrologie en topografie bepalen voornamelijk de mogelijkheden voor landbouwkundige ontwikkeling in het kustgebied. Dit verband noemt men hydro-topografie. Hydro-topografie kan gedefinieerd worden als de hoogte van het land in verhouding tot hoge of lage rivierwaterpeilen bij het inlaatpunt en op het land. Hydro-topografie wordt uitgedrukt door de mogelijkheden van irrigatie tijdens het droge seizoen en de mogelijkheden van afwatering tijdens het natte seizoen. Tijdens hoogwater, kan het water in de polders stromen en tijdens laagwater kan het naar de rivieren geloosd worden. De actuele hydro-topografische omstandigheden van een polder hangen af van het waterpeil van een getijde rivier, het geleidelijk veranderende niveau van het maaiveld en de topografie. De hydro-topografie is niet uniform en constant in ruimte en tijd. Ze varieert bijvoorbeeld met de variaties op micro niveau in de topografie. De hydro-topografische omstandigheden bepalen echter welke ranges beschikbaar zijn voor de boeren op het gebied van landbouw methoden en waterbeheer. De volgende hydro-topografische categorieën zijn door Suryadi bepaald voor de laaglanden onder invloed van getij in Indonesië:

A: getij geïrrigeerde gebieden, zowel in het natte als in het droge seizoen;
B: getij geïrrigeerde gebieden, alleen in het droge seizoen;
C: gebieden net boven (≤ 0.50 m) het gemiddelde hoogwaterpeil in het droge seizoen;
D: hoger gelegen gebieden, waarin het waterpeil onafhankelijk is van de invloed van het getij.

De onderzoeker introduceerde deze hydro-topografische categorieën gebaseerd op de prevalerende omstandigheden in polder 43/2A.

De behoefte aan waterbeheer is verschillend voor elk type landgebruik en vereist verschillende interventies. Verbouwen van rijst vraagt om ondergelopen land, terwijl het verbouwen van Rabi gewassen een bepaalde bodemvochtigheid nodig heeft. De kanalen hebben een zodanig waterpeil nodig dat de juiste condities voor irrigatie en afwatering worden geschapen en waar toepasbaar geschikte condities voor de visserij en huishoudelijk gebruik van water. Het waterbeheer in de poldergebieden moet zich daarom richten op de controle van het waterpeil en op het voorkomen van stagnant water. In kustgebieden zijn er twee mogelijkheden: afwatering en doorspoelen om slechte waterbeheersing situaties te verbeteren. Ten einde dit te bereiken moeten de sluizen zodanig worden bediend dat water in de polder wordt geborgen wanneer dit tijdens droge omstandigheden noodzakelijk is, hetgeen betekent dat de deuren open staan tijdens vloed en gesloten blijven tijdens eb of water wordt geloosd wanneer het nodig is in het natte seizoen, hetgeen betekent dat de deuren dicht zijn tijdens vloed en open tijdens eb.

De omstandigheden met betrekking tot de afwatering spelen een belangrijke rol in het bepalen van de landbouwkundige en waterbeheersings mogelijkheden voor de boeren. Gedurende het natte seizoen wordt het overtollige neerslagwater normaal gesproken door de sluizen uit het FCD gebied afgevoerd. Verlagen van het waterpeil door afwatering moet op een zodanige wijze worden gerealiseerd dat ook naar behoren rekening wordt gehouden met het kweken van vis en milieubelangen. De afwateringscriteria voor de FCD gebieden moeten worden ontwikkeld op basis van de inundatie diepte die gedurende zware regenval in het natte seizoen mag voorkomen. Een grotere waterdiepte dan 0.3 m gedurende drie dagen is voor geen enkel rijst gewas acceptabel. Derhalve moet het opereren van de sluizen erop zijn afgestemd dat het waterpeil binnen drie dagen tot 0.3 m kan worden verlaagd.

Een effectief en duurzaam waterbeheer vereist een institutioneel kader dat de democratische vertegenwoordiging van de verschillende watergebruikers en hun belangen kan garanderen. De opzet van het kader zou zo moeten zijn dat de uiteenlopende belangen van de verschillende gebruikers erin vastgelegd kunnen worden. Men zou moeite moeten doen om gelegenheid te creëren om de verschillende gebruikers zeggenschap te geven in de verschillende stadia. Om dit te bereiken is een institutionele opzet in twee stadia ontwikkeld. In deze studie zijn voor verbetering van het waterbeheer in FCD gebieden de volgende stappen voorgesteld:

Stap 1: Onderzoek naar de belangstelling van de belanghebbenden voor verbeteringen en hun bereidwilligheid om bij te dragen aan de verbeteringen en het resulterende beheer en onderhoud;

Stap 2: In kaart brengen van het bestaande waterbeheer;

Stap 3: Het plaatsen van een team van deskundige mensen in het gebied;

Stap 4: Intensieve vergaderingen met de belanghebbenden en andere geïnteresseerde groeperingen betreffende alternatieve opties voor waterbeheer en de voor en nadelen ervan;

Stap 5: Stichten van een waterschap en waterbeheersings groepen van belanghebbenden;

Stap 6: Ontwikkeling van een voorlopig beheer- en onderhoudsplan. Een voorlopige overeenkomst met de betrokken partijen inzake de waterbeheersingstrategie en het vereiste beheer en onderhoud en de rol en bijdrage van iedere partij;

Stap 7: In kaart brengen van de benodigde reparaties en wat iedere partij moet bijdragen aan deze reparaties;

Stap 8: Reparatie van de sluizen en de dijk;

Stap 9: Start van beheer en onderhoud op basis van de voorlopig overeengekomen waterbeheersingstrategie en gebaseerd op de overeengekomen rollen, verantwoordelijkheden en verdeling;

Stap 10: Bediening van de sluizen op zijn minst gedurende een nat seizoen en een droog seizoen. Discussie over de positieve en de negatieve gevolgen van het beheer met de belanghebbenden en verbetering ervan wanneer men het er over eens is dat het nodig is;

Stap 11: Definitief maken van het beheer- en onderhoudsplan door het waterschap en de waterbeheersings groepen;

Stap 12: Overdracht van de verantwoordelijkheid voor beheer en onderhoud en het eigendom van overeengekomen onderdelen van het systeem van de Dienst aan het waterschap;

Stap 13: Beheer en onderhoud door het waterschap en de waterbeheersings groepen.

Met de veranderende behoefte van de mensen wordt doorspoelen voor irrigatie een van de belangrijkste voorwaarden. De mensen in dit gebied waren zijn nog steeds voorstanders van doorspoelen (stroming onder invloed van de zwaartekracht) zoals dit werd toegepast voordat de systemen werden aangelegd. Maar na de landaanwinning werden de mogelijkheden om door te spoelen echter kleiner door minder openingen (sluizen en inlaten) vergeleken met de situatie ervoor. Het doorspoelen heeft betrekking op de verbetering van de aanvoer van zoet water in het gebied. Doorspoeling door de sluizen in de lager gelegen gebieden en door pompjes, of door traditionele opvoerwerktuigen, of het inlaten van water voor irrigatie voor de hoger gelegen gebieden. Doorspoelen is voornamelijk nodig in april (voor het natte seizoen) voor het gereed maken van het land en het transplanten van T. Aus. Tijdens het doorspoelen moet de bediening van de sluizen met de veel zorg gebeuren in verband met de binnenvisserij in het gebied. In deze periode komt de vis gewoonlijk in de uiterwaarden en blijft dan tot hij groot genoeg is. In het droge seizoen is doorspoelen ook nodig, afhankelijk van de fluctuatie van het waterpeil onder invloed van het getij in de hoofdrivier. Als er in het natte seizoen een droge periode optreedt kan doorspoelen ook belangrijk zijn. Er zijn voor de oppervlakte irrigatie voor de rijst kleine ruggen in het land nodig om het water tot een zekere diepte vast te houden. Maar in dit gebied van Bangladesh zijn tot op heden geen ruggen toegepast. Regenwater en irrigatiewater kunnen niet worden opgeslagen in het veld en dit kan problemen veroorzaken in de lager gelegen gebieden.

Het onderzoeksgebied polder 43/2A

De onderzoeker heeft voor zijn proefgebied polder 43/2A gekozen. De polder ligt onder Patuakhali sadar thana in het Patuakhali district. Het hele gebied is 5,100 ha groot en het netto te bebouwen gebied 3,500 ha. In het westen en noorden grenst de polder aan de Payra (Bighai) rivier en in het oosten en zuiden aan de Gulisa Khali rivier. Het gebied heeft 19 administratieve dorpseenheden in drie dorpsgemeenschappen namelijk Bora Bighai, Chota Bighai en Matherbunia. Het gebied ligt in redelijk vlak land met een gemiddelde maaiveldhoogte variërend van 1.10 tot 2.10 m+PWD (‘Public Works Department Datum’). Het gebied wordt omgeven door relatief hoog land en in het midden is het relatief laag in de vorm van een schotel.

Voor de landaanwinning kwam getijde water in het gebied door de khals. Gedurende het natte seizoen zorgden hevige regenval samen met de getij stromingen voor ernstige overstromingen en overlopen van afwateringskanalen in het gebied. Deze overstroming en onvoldoende waterafvoer veroorzaakten een steeds terugkerende schade aan de gewassen, boerderijen en eigendommen met als resultaat enorme verliezen voor de bevolking. Om de problemen door de voortdurende overstromingen en onvoldoende waterafvoer te overwinnen maakte het gebied onderdeel uit van het ‘Coastal Embankment Project’ fase II (als 43/2). Het genoemde project startte niet op tijd door de benodigde hoge investeringen en door gebrek aan belangstelling van de donoren. Later is de polder (43/2) onderverdeeld in zeven kleine polders, 43/2A was er een van. In 1988 was de polder klaar. De oorspronkelijke doelstelling van deze landaanwinning was het vergroten van de voedselproductie door bescherming tegen overstromingen, door het voorkomen dat zout binnen kon dringen en door verbetering van de afwatering. Het hele gebied wordt omgeven door 40 km lange ringdijk. Er zijn zes afwaterings- en oppervlakte afwaterings sluizen gebouwd die verbonden zijn met zes van de zestien khals. De andere khals zijn helemaal afgesloten door de ringdijk en afsluitingen.

In het algemeen geven de bewoners in dit gebied toe dat hun levensomstandigheden in belangrijke mate veranderd zijn sinds het gereed komen van de polder. Het algemene gevoel heerst dat de effecten van de interventies overwegend positief zijn. Ook zijn er enkele negatieve effecten op de levensomstandigheden.

In het gebied wordt landbouw met en zonder irrigatie toegepast. Enkele kritieke punten voor de rijstcultuur die de onderzoeker vastgesteld heeft zijn:

- voor T. Aus (lokale variëteit en hoogwaardige variëteit):
  - het is niet mogelijk de zaaibedden te bewerken en te transplanten als er onvoldoende regen valt in april en mei;
  - vermindering van de opbrengst als er te weinig regen valt tijdens de groei van de planten in mei en juni;
  - soms worden de gewassen in de periode dat ze afrijpen door overvloedige regenval in juli en augustus ernstig beschadigd;
- voor T. Aman (lokale variëteit en hoogwaardige variëteit):
  - in sommige jaren kan het land niet op tijd bewerkt worden door onvoldoende afwatering, veroorzaakt door overvloedige regenval in juli en augustus;
  - soms zijn de gewassen beschadigd tijdens de rijpings- of bloeiperiodes als er geen of weinig regenval is in oktober.

Na de analyse van de algemene waterbeheersingssituatie in Bangladesh en na het onderzoek in het onderzoeksgebied polder 43/2A (model simulatie) is een benadering ontwikkeld om het waterbeheer in de FCD gebieden te verbeteren. Bij het ontwikkelen van deze benadering zijn de behoeften van landbouw, visserij, scheepvaart en milieu op een geïntegreerde wijze in beschouwing genomen.

Modelbenadering en simulatie

De polder wordt doorkruist door een groot aantal kanalen, enkele daarvan zijn zeer groot en de overige zijn kleiner van formaat (lengte en breedte). Rekening houdend met milieuaspecten dient in de kanalen bij voorkeur een hoog waterpeil te worden gehandhaafd. Omdat de hydraulische gradiënten in de polder marginaal zijn, is voor de hydrodynamische schematisatie het poldergebied vereenvoudigd tot een reservoir. Er zijn dwarsprofielen van de onderscheiden secties zijn bepaald op basis van de contouren, dit is gedaan met de ‘Area module’ van het Geografische Informatie Systeem IDRISI.

Voor de hydrodynamische simulatie zijn twee situaties ontwikkeld, namelijk doorspoelen en afwatering. Het doorspoelen is bedoeld om water te bergen in de polder om dit voor irrigatie te gebruiken. De afwaterings- of overstromingssituatie is onderzocht om na te gaan welke waterpeilen de voorkeur hebben tijdens het natte seizoen en de afvoercapaciteit om het teveel aan water na hevige regen te verwijderen te bepalen. Dit laatste is nodig om de schade bij de huidige gewassen te bepalen en een mogelijke strategie voor verbetering te ontwikkelen. In beide gevallen zijn alleen de bestaande sluizen en de dijk bestudeerd in de simulaties.

Gebaseerd op de regenduurlijnen voor het Patuakhali station is de drie daagse neerslag bepaald en de waarden bij een herhalingstijd van 5 of 10 jaar zijn gekozen voor de water balans simulaties met het hydrodynamische model DUFLOW om de bestaande afvoercapaciteit van de sluizen te bepalen.

De bergingmogelijkheden in het droge seizoen (april - mei) hangen volledig af van de waterpeilen onder invloed van het getij in de rivier. Gegevens van het Mirjagonj station laten zien dat water in het droge seizoen alleen geborgen kan worden tijdens springtij. Gewoonlijk is het tweemaal per maand springtij. Gebaseerd op de verzamelde gegevens werd een sinusoïde ontwikkeld als randvoorwaarde. Op verzoek van de boeren en met in acht neming van de bestaande problemen werd de simulatie voor een maand gedaan om het maximale waterpeil dat bereikt kan worden in het droge seizoen, in het bijzonder in april, te bepalen. Tijdens het natte seizoen is de simulatie gedaan voor augustus, omdat dat de kritieke maand is voor de afwatering. De hoogste springtijwaarden komen in deze maand voor. Daardoor zijn de resultaten voor deze maand meer representatief dan voor andere maanden. Ook kon de afvoercapaciteit van de sluizen geverifieerd worden.

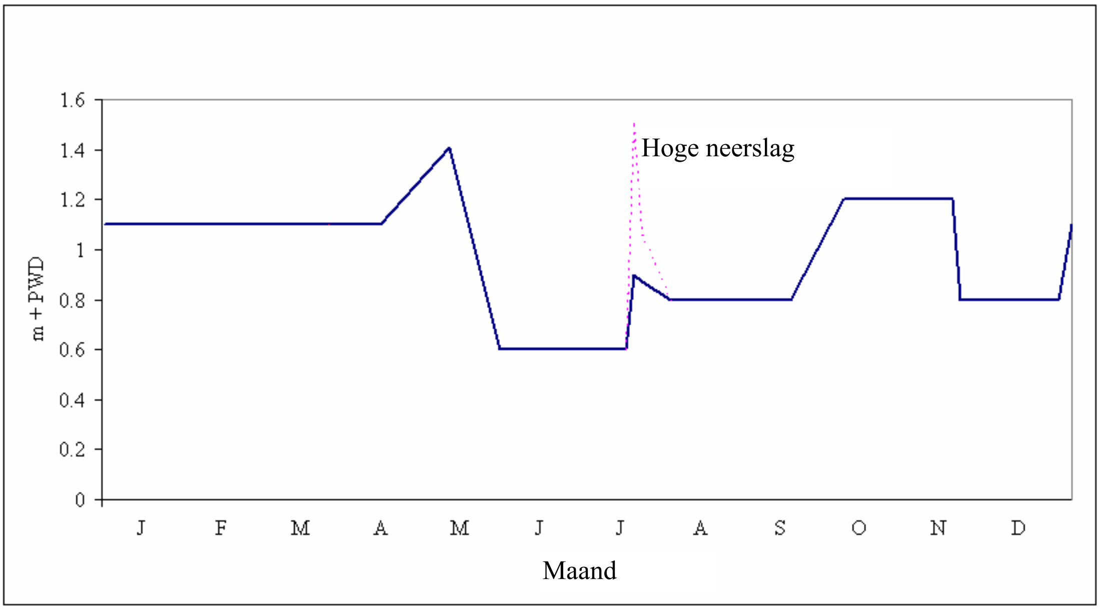
De simulaties laten de voordelen van de bediening van de sluizen in de huidige situatie zien. De resultaten tonen ook de huidige wateroverlast in de polder als er geen adequate bediening van de sluizen is. De resultaten van twee waarschijnlijke condities (herhalingstijd 5 en 10 jaar) zijn, vergeleken met de normale situatie, aan de veilige kant. Het maximale waterpeil in het droge seizoen (april) kon na 14 dagen bediening van de sluizen bereikt worden. Voor berging is er een leemte van 7 à 8 dagen in de bediening van de sluizen door de beschikbare (spring)tij waterpeilen in de rivier.

Het identificeren van de hydro-topografische categorieën is de eerste stap om de land geschiktheid zones in kaart te brengen. Ten einde de vraag te beantwoorden welke landbouwkundige ontwikkeling in de verschillende delen van het gebied geschikt zou zijn, moet met verschillende factoren rekening worden gehouden, te weten zoutindringing, bodemeigenschappen, de getijde amplitude, getijde irrigatie niveau en de waterpeilen in de natte tijd. Vanuit landbouwkundig oogpunt vormt het zoutgehalte in dit gebied in de meeste gevallen geen probleem. Teneinde een geschikte waterbeheersingsstrategie te ontwikkelen moeten de land geschiktheid zones worden onderzocht. Dit vereist een systematische en veelomvattende analyse.

Uitgaande van de hydro-topografische kaart is een doorspoel (irrigatie) en waterpeilen kaart voor het natte seizoen gemaakt. Gebaseerd op de ontwikkelde criteria en op de waterbeheersingsstrategie is een analyse gemaakt van de land geschiktheid. Deze analyse werd gedaan op basis van de huidige en de mogelijke condities. Uiteindelijk is er een kaart gemaakt die de land geschiktheid zones toont voor verschillende vormen van landbouw en waar verbeteringen nodig zijn ten opzichte van de huidige situatie. Gebaseerd op deze kaart kunnen plannen voor de toekomst worden gemaakt. De veranderingen in de land geschiktheid zones kunnen worden berekend.

Waterbeheersingstrategie

Op basis van de vereisten in het gebied en de resultaten van de hydrodynamische simulaties is een nieuwe waterbeheersingsstrategie voor het gehele jaar ontwikkeld die heeft geresulteerd in streefpeilen zoals getoond in Figuur 1. De strategie is er op gericht om de normale praktijken van de boeren en om de huidige landbouwkundige exploitatie te ondersteunen, alsmede om een optimaal milieu te handhaven. Om de waterbeheersingstrategie te ontwikkelen zijn verscheidene vergaderingen gehouden en discussies gevoerd met de boeren in het gebied en met verschillende professionele groeperingen.



Figuur 1 Streefpeilen behorend bij de waterbeheersingsstrategie voor polder 43/2A

De waterbeheersingstrategie is gebaseerd op de volgende overwegingen. Aan het begin van het jaar zal er een constant waterpeil zijn van 1.10 m+PWD. Dit peil moet tot midden april gehandhaafd worden. Dit peil is geschikt voor het handhaven van voldoende bodemvochtigheid en voor de verbouw van Rabi gewassen en Boro. Dit peil is ook gekozen wegens het huishoudelijk gebruik van water binnen het gebied en wegens de visserij. Als het waterpeil in de rivier het toelaat kan het opgeslagen water tijdens deze periode eenmalig worden ververst om de kwaliteit t verbeteren. Gedurende de periode van midden april tot midden mei zal voor het transplanten van Aus het water op basis van het waterpeil in de rivier binnen 14 dagen tot het maximum peil (1.40 m+PWD) geborgen worden. Naargelang de eisen in het veld kan dat waterpeil binnen 3 - 7 dagen verlaagd worden op basis van de wensen van de boeren en voor het transplanten van het volgende gewas. Dit verlaagde peil zou moeten worden gehandhaafd, gebaseerd op overwegingen met betrekking tot de scheepvaart in het gebied en van de visserij. Daarna kan Aus zonder irrigatie groeien. Hierna kunnen de boeren de sluizen bedienen om het waterpeil tijdens zware regenval in de polder te verlagen wanneer het rivierwaterpeil relatief hoog blijft. Voor het verbouwen van Aman is bescherming tegen overstroming nodig, die reeds geleverd wordt door de bestaande dijk. Soms is voor Aman aanvullende irrigatie nodig, wat ook mogelijk is met deze waterbeheersingsstrategie. Als de Aman rijp is kan het waterpeil in de polder weer verhoogd worden om daar waar de boeren Rabi gewassen willen verbouwen een voldoende bodemvochtigheid te bewerkstelligen. Gedurende de oogstperiode van Aman kan het waterpeil weer worden verlaagd om veilig te kunnen oogsten.

De waterpeilen binnen de polder en in de omliggende rivieren zijn tijdens deze studie op verschillende momenten gemeten. De onderzoeker heeft geprobeerd de deuren van alle sluizen te repareren om een beter waterbeheer te kunnen realiseren en om de resultaten aan de boeren te laten zien, maar door geldgebrek was dit niet mogelijk. Daarom heeft hij twee sluizen uitgekozen waaraan slechts kleine reparaties moesten worden verricht. De onderzoeker heeft de deuren hiervan gerepareerd en het verbindende kanaalnetwerk werd uitgediept door de 'Union Parishad'. De metingen zijn in 2001 verricht in het geselecteerde gebied van de polder. Verscheidene tijdelijke meetinstrumenten zijn voor dat doel geïnstalleerd. De afwaterings- en doorspoelcondities van de polder zijn tijdens een bepaald jaar gemeten. De veldmetingen zijn verricht in de droge en natte seizoenen van 1998 en 1999. Tijdens het veldwerk van de onderzoeker is een experiment uitgevoerd om de mogelijke waterbergingscapaciteit van een van de sluizen te bepalen. Voor dat doel werd de Kazirhat sluis (3 kleppen) uitgekozen. Op basis van deze metingen kon worden geconcludeerd dat er voldoende doorspoelcapaciteit kan zijn om watertekorten tijdens het droge seizoen te voorkomen.

Verscheidene vergaderingen zijn gehouden en discussies gevoerd met de gebruiker van het gebied betreffende de gemeten waterpeilen en de resultaten van de hydrodynamische simulaties en de geografische analyse. De nieuw ontwikkelde waterbeheersingsstrategie is ook gepresenteerd. Alle mogelijke consequenties van de strategie zijn gepresenteerd aan de gebruikers in samenhang met hun rol in het waterbeheer. Om de modelresultaten te verifiëren en de aanpassingen in het waterbeheer te realiseren installeerde de onderzoeker nog een set van tijdelijke meetinstrumenten in een geselecteerd gebied van de polder.

Omdat het springtij in 2001 uitzonderlijk hoog was zijn niet alle waargenomen waterpeilen representatief. Bij dit hoge springtij gaf de bediening van de sluis veel betere resultaten dan mag worden verwacht van de bediening zoals beschreven in de nieuwe benadering. De resultaten kunnen zelfs beter zijn onder normale omstandigheden. Waterpeilen kunnen lager zijn, op dezelfde wijze zoals de resultaten van het model laten zien. De resultaten van de simulaties voor de afwatering en doorspoelen waren wel representatief voor het waterpeil vergeleken met de gemeten waarden.

Evaluatie

De mogelijkheden voor nieuwe landaanwinningsprojecten nemen over de hele wereld met de dag af door financiële restricties en uit milieuoverwegingen. In Bangladesh is het niet anders. Door de jaren heen zijn er enorme investeringen in deze sector gedaan, maar de opbrengsten van deze projecten zijn niet bevredigend. Daarom is de regering nu druk bezig om het functioneren van de bestaande systemen te verbeteren. Ze loopt echter nog ver achter met het vinden van geschikte benaderingen voor wat betreft de relevante aspecten van waterbeheer. Er waren geen regelingen voor het beheer en er zijn geen streefpeilen vastgesteld om het maximale rendement uit de systemen te halen. Zich van de noodzaak hiervan bewust heeft onderzoeker een waterbeheersingsstrategie ontwikkeld om te bereiken dat de streefpeilen in een poldergebied gerealiseerd worden waarbij de fysieke mogelijkheden van de systemen, de huidige praktijken van de boeren, de belangen van de verschillende gebruikers en de milieueffecten in ogenschouw zijn genomen.

FCD gebieden en irrigatiesystemen moeten verschillend behandeld worden. De behoefte van de belanghebbenden en de eisen met betrekking tot het waterbeheer zijn totaal verschillend in de FCD gebieden in vergelijking met irrigatiesystemen. Voor de FCD gebieden is een andere waterbeheersingsstrategie nodig. Enkele voorbeelden kunnen worden ontleend aan de irrigatiesystemen, maar niet als een geheel zoals eerder gedaan is.

De FCD gebieden zouden alleen verbeterd, aangepast en hersteld moeten worden als de belanghebbenden het erover eens worden om de verantwoording voor beheer en onderhoud over te nemen en bij te dragen in de kosten. De belanghebbenden moeten direct vanaf het begin van de moderniseringswerk betrokken worden in de planning, ontwerp en uitvoering (indien van toepassing) van de maatregelen die nodig zijn voor verbetering en in de toekomst moeten zij bijdragen aan beheer en onderhoud. Betrokkenheid van de mensen bij beheer en onderhoud van de waterbeheersingsystemen in de FCD gebieden, een eerste vereiste voor de voortgang in dit verband, vraagt ook een sterke politieke wil van de regering. Nadat men de resultaten van de benadering zoals deze ontwikkeld is in deze studie heeft laten zien kunnen de systemen voor beheer en onderhoud overgedragen worden aan de belanghebbenden.

Beseft dient te worden dat de hydro-topografische (afwatering en doorspoeling onder invloed van getij) omstandigheden dynamisch zijn en kunnen veranderen door natuurlijke verschijnselen of door ingrijpen van de mens (zeespiegelrijzing, bodemdaling, obstructies in de kanalen). Zonering van de land geschiktheid laat de mogelijkheden voor toekomstige ontwikkelingen zien voor de huidige en potentiële condities. Deze analyse kan toegepast worden op andere FCD gebieden om conflicten op het gebied van waterbeheer tussen mensen op verschillende soorten land of met een ander beroep op te lossen. De potentiële condities kunnen aanleiding geven tot nieuwe interventies.

De verwachting is dat het voorgestelde waterbeheersingsstrategie een positieve uitwerking zal hebben op het leven en de levensomstandigheden van de mensen. Deze strategie is ontworpen om te bewerkstelligen dat de streefpeilen door het jaar heen worden gehandhaafd wat nieuwe voordelen geeft waaraan men vroeger niet dacht. De voorgestelde streefpeilen moeten aan het begin van het groeiseizoen worden uitgelegd aan de boeren. Waterbeheer in de FCD gebieden zal op zich geen gelijke verdeling van voordelen onder de verschillende categorieën mensen in het gebied garanderen, er zijn andere sociaal-economische parameters die daarvoor in beschouwing moeten worden genomen.

De waterbeheersing strategie is niet gefixeerd en kan op verzoek van de boeren in het gebied worden aangepast. De streefpeilen zoals ontwikkeld in deze studie zijn gebaseerd op een statistische analyse. Gebruikers kunnen kleine afwijkingen aantreffen wanneer ze deze strategie volgen. De waterpeilen zijn echter zeker binnen toelaatbare grenzen. Om aan deze nieuw ontwikkelde streefpeilen te wennen is tijd nodig, omdat het betrekken van mensen bij integraal waterbeheer tijd kost.

Als in een polder integraal waterbeheer wordt toegepast zal heel waarschijnlijk het huidige landgebruik toenemen, wat leidt tot een grotere opbrengst van de rijstoogst, geschat op 6,200 ton per jaar. Dit zal leiden tot het toenemen van het aantal boerenfamilies die profiteren landbouw in de polder. De werkgelegenheid, in het bijzonder de agrarische, kan door een intensief landbouwprogramma toenemen tot 260,000 mandagen. Van de voorgestelde waterbeheersingsstrategie wordt verwacht dat hierdoor de visopbrengst toeneemt met 140 ton per jaar en dat de visconsumptie toeneemt.

CURRICULUM VITAE

Md. Liakath Ali

The author of this dissertation was born in Comilla, Bangladesh. He did his secondary school in Sylhet and finished his higher secondary school in Habigonj. After that he studied civil engineering at the Bangladesh University of Engineering and Technology (BUET) in Dhaka.

From 1988 till today, he has been working in the Bangladesh Water Development Board. Immediately after joining he was posted in the Planning wing of the Board. In 1991 he was posted in the Netherlands Government aided project called 'Early Implementation Project'. He was dealing with the preparation of feasibility study report for new schemes and at the same time monitoring of the ongoing schemes under this project. He successfully prepared several feasibility study reports during the working period of the 'Early Implementation Project', which were located all over Bangladesh.

He came to The Netherlands to attend the post graduate diploma course for the academic session 1993 – 1994 in the Land and Water Development core of the Hydraulic Engineering Department, International Institute for Infrastructural, Hydraulic and Environmental Engineering (IHE). Thereafter he started his MSc study in the same Department under the supervision of Prof. E. Schultz and completed it in 1995. During his MSc study he dealt with a case study on submersible embankments in Bangladesh.

After obtaining his MSc degree, he again joined his previous office in the Board. There he worked as a responsible team member of the system planning cell (a specialised study team for planning) of the 'Early Implementation Project' for several years. During his service period in the Board he attended and successfully completed several on job training programmes. He also gave several lectures and presentations for the newly recruited engineers of the Board.

In August 1998, he started to work as a research fellow at the Land and Water Development Core of IHE. The research included a case study of Bangladeshi polders in the coastal belt. During his research period he went to Bangladesh several times for data collection, field investigation and measurements within the polder area. Along with his research work he supervised an MSc participant and assisted the regular Master Engineering participants of the Land and Water Development core during hydraulic laboratory experiments.

He has attended two conferences of the International Commission on Irrigation and Drainage (ICID) in respectively New Delhi, India and Seoul, South Korea. In the Korea conference, he presented a paper related to his research work. In Canada conference of the International Commission on Irrigation and Drainage (ICID), another paper related to his research work has also been published.