RESEARCH ON WATER MANAGEMENT AND CONTROL IN THE SUNDERBANS, WEST BENGAL, INDIA

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1. INTRODUCTION

The Sunderbans, to the south and southeast of Calcutta town, is a deltaic coastal region shared with Bangladesh and India. It consists of a natural system of numerous islands formed by the sedimentation of silts carried by the branches of the Ganges and Brahmaputra Rivers flowing to the Bay of Bengal (Figure 1).

The delta is the largest in the world and covers about 80 000 km^2. It has\the largest remaining mangrove forest in the world, with a total area of about 8 000 km^2 . The name Sunderbans is derived from the Sundri tree, the local name of the Heritiera tree, one of the dominating species in the forest. And the Bengalese word *ban* for forest. It is the home of the Bengal tiger, which animal spends his time in the trees at high tidal level to keep its “feet” dry.

The major part of the Sunderbans is in agricultural use for its dense and fast-growing population. The mangrove forests constitute an important coastal defense zone, sheltering the reclaimed areas against the extreme oceanic storm surges.

The Central Soil Salinity Research Institute, with main office at Karnal, Haryana state, maintains a research station at Canning Town in the state of West Bengal, India, to study the reclamation of coastal saline soils.

In the following paragraphs the authors discuss the environmental conditions of the area, the constraints to agriculture, and the potential developments.

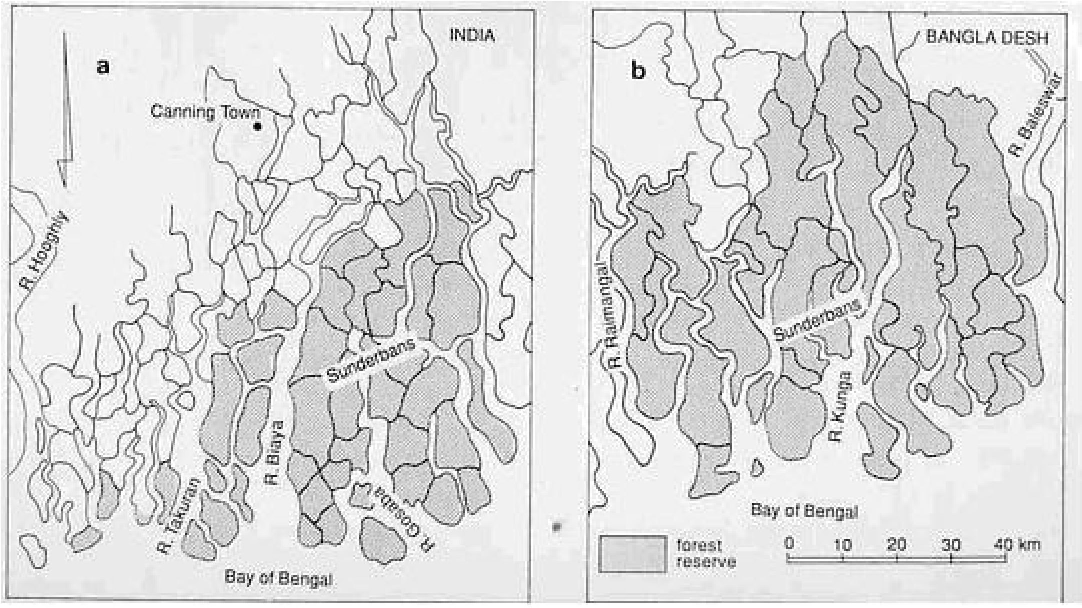

Figure 1. The Sunderbans in India (a) and Bangladesh (b)

2. AGRICULTURE AND ENVIRONMENTAL CONDITIONS

2.1 Ecological and Economic Importance of the Mangroves

A good segment of the Sunderbans is a forest reserve, a smaller part of which is a nature reserve where forestry is not permitted. Another segment is protected from tidal inundations by bunds and dikes and is used for human settlement and agriculture.

The reserves have high intrinsic values both for man and wildlife and endangered species, like the Bengal tiger, whose survival depends on the provision of sufficient protected area as a habitat for itself and its prey: the spotted deer and the wild bore. Also found amongst the precious living creatures are the wild cat and the Gangetic dolphin. Unfortunately, a large fraction of the original mammals has been lost, notably the Rhinoceros. The mugger crocodile has also become extinct. Other reptiles, like the Varan lizards, Python snakes, and marine or riverine turtles have rapidly decreasing populations, mainly because of hunting.

The Sunderbans harbors a varied and colorful bird-life, amongst which are various species of threatened birds. It would require the knowledge of an ornithologist to describe the wealth of bird communities.

Further, the Sunderbans forms an important breeding and feeding place for fish. Both coastal and off-shore fisheries depend heavily on the mangroves (Photo 1.)

Photo 1. Coastal fishermen in a creek along the mangrove shore

2.2 Hydrology, Tides, and Waterways

The islands of the Sunderbans are separated by an intricate pattern of tidal waterways, ranging from large tidal estuaries (Photo 2) to smaller tidal creeks. The estuaries are able to transmit the tidal waves far inland. The water in the estuaries is salty to a distance of 200 km inland or more, except when they receive a sizeable supply of fresh water from the Ganges or Brahmaputra Rivers, i.e. during the monsoon season. There are only six major fresh-water rivers in the area. The other estuaries are former river branches, cut-off from their fresh-water supplies, and are gradually silting up.

The area of the Sunderbans is shared by India, the state of West Bengal, and Bangladesh. In the Indian part there is only one fresh-water river, the Hooghly, one of the main branches of the Ganges. Near the fresh-water rivers, dry-season irrigation is practiced, but elsewhere no flowing natural source of fresh water is available for dry-season cropping. However, monsoonal rain water is preserved in ponds for this purpose, as discussed in section 2.3.3.

Following the completion of the Fakkara barrage in India (1974) up to 40% of the dry-season flow of the Ganges River has been diverted upstream. This has resulted in a further ingress of salt water into the major rivers during the dry season.

Photo 2. Showing one of the Matla river, on of the many large tidal estuaries.   Note the decay of the protective bunds.

Along the shores of the Bay of Bengal, the diurnal tidal range at spring tide is about 4 m. At the mouth of the estuaries, the tidal range increases to more than 5 m because of the upsurge, but more inland, this range gradually diminishes because of flow resistance to the wave and the dissipation of its energy. An accurate prediction of the tidal range from place to place is difficult to make. Such predictions are further complicated by the occurrence of cyclones: the low air pressure in the eye of the cyclone can increase the highest tidal levels by another 1 to 2 m.

2.3 Agriculture and its Constraints

2.3.1 Climatic Factors

Agriculture in the reclaimed areas is constrained by excess water during the rainy monsoon period (*kharif*) and the scarcity of water during the dry season (*rabi*). The main *kharif* crop is rice of a traditional variety, which is able to survive deep water-logging.

During *rabi*, most of the land is left fallow, and is used to graze cattle (Photo 3), but some smaller areas are irrigated from village ponds, where water from the monsoon season is stored. Only in the areas near the few fresh-water rivers, and mainly in their upstream part, is irrigation possible through diversion canals.

Table 1 shows the values of some monthly average climatic factors at Canning town. As can be seen, the excess rainfall (R-E) occurs mainly during the months of June to September. In May also, a considerable amount of rainfall occurs, but it consists of unpredictable pre-monsoon showers. At the same time, the evaporation values (E) are fairly high in May, so that on the whole this is a dry month. In October, the amount of rainfall (R) is similar to that in May, but the evaporation is much less. Although the excess rainfall in October is small, this month is still considered a wet month. From November to April the amount of rainfall is insignificant.

Photo 3. Extensive rice fields used as pasture during the dry season. In the foreground a farm storage pond of monsoon rain water.

Table 1. Mean monthly values of some climatic factors at Canning town (CSSRI, 1981)

Month	Humidity (%)	Sunshine (hr/day)	Rainfall R (mm)	Potential evaporation E (mm)	Excess or deficit R - E
Jan.	66	9.1	15	86	- 77
Feb.	65	9.3	21	115	- 94
Mar.	67	9.2	34	183	-149
Apr.	66	9.3	59	219	-160
May	75	9.7	135	233	- 99
Jun.	84	6.3	296	150	+146
Jul.	87	4.8	378	111	+257
Aug.	89	4.5	360	112	+248
Sep.	87	6.1	293	111	+182
Oct.	81	8.4	132	102	+ 30
Nov.	71	8.4	23	90	- 67
Dec.	67	8.9	14	96	- 82

Table 1 also shows two other phenomena that constrain agriculture during the monsoon season: a high humidity, which is inductive to the occurrence of pests and diseases, and a small number of sunshine hours, which limits plant growth.

2.3.2 Drainage Conditions and Kharif *Cropping*

The drainage infrastructure in the cultivated parts of the Sunderbans is poorly developed. Field drainage systems are practically non-existent, which is particularly because of a low density of the main drainage network, and partly because of the small size of the land holdings (about 0.5 ha). Landowners and sharecroppers are therefore not inclined to sacrifice land for a more intensive network of drainage canals.

Since the land is not absolutely flat and many areal depressions exist, high water levels of 0.5 m and more occur frequently on the rice fields during the monsoon period (Figure 2).

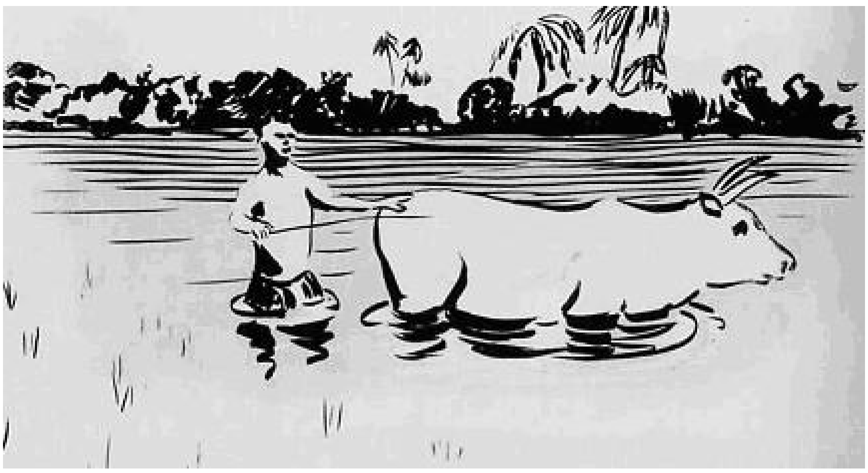

Figure 2. Very high water levels on the lower lying paddy fields in the monsoon season. Artists’ impression of a CSSRI photograph.

The rice fields in the higher parts of the land are usually not provided with bunds, so that the runoff from them contributes to the water-logging in the lower parts. Only when the higher parts loose their rainfall too rapidly, so that they may fall dry from time to time, will bunds be made to preserve the water.

The cultivation of high-yielding rice varieties is only possible in the relatively higher-lying areas, but their use is not wide-spread for yet unknown agronomic reasons. On the other hand, a large number of the traditional *Indica* rice varieties are available, which have a long growing season (more than 130 days). They are photosensitive (i.e. they mature in the same month), have long straw, and are tolerant to high levels of water-logging in mid-season. Further, the rice straw is an important material for roof thatching. Simultaneously with these varieties, the husbandry of fresh-water fish (e.g. Tilapia) is practiced.

2.3.3 Irrigation and* Rabi *Cropping

Some of the few main drains and natural creeks are used to store rain water for irrigation in the dry season (Photo 4). The water in these channels is permitted to be drained only after particularly heavy rainstorms. This drainage can only take place for a few hours at low tide (Figure 3). A typical heavy rainstorm is a 5-day rainfall of 250 mm, which is exceeded on the average only once in 5 years. With less rainfall, the outlet remains closed.

Photo 4. An excavated natural creek serves as a village pond and stores water for domestic purposes, the irrigation of Rabi *crops, and fish culture.*

The practice of water conservation in drains and creeks is in conflict with the drainage requirements of the depressional areas. Also, this practice is in conflict with the desire to have free inflow of salt water into the drains and creeks for brackish water fisheries. It is not easy to strike a balance between these conflicting interests.

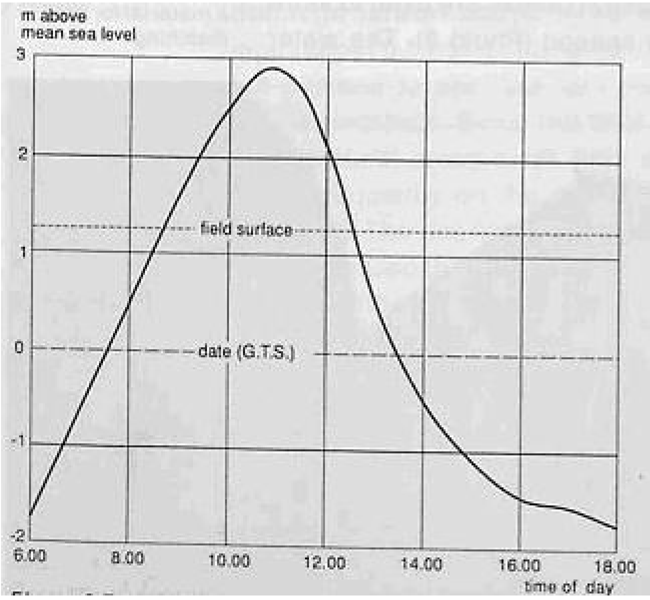

Figure 3. Example of an average tidal wave

The conflict of interests is one of the reasons why CSSRI is propagating the implementation of new farm ponds for storage of fresh water (Photo 5). Village ponds are already extensively used to store water for domestic purposes and fish culture, but farm ponds for the irrigation of *rabi* crops are much less common. Yet, CSSRI has estimated that a sacrifice of 20% of the land for irrigation ponds permits double cropping on the remaining 80% of the land (J.S.P. Yadav et al. 1981: *Management of Coastal Saline Soils of the Sunderbans.* CSSRI bulletin 7, pp. 13-15).

Further, the farm ponds for irrigation can play a role in alleviating the drainage problems during the *kharif* cropping season; the soil material excavated from the ponds can be used to raise the land surface, and the drainage water from the fields can be admitted to the ponds, which can also be used for fish cultivation. A further discussion on this topic is found in section 4.

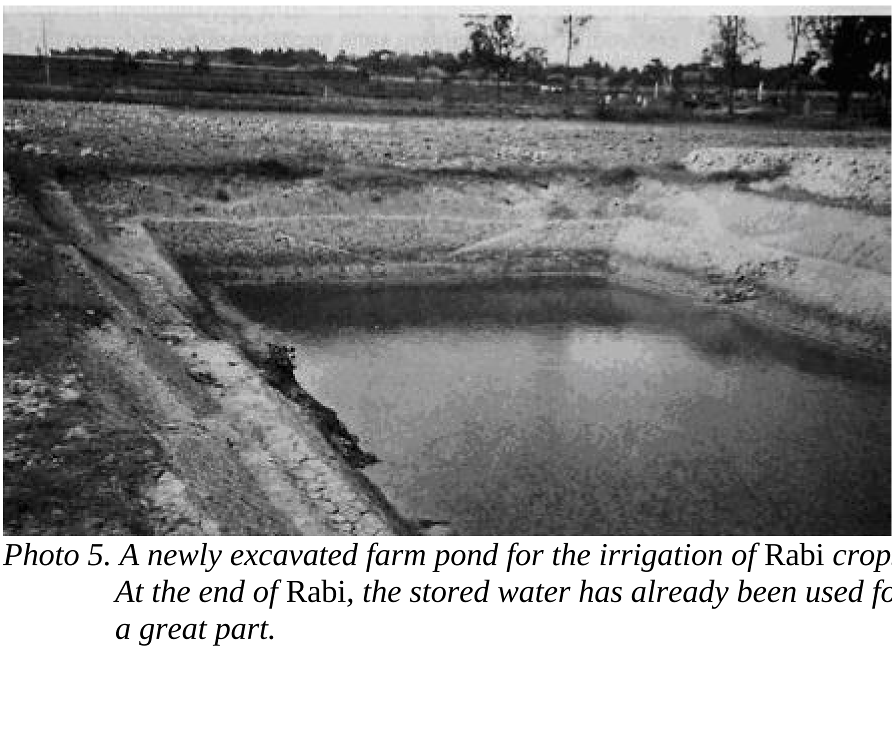

Photo 5. A newly excavated farm pond for the irrigation of Rabi *crops. At the end of* Rabi, *the stored water has already been used for a great part.*

2.3.4 Groundwater conditions

The groundwater is normally quite salty, except at great depth (> 300 m), where apparently a fresh-water aquifer exists which is fed by water infiltrating in far-away hilly lands. This aquifer takes the water into the sea. The deeper aquifer can be tapped only with advanced tube-well techniques, which are beyond the scope of the rural population. However, in the public sector, such wells are often installed to provide drinking water.

The poor quality of the shallow groundwater, together with the low hydraulic conductivity of the thick clay layers, makes its exploitation for irrigated agriculture unfeasible.

2.3.5 Soil salinity

In the reclaimed lands of the Sunderbans, soil salinity problems are usually not encountered during the monsoon season. Nevertheless, not all the salts that were originally present in the soils, owing to the sedimentation in a marine environment, have been removed. These remaining salts become apparent during the dry season. The excess evaporation and drying out of the topsoil cause an upward capillary flow of groundwater, which brings these salts to the surface. At the onset of the rainy period, these salts are washed down again and are stored in the subsoil. There is apparently insufficient natural drainage in the underground for the complete removal of the salts during the monsoon. The main reason is the probably low hydraulic conductivity and unripeness of the thick clay layers of the underground. At the same time, this condition prevents the inflow of salty groundwater from the estuaries at high tide.

As a result of these phenomena there is a seasonal upward and a seasonal downward movement of salt remnants, with simultaneous movements of the water-table, but in the opposite direction (Figure 4). In other words, during the *rabi* season the soil becomes dry and the water table drops, but the salts move upward with the capillary rise. In the monsoon season, the soil becomes wet and the water table rises, but the salts move downward with the infiltrating water, which percolates only to a depth over which the soil is unsaturated. This depth is, at its maximum, 1 m.

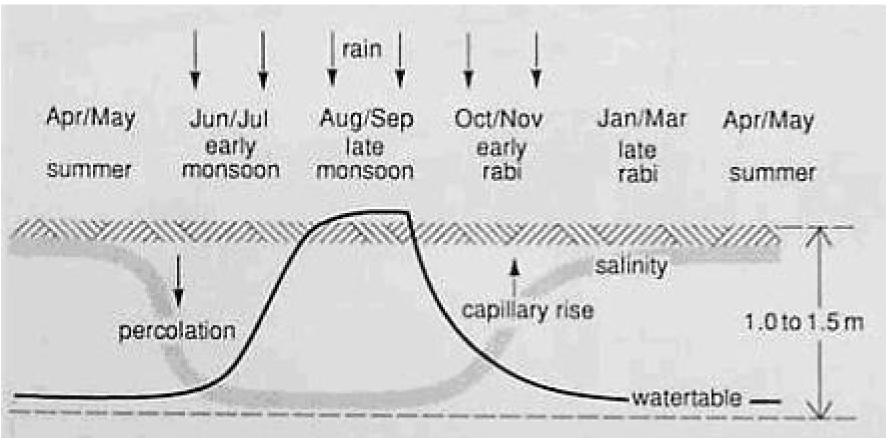

Figure 4. Opposite seasonal movements of salinity and water table.

A further indication of the annual stagnation of the soil salinity is the unchanging perennial salinity status of the fish pond at the CSSRI farm at Canning, which is filled with brackish water from a main drain during the dry season. This drain, though provided with a flap-gate to prevent the entry of salt water from the Matla river, is usually permitted to undergo a free tidal movement. During the rainy season, the pond is used for rice cultivation. The data confirm that the pond is not subject to a process of salinization , despite the seasonal introduction of salty water, and the paddy yields remain satisfactory (personal communication from C.R. Biswas).The exact seasonal changes of the salinity, however, are unknown.

In a salty part of its experimental farm, CSSRI has managed to remove the salts by introducing subsurface drains of the open ditch type (CSSRI 1988: *Coastal Saline Soils and their Management*, Bulletin 13, Table 59, p. 153; and K.V.G.K. Rao: *CSSRI Annual Report 1981*). The drains had to be pumped to evacuate their waters. In the Sunderbans, the large-scale introduction of ditch-drainage systems for salinity control does not seem feasible for want of large investments, the absence of suitable outlet conditions, and the loss of land.

3.2.6 Soil Acidity, Alkalinity

Surprisingly, the coastal soils of West Bengal are not very acid: 75% of the top-soils have pH values above 5. This is in contrast to reclaimed mangrove forests in other tropical parts of the world. In many areas of the Sunderbans, subsurface horizons show the presence of free Calcium Carbonates, which prevent the formation of acids. Thos soils that are acid by nature (pH < 5) probably owe their acidity to the presence of organic matter.

In general, the soils are not alkaline either, 80% of them having pH values below 8 (B. Maji, B.K. Bandyopahyay, and H.S. Sen: *Characterization of Coastal Saline Soils of West Bengal and Orissa*. CSSRI Annual Report 1989/90, pp. 174-177).

Potential sulfuric acidity from pyritic minerals, however, has occasionally been detected at greater soil depths, say from 1 to 2 m. There is thus a risk involved in the practice of digging farm-ponds or excavating natural creeks for the storage of rain-water, because the excavated soil is spread over the land. Instances have been reported whereby the spread soil material has acidified, making agriculture impossible for several years. On the other hand, it has also been reported that this phenomenon is only temporary, the soils having recuperated by natural processes within two or 3 years after being spread.

3. RESEARCH RECLAMATION METHODS OF SALINE SOILS

One may think of two alternatives for the reclamation of saline soils: (1) a system of temporary open dug wells, and (2) a system of furrows and beddings.

3.1 Temporary open dug wells

Figure 5 shows a system of five open dug wells, both in layout and cross-section. The depth of the wells is 2.5 to 3 m; their diameter is about 1 m. The required number of wells per ha and their spacing have yet to be determined by experimental research.

This can take place in one of the salty fields of the CSSRI experimental farm at Canning, with one well in each corner of the field and one well in the centre. During the *rabi* season, a portable pump can empty the wells into the outlet.

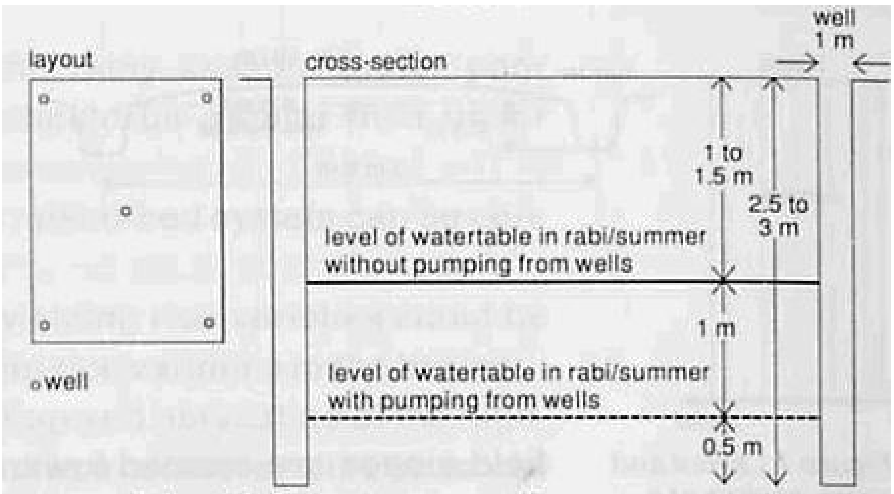

Figure 5. Layout and cross-section of a system of five open dug wells for the reclamation of saline soils.

Pumping from the wells in the dry season can lower the dept the water table to a depth of 2 to 2.5 m below the soil surface (Figure 6). This depth is greater than the usual 1 to 1.5 m which results from the capillary upward flow of groundwater (Figure 4). The salts that have accumulated near the soil surface in the dry season will, in the subsequent rainy season be washed down to a depth of 1.5 to 2 m instead of the usual 0.5 to 1 m. Pumping in the rainy season is not required, nor would it be practical.

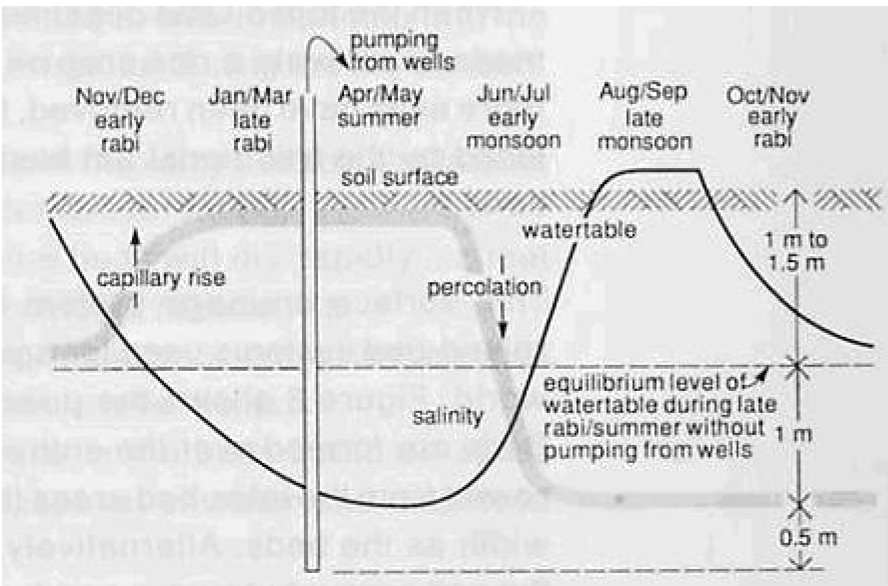

Figure 6. Pumping from the wells during rabi *lowers the water table. During the ensuing monsoon season, the salts are washed down to a greater depth than depicted in Figure 4 (without wells).*

It is hypothesized that the storage depth of the salts at 1.5 to 2 m depth is sufficient to keep them out of the reach of the capillary action, so that in the next dry season no more salinization of the top soil occurs and no more pumping is required. In other words, the salts are not evacuated, but are tucked away safely in the deeper soil layers. Hence, the reclamation by wells need only be a temporary measure, and the wells can be eliminated after the reclamation has succeeded.

From the above experiment, it would be possible to draw conclusions about the applicability of the method for a large-scale reclamation of the saline soils in the Sunderbans by farmers or tenants themselves. Recommendations can also be formulated for the most practical layout of the wells and the optimum pumping practices, and further improved experiments can be designed on the basis of the experience gained.

3.2 Beddings and furrows

Figure 7 shows a field drainage system with furrows. These are about 0.5 m deep with a 1:1 side slope and are spaced at 3 to 6 m. the excavated material is used to give the beds between the furrows a concave shape, so that gentle field slopes are created towards the furrows, which need to be connected to an outlet. With the first monsoon rains, a flow of water over the field surface towards the furrows will be created. At the same time the salts that have accumulated at the soil surface will be dissolved in the surface water and will be evacuated with it through the furrows to the outlet.

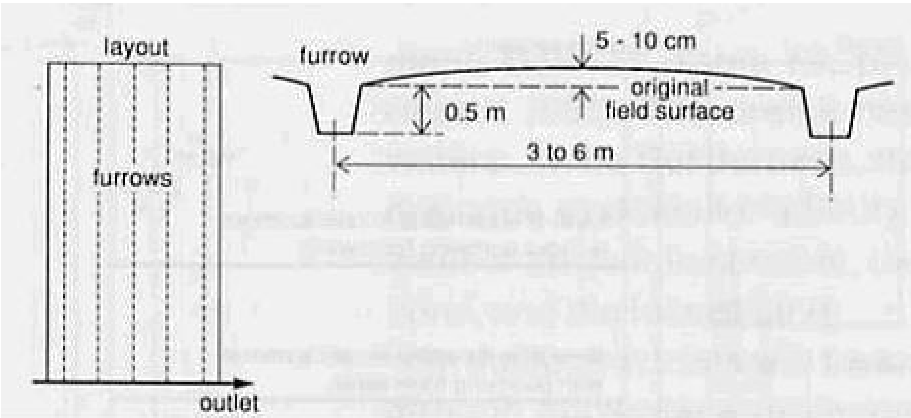

Figure 7. Layout and cross-section of a surface field drainage system of furrows for the reclamation of saline soils.

When the topsoil has desalinized sufficiently, attempts may be made to cultivate a rice crop on the beds. At a later stage, when more salts have been removed, the bedding system could be replaced by the traditional flat basin system for future rice cultivation.

3.3 Raised-bed systems

The surface drainage system resembles to some extent the raised-bed systems used for agriculture in many wetlands of the world. Figure 8 shows the principles of the raised-bed system. Beds are formed over the entire length of the field with soil borrowed from the inter-bed areas (the basins), which have the same width as the beds. Alternatively, the beds could be formed with the soil excavated from a pond.

The optimum height and width of the beds need to be determined by experimentation. The widt should surpass a certain minimum value so that the beds can be leveled and puddle for a *kharif* rice crop (e.g. a high yielding variety), but it should be less than a certain maximum value dictated by the maximum permissible effort for earth moving.

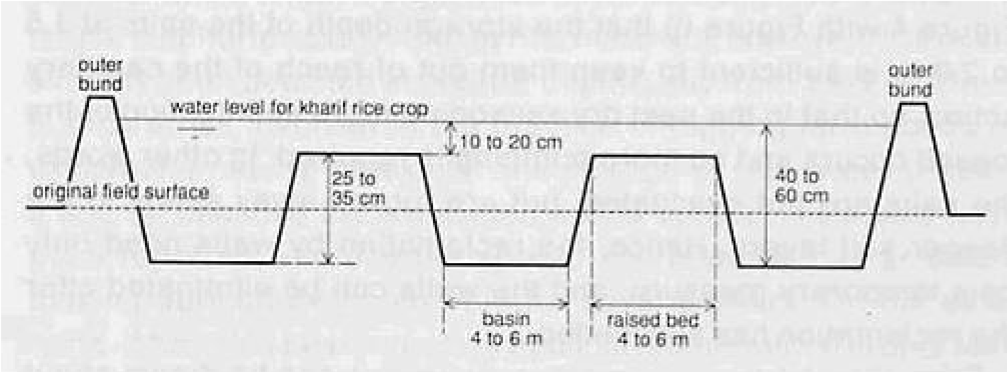

Figure 8. Principles of the raised-bed system.

The height of the beds is somehow determined by the local hydrological and water-logging conditions encountered during the rainy season. Under poor drainage conditions, the height should be greater than under good drainage conditions.

The possible advantages of the raised-bed system can be conceptualized as follows:

1. - During the rainy season, high-yielding rice varieties could be grown on the beds and traditional rice varieties in the basins;
2. - Because the dates of transplanting and harvesting of the high-yielding and the traditional varieties are different, the seasonal labor requirements are more evenly spread
3. - The basins could be connected to an outlet for water, so that they can act as surface drains during periods of excessively high rainfall, in a fashion similar to the furrows described in the surface drainage system;
4. - The basins could also be connected to a farm-pond so that the runoff ater can be stored for irrigation during the dry season (see also section 4);
5. - During the occasional dry spells in the rainy season, the basins could serve the purpose of water conservation;
6. - During the early *rabi* season, the beds will dry rapidly so that early sowing of *rabi* crops is promoted (see also section 4);
7. - During the pre-monsoon rains, these *rabi* crops will be less affected by excess moisture than in level fields;
8. - An initial problem of soil salinity in the beds could be cured by surface drainage and the disposal of water and dissolved salts via the basins;
9. - The beds are less susceptible to resalinization during the dry season than level land;

10 -During the *rabi* season, the basins could be used for a (fodder) crop with a high soil moisture tolerance/requirement, or *boro* rice (rice grown in *rabi* season);

11 - The possibilities for agricultural diversification are enhanced.

4. IRRIGATION POTENTIAL OF FARM PONDS FOR *RABI* CROPS

CSSRI recommends that farm-ponds be dug to store fresh water from the rainy season.; this water can be used to irrigate *rabi* crops in the dry season. Such ponds should occupy a maximum of 20% of the total farm area. With such a pond, the remaining 80% of the farm-land can be double cropped. Further advantages of the ponds are claimed to be as follows:
1. - Excess water can be diverted from the adjoining cultivated rice area to reduce the drainage needs of the *kharif* crops;
2. - The level of the adjoining cultivated area can be raised with the excavated soil from the pond to diminish the water-logging problem and facilitate the cultivation of high-yielding *kharif* rice varieties; it also helps in early sowing of the *rabi* crops, which would boost their productivity;
3. - Additional income can be generated with the introduction of pisci-culture in the pond.

The normal way in which the farmers apply irrigation water to their *rabi* crops is to carry the water in pitchers and sprinkle the plants directly from the pitcher. The system is mainly used for crops like watermelon, chili, and other vegetable crops. Some farmers pump the water from the pond into flat basins or into furrowed basins. The flat basins are used especially for *rabi* rice (*boro* rice).

Rabi crops that are found to be promising are linseed, cotton, tamato, and fodder crops like barley and coix. Some of these crops need to be grown in fenced fields to protect them from the invasion of stray cattle.

Some specifications of the recommended farm ponds are given Table 2 (Yadav, J.S.P. et al.: *Management of Coastal Saline Soils*. CSSRI Bulletin 7, 1981). At present, however, CSSRI is conducting experiments with the irrigation requirements of *rabi* cops so that the irrigation requirement will be better defined than in Table 2. Tentatively, the water balance of the pond during the monsoon season is presented in Table 3, which is based on the data of Table 2 and Figure 9.

Table 2. Specifications of farm ponds and corresponding water balance for Irrigated rabi *crop (CSSRI 1981).*

Item	Dimension
Size of holding	1 ha
Surface area of pond (42.3 m x 42.3 m)	1970 m^2
Depth of pond	3 m
Side slope	1:1 m/m
Volume of pond	4700 m^3
Volume of bunds	700 m^3
Irrigable area	0.8 m^2
Height by which the irrigable area is raised	0.5 m
Depth of water remaining for pisciculture	1.5 m
Volume of water available for irrigation	2560 m^3
Irrigation requirement of rabi crops (chili, barley, watermelon)	1200 m^3
Water losses from pond during rabi (evaporation, seepage: 5mm/day during 150 days)	1300 m^3

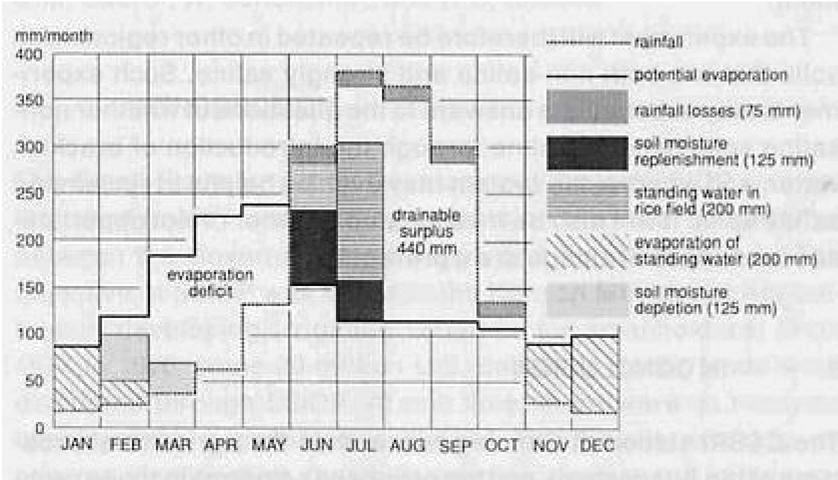

Figure 9. Estimate of drainable surplus during the monsoon season

Table 3. Tentative water balance of farm ponds during the monsoon season

Item	dimension
Depletion from pond during previous rabi season	1.5 m
Excess rainfall during monsoon season (Figure 3)	0.84 m
Required replenishment of pond by surface drainage	0.66 m
Drainage from cultivable area to pond	1100 m^3
Drainable surplus from cultivable area (Figure 9)	0.14 m
Percentage of drainable surplus required for pond replenishment	32 %
Potential extra storage in pond from drainable surplus	1.0 m
Potential extra storage as a percentage of drainable surplus	48 %

5. BRACKISH FISH PONDS IN *RABI* WITH A *KHARIF* RICE CROP

At the CSSRI experimental farm at Canning, successful trials have been going on since 1982 with a system of fish cropping in brackish water during the dry season, followed by a *kharif* rice crop. The water for the fishpond is derived from a main drain, which is under the tidal influence of the Matla river. Fresh-water fish are grown along with *kharif* rice (C.R. Biswas and H.S. Sen: *Rice-cum-Fish Culture in Coastal Areas*, CSSRI Annual Report 1989/90). This culture was practiced in an area where no *rabi* cropping was possible because of soil salinity.

Despite the success of the experiment, local farmers are reluctant to adopt the brackish-water fish culture in their fields for fear of soil salinization and smage to their *kharif* rice crop, even though such salinization was not manifest in the CSSRI experiment.

The experiment will therefore be repeated in other regions with non-saline and also strongly saline soils. Such experiments may substantiate answers to the questions of whether non-saline soils become saline through the introduction of the brackish water, and whether the system may even be helpful in reclaiming saline soils. It will also be investigated whether or not opportunities for surface drainage are a prerequisite.

6. IN CONCLUSION

The CSSRI station at Canning town, West Bengal, researches the agricultural problems of the Sunderbans and the proposed solutions to these problems, both at a theoretical level and, first and foremost, at a practical levl.

The authors do not claim any exhaustiveness in the research subjects presented in this article, nor do they imagine that all research efforts will lead to success.

Neither do they claim that any of the measures, when found successful in the experimental stage, are fit to be introduced on a large, practical, scale. This is firstly because a large-scale introduction depends on the acceptance of the measures by the local farmers and tenants; their acceptance, in turn, is governed by their socio-economic conditions, their incentives, and their perception of risk. Secondly, because of the variability of the natural farming conditions in the Sunderbans, none of the measures can be successful at all places and at all times. The authors, therefore, expect that some of the measures, when proven feasible, will be applied more in one region then in another.