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SUMMARY OF CURRENT ISSUES IN WATER MANAGEMENT ON-FARM IN RELATION TO RAIN-FED FARMING SYSTEMS OF E-INDIA

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Current Issues in Water Management On-Farm, in relation to the rain-fed farming systems of N.E. India, A Review of Options

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1. Introduction

In semi-arid environments, water is the major constraint to production. Over the long term, erosion can lead to environmental degradation and desertification. However in the short-run, it is water availability that constrains production of food, fodder and fuel. However, since only about one third of available water is used for the growth of useful plants in both irrigated and dryland agriculture, there are options for better management of available water (Wallace & Batchelor, 1997).

The area under study suffers from the paradoxical situation of being classed as both 'high potential' and a 'dry upland'. The high potential arises from its soils being relatively fertile, especially in localised areas, and its rainfall generally being between 1000mm y^{-1} and 1500mm y^{-1}. The area is seen as dry because the unimodal rainfall pattern limits most cropping to the kharif season. There is marked water shortage during the rabi, and only limited irrigation capacity. This is a paradox based on the description of the physical environment of the area. It should be noted that no such difficulty exists for socio-economical classification of the project area, which has high levels of rural poverty. Ryan (1997) shows that although absolute poverty is deeper in marginal environments, it is more pervasive (broader) in agro-ecological environments of higher potential.

The area falls on the cusp of much traditional institutionally based research. Most of Asia's high potential area is under intensive rice production, but there are now concerns about the ability of rice-based systems to feed a predicted 4 billion people by 2020 (Lampe, 1995; Pingali *et al*, 1997). Rice research in NARS and CG Centres in the region is therefore addressing issues of better use of water resources and other inputs (Cassman & Pingali, 1995), soil fertility, and other topics are relevant to the complex, diverse and risk-prone (CDR) farming systems such as occur in the project area. Parts of the research on irrigated farming systems, such as that at IIMI, particularly that on water use efficiency and conjunctive ground and surface water use is relevant to the production systems of the project area. In relation to farming during the rabi season, research on dryland agriculture, such as that at ICRISAT and CRIDA and under AICRPDA, with programmes on moisture conservation and rain-water harvesting technologies (Singh, 1989; Kaytal, 1997) is relevant.

Nonetheless, there is no comprehensive package of water management options that can be taken up immediately. Options arise from a number of sources. Katyal's (1997) review of research for rainfed farming in India reports that very few research findings are tailored to the socio-economic status of CDR rainfed farmers. There is a need to set a research agenda and undertake participatory research which will involve not only indigenous technologies but also exogenous ones, such as those from programmes outlined above. This paper examines some of this diversity of options, and sets them in the project context: water management and the introduction of aquaculture.

2. Background

The project is based on the rainfed upland areas of Eastern India, generally coincident with the area addressed by the DFID-funded KRIBP-E Indo-British Rainfed Farming Project[1]. Broadly, this area lies at the conjunction of Bihar, Orissa and West Bengal states (Haylor, 1996). The area is bounded within 20 - 24º N and 84 - 89º E. As described by Singh (1971), the central part of this area is the Chotanagpur Region, with Ranchi at its centre (***Map 1***)[2]; bording this region to the south is the Orissa Highland Region (***Map 2***), to the east, the Lower Ganga Plain (***Map 3***), and to the north, the South Bihar Plain. The project area therefore includes a diversity of land types ranging from the dominant upland plateaus with different degrees of dissection by drainage lines, through to low lying Gangetic floodplain. This offers a number of potential options for integrating aquaculture into rainfed farming systems.

Chotanagpur is a distinct physiographic entity of predominantly plateau topography, is has also traditionally been a recognised cultural unit of aboriginal tribes (Singh, 1971). The Orissa Hills, bounded to the south by the coastal plains and to the east by the Gangetic plains of West Bengal, are a complex of 'denuded hills, plateaus, sharp ridges, and mature valleys' (Singh, *ibid*). The Lower Ganga Plain includes the whole of West Bengal State, excluding Purulia (which is physiographically classified as part of the Chotanagpur region), plus most of Bangladesh, and is essentially deltaic. The delta is dissected by

[1] KRIBP-E covers nine Districts: Bihar - Ranchi, Hazaribagh, Palamu, Chatra; Orissa - Dehnkanal, Keonjhar; West Bengal - Purulia, Midnapur, Birbhum. (KRIBHCO & DFID, 1997).

[2] See Annex 1 for maps.

tributaries and distributaries of the main rivers, particularly the Ganges. The alluvial plain is characterised by beels, baids, ox-bow lakes and other similar features attributable to the action of water and deposition of alluvium.

2.1 Climate

The area experiences a unimodal monsoonal rainfall pattern, with the bulk of rain falling in the period June - October (Singh, 1971). There is some rainfall to the east in April due to the 'Norwester' pre-monsoon showers during the hottest time of year ($\leq$ 45º C in West Bengal). The Orrisa Hills receive some 77% of their rainfall in the 3½ months between mid-June and the end of September. This whole area generally appears to fall between the 1000mm y^{-1} and 1500mm y^{-1} isohyets (Carter, 1954). According to Singh, Ranchi has a mean annual rainfall of 1510 mm, and Dhanbad to the east, 1310 mm. The broad pattern is for greater rainfall in the south and east of the Chotanagpur area, although there will be local topographical effects on this distribution. The Lower Ganga Plains have a large temperature variation, from minima of about 5º C in January, to maxima of above 40º C in May. The southern parts of the Plains receive greater than 1500mm annual rainfall. The monsoon rainfall pattern pertains, with August being the wettest month, and December the driest, however, a certain erraticness to the pattern of precipitation is reported here (Singh, 1971).

2.2 Soils

The parent material of the Chotonagpur region is predominantly granite and gneiss, and consequently the common soils are red ferruginous soils, thin on upper slopes and deeper on foot slopes. Soils in depressions are more fertile and have the highest potential, especially when managed with irrigation.

Igneous rocks also dominate in the Orissa Hills, and as in the Chotonagpur region, there is also a deposit of Gondwana sedimentary rocks, including sandstones and shales. Similarly, both regions have lateritic areas in certain hill locations. In addition to lateritic soils, the Orissa Hills are represented by river alluviums in the coastal region, red soils on the plateau areas, and patches of brown soil in the south and Vertisols in the central part.

In the Lower Ganga Plains, the undulating region bordering the Chotanagpur highlands is represented by acid and lateritic soils with poor moisture holding capacity. Where these soils have been eroded and deposited through alluvial processes, they are deposited as lateritic alluviums (Red soils). These are also acidic soils of low fertility. The dominant soil type in this region, particularly the southern part, is Gangetic alluvial soil. This is more fertile and of alkaline reaction. Texture relates to depositional position, with water holding clays in lower positions.

2.3 Demography & Farming Systems

A basic summary of the typical farming system of the project area is given here (Table 1), based on KRIBHCO & DFID (1997) who analysed 9,597 households in the project area and produced a 'socio-agro-economic' profile. For more detailed information on the resource base and farming system of the project area, see this workshop, KRIBP-E (author?) (1998) - 'Rain-fed farming systems of India's eastern plateau: Products, production estimates, on and off-farm resources and their use - A baseline study'.

Detailed farming system description is available in another workshop paper.

In relation to water management, distinction needs to be made between cropping pattern on different land types. The plateau area of the study is undulating - the lowlands get seasonally inundated, sometimes very deeply, and consequently grow longer-strawed varieties of paddy; the medium lands may have sufficient residual moisture to produce a short season rabi crop after the paddy. Rice is also the main crop on more favourable parts of the uplands, but pulses, maize, small grains are more common. The main aim for farmers is to grow as much rice as possible, and rice cultivation is related to social status (Katyal & Farrington, 1997). Thus rice dominates the cropping system, despite there being many other more water efficient crops.

Table 1. Outline of farming system in the project area.

Size:	2.84 acres (46% upland, 31% medium land, 23% lowland)
Farm family:	5.8 persons/HH*
Off-farm economy:	34.5% of people in non-farm employment; 24.6% of HH with migrant members
Cultivation pattern:	2.4 acres in kharif, 0.28 acres in rabi, 0.02 acres in summer
Cropping intensity	96%
Cropping system	Rice-based + other crops; kharif-focused
Crops grown (ranked by importance)	Grains: paddy, maize, sorghum, millets Pulses: pigeon pea, black/green gram, chick pea, horse gram Oilseeds: niger, sesame, groundnut Industrial: jute, safflower Vegetables and Fruit
Irrigation provision	0.24 acres/HH
Irrigation use	29.2% HH ('life-saving' or on high value crops)
Use of HYVs	32.7% HH
Livestock (head/HH)	2.6 cattle, 0.4 buffalo, 0.3 sheep, 1.5 goats, 0.2 pigs, 4.1 poultry
Landlessness (HH/village)	11.7%

* HH = household

This section is deficient in information on food security, ratio of produce marketed or consumed by farm-family, and watering demands and arrangements for livestock.

3. Current Approaches to Water Management

This section sets out a conceptual framework based on current thinking on water management.

3.1 Classifying Development Potential

Recent research undertaken by the Overseas Development Institute (ODI) has tried to develop an analytical framework for the analysis of the important issues in better water management and conservation in what they term Drought-Prone Uplands (DPUs) (Turton & Bottrall, 1997). DPUs are described as "physically heterogenous, socially and politically marginal with poor infrastructure and exhibit a wide range of land use and tenure arrangements". They mainly occur in upper catchments, are "undulating, hilly or plateau terrains" and experience rainfall regimes of 400 - 1500mm per annum. The question is whether all or some of the project area may be classified as a DPU. If this classification is accepted, it provides a useful basis for examining the issues in catchment scale and smaller scale on-farm water management.

The potential of DPUs for water-based development depends on a matrix of interacting socio-economic, physical and politico-institutional factors (Table 2).

On this basis, a number of factors in the project area indicate a quite reasonable potential for water-based development in the project's DPUs. Rainfall at 1000 - 1500mm yr^{-1} is relatively high by semi-arid tropics (SAT) and DPU standards. The availability of groundwater, particularly from Artesian springs, means that the physcial factors are favourable. Caution should be given to generalising too broadly, and it is particularly difficult to generalise about the socio-economic and politico-institutional actors, other than to say that the KRIBP-E project represents a strong support service. Consideration should be given to key factors such as likelihood of collective action (see below on scale issues and watershed approaches), the population density and related availability of labour, and the access to markets. Work at Machakos in SAT Kenya has demonstrated the Boserupian theory of agricultural intensification under high populations, and this is particularly attributed to factors including available labour for labour intensive SWC works such as bench terracing, access to the urban markets of Nairobi, and collective work, especially by women's Mwethya groups (Tiffen, Mortimore and Gichuki, 1994).

Table 2. Factors in the potential for water-based development of DPUs

	Potential for Development			Project area conditions	
	Limited	to	**High**		
Physical					
Rainfall	low	to	high	• High: 1000 - 1500mm y^{-1}	**F***
Groundwater	not available	to	available	• Locally/seasonally available: TWs & Artesian springs	**F**
Socio-economic					
Indigenous SWC practices	none/few	to	well developed	• Well developed: esp. on L & M land; *nala* dams, terracing, etc	**F**
Population density	low	to	high	• High: especially W. Bengal	**F**
Propensity to co-operate	unfavourable	to	favourable	• ?Yes: due to KRIBP-E	**?F**
Migration	heavy	to	light	• Seasonally heavy: especially men	**U**
Market access	poor	to	good	• ?: Good local markets; Poor links to distant markets	**U**
Politico-institutional					
Prices/subsidies	unfavourable	to	favourable	• ?: Rice price subsidised; poor price for other commodities. Input prices: **?**	**?F**
Available investment	limited	to	substantial	**?** limited?	**?**
Land/water rights	tightly controlled	to	open access	• ?: A range of land/water tenure arrangements; private/CPR	**V**
Support services	weak	to	strong	• Strong: KRIBP-E	**F**

(after Turton & Bottrall, 1997)

*__Key:__ potential for water development in project area.

Favourable	**F**
Unfavourable	**U**
Variable	**V**
Uncertain	**?**

Turton and Bottrall (1997) note that existence of indigenous SWC practices can be important for development of DPUs. Kerr and Sanghi (1992, 1997) illustrate a number of such practices for the Indian case. However, Turton and Bottrall caution that in recently settled areas, they may be few indigenous practices to build on. This may be the case for parts of the project area which have traditionally been under transhumant type livestock herding, having been more recently settled by peoples who may not have a tradition of water management in DPUs.

At the moister end of the DPU spectrum (as occurs in the project area), Turton and Bottrall (*ibid*) recognise three types of farming system which they suggest should approach water development in different ways (Table 3).

Table 3. DPU farming systems and water-based development strategies

Type of Farming System	Explanation	Type of Development	Explanation
Transitional systems	High/increasing population High level of out migration History of indigenous technologies Declining rainfall due to climatic change	Evolution of the production system e.g SWC technologies & participatory planning	Build on and develop indigenous technologies
High potential systems (*closest to project situation*)	>1000mm yr^{-1} rainfall Favourable groundwater High population Access to markets Good infrastructure	Transformational approach to water conservation and development.	Market access & good water supply change the economics of water → change and development in farming systems and crop production technology (*including introduction of aquaculture*).
Dislocated systems	Newly settled areas - many inward migrants Increased market integration Increased accessibility	Innovative R&D Improvement of communication, education and training.	Few indigenous technologies

(after Turton & Bottrall, 1997)

In so-called transformational (high potential) systems, there is a risk that the development potential of comparatively available water supplies may be grasped by a powerful few, and lead to inequitable distribution of benefits. Where transformation is linked to management of water as a common property resource (CPR), this is avoided (Turton & Bottrall, *ibid*). Thus it would appear that a transformational development path, based on collective action/CPRs, together with appropriate evolution of indigenous technologies (such as tanks) is appropriate for this project.

3.2 Scale Issues - The Unit of Action: Farm or Catchment?

One of the key questions in water management relates to the issue of scale. The catchment or watershed approach to land and water management is now widely established in India. The Indian Government is disbursing about US$300m/yr on watershed management interventions (Farrington & Lobo, 1997).

This relatively large scale approach attempts to recognise the importance of collective action in sustainable management of natural resources. This contrasts with on-farm soil and water management where farmers may take independent action in response to water supply on their land and the demands of their production system. It is this smaller scale, at which farmers must balance supply and use of water on their farm that is implicitly the focus here. Nonetheless, the watershed management approach is of fundamental relevance in those areas where it is being, or could be, practised as the technical components of these programmes result in improved recharge of groundwater (Farrington & Lobo, 1997), and thus greater options for on-farm water management for farmers in those catchments. As illustrated by Beets (1990), improvements in rice-based farming systems occur effectively where macro-level and micro-level water management aspects have been addressed, together with the socio-economic aspects at community and farm/field levels.

> On a technical basis, water can be managed on-farm or across a catchment. The difference between these scales relates to individual and collective actions respectively.

> Technical water management issues cannot be removed from social ones.

This concept of micro-level, individually based, on-farm actions linking to macro-scale, community-based, watershed-wide actions coheres well with the framework for sustainable agriculture proposed by Jules Pretty at IIED[3] (Pretty, 1995). Pretty argues that four conditions need to occur together in order to achieve sustainable agriculture at meaningful scales (Table 4).

Though outside the scope of this paper, it would be useful to reflect on the existence of all four conditions in relation to the project more generally. In appears that collective perception and action on

[3] IIED = International Institute for Environment and Development.

soil and water management problems (in the form of community problem analysis [CPA]) is not universal in the KRIBP-E area (Smith, 1997).

Table 4. The conditions for sustainable agriculture.

1) The existence and use of resource conserving technologies (the on-farm actions)
In the case of this project, these might be improved on-farm water management, rice-fish co-production and aquaculture.
2) Functioning local groups and institutions
Groups that can co-ordinate and facilitate collective actions (the macro-scale) - watershed and micro-watershed groups and societies in the Indian case.
3) Enabling external institutions
GOs and NGOs that are willing to accept and promote the participatory paradigm for development, realising that agendas must be set by local people, that local people must be central in their own development, and that this may take a Freirean direction towards peoples' empowerment/emancipation. KRIBP-E may be an example of such an external institution; MYRADA in Karnataka is a well known one.
4) Supportive policies
Conditions 1 - 3 are interlinking areas of increasing scale, but all three exist in an arena that is defined by regional and national policies (see Figure 1)[4]. These policies need to support sustainable agricultural/NRM practices, through measures such as land tenure reform, IPM/pesticide legislation, and economic policies, for individual, collective and institutional initiatives to succeed.

Turton and Bottrall (1997) believe that collective initiative in water management tends to be promoted by "action-oriented agencies" such as NGOs, often with no linkage to research. Research organisations normally work at the farm level in so-called recommendation domains. The current DFID research project is good illustration where the two levels have come together to "agree a common framework for experimental action".

The USAID-funded Shared Control Of Natural Resources (SCOR) project in Sri Lanka takes a participatory approach to watershed-based land and water management (Wijayaratna, 1995; IIMI, 1997). It also recognises that social factors must be addressed as well as the technical. It aims to improve soil and water management Technologies, Organization - the institutional context of access and use of resources, and Resources conservation (TOR). This model has similarities with the IIED model and thus yields some useful and relevant outputs, though aquaculture is not evidently one.

Making the best use of available water for crop production depends on both technical and non-technical constraints (Wallace and Batchelor, 1997). In the four-part IIED scenario above, technical constraints fall mainly within condition 1) (on-farm), whilst the non-technical constraints (human, economic, institutional and organisational factors) relate to the other 3 conditions. The options available to individual farmers on their own farms are mainly choices between different technical options in water management. Off-farm, farmers can make choices such as joining farmers' watershed management groups and societies, that may also have technical dimensions, and will affect their on-farm water situation. The project thus needs to consider the sclae and organisational factors in any research developments. Despite optimistic words about the success of collective actions, a cautionary note comes from Kerr and Sanghi (1992), in the recommendation that, where possible, SWC technologies should focus on those which require minimum co-operation.

3.3 The 'New IIMI Paradigm' and Taking the Systems Perspective

The new paradigm that has emerged from work at IIMI takes a systems view of irrigation and water resource management. The system in question is normally a basin. Operating at this scale, the water resource can be perceived in holistic terms - knock-on effects of water management practices are felt throughout the system. Two types of system are defined - open systems wherein the basin can be further developed without detriment to other water users, and closed systems where all the water in a basin is committed, so that a modification in water use affects the 'quantity, quality, location and time of resource

[4] All Figures are in Annex 2.

availability' to other users. A basin becomes closed when there is no dry season flow into sinks (IIMI, 1997).

This model can be applied at catchment level also; catchments having some of the properties of being 'closed', particularly during the rabi. Thus, hypothetically, upstream farmers could improve the 'efficiency' of their water management by reducing losses off-farm through use of SWC measures. This might result in much reduced flows in run-off drains and *nala* streams. If farmers lower in the (micro)catchment are capturing and storing or directly using water from the *nala*, then the increased 'efficiency' upslope has a detrimental impact downslope. The result is a 'zero-sum game' - gains and losses are balanced out. The upslope SWC will however also improve groundwater recharge - this will be directly beneficial, and it should also improve the availability of groundwater downslope - but groundwater is more expensive to extract than surface water.

Better water management upslope may have a negative effect downslope - it is necessary to consider the whole system (ie catchment).

The implications of this 'systems view' of water are that i) it is necessary to work at greater than the farm scale when considering water management, ii) the project should consider (and explore in the village) the systems implications of any proposed water management initiatives. Palanisami and Flinn (1988) have done this by modelling the impact of various modifications to tank irrigation management, measured in terms of both traditional yield performance, and also equity in water allocation between catchment farmers and command area farmers. They found that most modifications, such as lining the distribution canal reduced water losses and thus improved productivity, but the benefits accrued disproportionately to command area farmers.

4. Farm Water Balance

At a crude level, the bottom-line water availability for the farming system maybe presented as:

$$P (+ G) - Et \pm S = Q$$ (after Newson, 1992)

where P = precipitation
G = groundwater (where available)
Et = evapotranspiration from crops (rice)
S = changes in (*surface*) stored water
Q = discharge/losses out of the system

The aims of on-farm water management strategies should be to:

Minimise Q, especially in paddy
Minimise Q generally
Maximise productive use of S
Optimise use of G

On the supply side, semi-arid rainfall patterns are characterised by most of the rainfall arriving in few intense storms. These can rapidly saturate the top soil, resulting in much of the rain running-off. Rainfall in excess of 50 - 75mm/day is normally excluded in calculations of water balances (Greenland, 1997). However, bunded paddies can retain rainwater from storm downpours. Heavy typhoon rainfall may over-top bunds, but rainfall from less intensive storms may maintained 100% effectively in bunded wet rice systems. (Greenland, *ibid*) (though as seen below, the water productivity of rice is only about 33%).

Over-topping may also be relevant on farms lower in the catchment. In catchments which have not been part of a watershed management programme, environmental degradation will mean that relatively less rainfall goes into groundwater recharge and more into surface flow. The downstream result of this is periodic receipt of storm water as indicated by a 'flashy' hydrograph. Where recharge has been improved through watershed management, increased stream and spring flows of longer duration are reported in the lower catchment. This will broaden the options for on-farm water use in lower areas, since supply should be improved.

To some extent the above equation takes a resource-limited approach, wherein all production activities place competitive demands on available water. This is not true, and in many farming systems of the world, production activities which have complementary demands for inputs are seem as fundamental to improved sustainability. Two examples pertinent to the present project are rice-fish systems, wherein fish are cultured the standing water in slightly modified paddies, and aquaculture systems in which fish are cultured in agricultural water storage devices (Little & Muir, 1987).

If aquaculture is considered a water <u>reuse</u> rather than a use, water use efficiency in greatly increased.

At the field scale, farmers are faced with the following hydrological cycle scenario (see Figure 2.):

Input:	Variable and unpredictable rainfall Groundwater
Storage/Stock:	Tank stored surface water / stored ground water Stored soil moisture
Output/Use:	Run-off Evaporation Percolation - Deep drainage Percolation - Soil storage Crop-growth (Transpiration) Aquatic production

Thus thee keys decisions in on-farm water management relate to:

- Balanced use of available water resources
- Cost-effective use of available water resources
- Ways to minimise losses of water
- Ways to maximise production from available water resources

These principles should guide the decision making processes in on-farm water management.

5. Water Supply Factors

5.1 Soil and Water Conservation

It is worth noting here that the on-farm water management approach, manifest through programmes with farming systems research and extension (FSRE), soil and water conservation (SWC) and small-scale irrigation elements, has often been characterised by a technological bent. Whereas the watershed approach has frequently added a participatory and institutional orientation to SWC (Turton & Bottrall, 1997; Farrington & Lobo, 1997).

Soil and water conservation (SWC) measures are often taken together as a unified approach to land husbandry. This review will primarily focus on water conservation as it is the element that directly links agriculture and aquaculture. Water conservation is primarily a dry season activity to mitigate seasonal drought, while soil conservation is primarily a wet season activity to reduce erosion due to high levels of run-off (there is also dry season wind erosion). Soil conservation is often synonymous with erosion control. This is not a major focus of the study, however eroded soil has a lower water conservation potential, and transported sediments can block or fill-up water conservation and storage structures, so some attention will be given to this issue. As a resulting of becoming denuded, uplands in the project area are seriously eroded. The eroded soil has caused siltation problems in tanks in the area, and they consequently need frequent excavation (Hancock, *pers. comm.*).

> Erosion control issues should be considered together with water conservation due to tank siltation.

Kerr and Sanghi (1992 & 1997) have studied Indian farmers' attitudes to SWC and their indigenous responses to the erosion. They found that farmers are aware of erosion and its potential effects on crop yield, but unless the soil is shallow, the erosion causes more concern due to loss of water and nutrients than soil itself. Farmers are more likely to practice SWC, particularly contour bunding systems, where they have applied farmyard manure (FYM), since without SWC, this valuable resource will also be lost. Of importance to the present project is Kerr and Sanghi's finding that farmers tend only to invest their time in SWC where the opportunity cost of labour is low. Where they may be more profitably employed doing something else, then SWC is neglected. Fish culture might be just such an activity competing for farmer labour. Kerr and Sanghi also found that the quality (potential productivity) of land affects investment in SWC, with farmers investing in more productive irrigated plots first. It is farmers without access to irrigation who care best for non-irrigated land. It might be surmised that, depending on ownership factors, plots directly upstream

> Will aquaculture compete with SWC for labour?

> Will the increased value of tanks/ponds result in better erosion control?

from tanks with fish culture might also then receive SWC since eroded material would create turbid conditions and silt the tank, decreasing the income potential of the tank.

In the project area, farmers' indigenous SWC practices include extensive terracing, especially on low and medium land, and the *nalas* bunded to trap silt (Hancock, *pers. comm.*).

5.2. Irrigation

Though a rainfed farming project, it is impossible to ignore irrigation - both current use and future opportunities. According to Abrol (1997), the groundwater resources of the study area have been poorly developed, and development of shallow tubewells is urgently required.

Irrigation may supply a crop's total water requirement or it may be supplemental to rainfall. Total irrigation occurs where supplies of water are reliable, affordable and of sufficient quantity. Supplemental irrigation is more common in monsoonal climates. Water for irrigation may come from groundwater - shallow and deep tube wells, and Artesian springs, or from surface water - beels, baids, rivers, ponds and tanks.

Tube well water is expensive, up to 38% of crop income (Palanisami and Ramasamy, 1997), and thus not easily accessible to the poorest sectors of the community. However some parts of the study area are fortunate to be supplied with groundwater through Artesian springs. This will locally affect use of irrigation. This water is also a resource that can be developed for aquaculture.

Supplemental irrigation using tanks is common in India, however tank performance is declining. In Tamil Nadu, farmers who depend on tanks for irrigation supplies are recommended to alter their cropping pattern away from rice to crops with low irrigation demands. This is due to rice crop losses occurring in 50% of years due to tank water becoming exhausted early in the crop growth period. Nonetheless farmers know little about cultivating less irrigation demanding crops, and also prefer to eat rice, and thus rice production is the norm under tank irrigation (Palanisami and Ramasamy, 1997). However, due to shortfalls in supply of water from tanks, yields are generally depressed by about 40% from their potential level (Palanisami & Flinn, 1989).

Tank supplies of water for irrigation of paddy are considered unreliable.

5.3 Water Storage

Of particular relevance to the present project is the storage of surface and extracted ground water in shallow reservoirs and ponds. These reservoirs, known as tanks, contrast with deep reservoirs, of which there about 50 large and 450 small and medium in India (Natarajan & Pathak, 1987). Though large reservoirs can buffer seasonal fluctuations in water availability and thereby facilitate intensive irrigated agriculture and fish culture, where they are not already in existence, their high fiscal, social and environmental costs (cf. Narmada) tend to be prohibitive (Wallace & Batchelor, 1997), making them outside the immediate scope of this study.

Innovative use of small-scale surface and groundwater resources are directly relevant to this study. Storage occurs in tanks and ponds. Tanks are found in all areas of India, and commonly date back to C18 & C19, constructed under the auspices of the *zamindari*. Palanisami and Ramasamy (1997) indicate that areas of undulating terrain, granite substrata and red soils (Alfisols) are well suited to tank construction. This describes well much of the project area, and it is therefore not surprising that up to 22.2% of the irrigated area in the States that make up the project area is supplied by tanks (Table 5).

Table 5. Importance of tank irrigation in project States

State	Area irrigated by tanks (000 ha; 1985-86)	Percent of total irrigated area
Bihar	121	3.0
Orissa	234	22.2
West Bengal	263	19.5

(after Palanisami & Ramasamy, 1997)

Nonetheless, von Oppen and Subba Rao (1987) show that the project area has a relative low density of irrigation tanks. Palanisami and Ramasamy (1997) report that considering all India, there was a 1.69% annual decline in the fraction of the irrigated area supplied from tanks between 1970/71 and 1985/86. This is important in the current project since tanks, in one form or another (i.e. also ponds), present one of the best options for multiple use/re-use of scarce water - particularly the case of water used for supplemental irrigation to crops together with fish culture.

> Tanks have declined due to groundwater development and poor maintenance.

Development of groundwater resources has reduced farmers' interest in tanks. This decline in interest is also due to poor tank performance, resulting from poor structure and maintenance of tanks, unauthorised tank-bed cultivation, weak collective management of tanks, lack of SWC and upper catchment deforestation, and erratic rainfall (von Oppen and Subba Rao, 1987). An increased income potential from tanks (e.g. from aquaculture) is likely to stimulate better levels of tank management, thereby additionally benefiting crop production through better resources for irrigation.

> Income potential from aquaculture could result in better tank management, with irrigation spin-offs.

Two types of tanks are recognised: system tanks, which receive water from streams or reservoirs in addition to rainfall and run-off, and non-system tanks, which are filled only from rainfall/run-off in their own catchment; these are usually only capable of irrigating a single crop. They may supplement rainfed paddy or be used for a rabi crop. Most tanks are non-system tanks, but tanks, especially a network of system and non-system tanks can create a successful source of irrigation. (Palanisami & Ramasamy, *ibid*).

Tank performance can be improved by an number of measures:

- conversion of non-system tanks to system tanks through establishment of catchment reservoirs and riparian linkages.
- removal of silt and prevention of siltation in tanks and tank feeder systems. Siltation is often linked to encroaching cultivation and deforestation on tank catchments.
- improved management of tank outlets - reducing waste from sluices, especially when there is no demand for water.
- regular repair and maintenance of tank infrastructure
- better control of extraction/distribution
- increased farmer/community participation in decision making about tank management.

Data from Palanisami and Easter (1987) indicate that tank storage is only adequate less than 50% of years. When farmers decide on their cropping strategy they can i) chose not to plant a crop (because they cannot afford supplemental irrigation when the tank is dry), ii) plant a crop accepting the risk that the tank may dry out - meaning that the crop will be lost, iii) plant a crop and if the tank dries out, buy supplemental ground water, and iv) plant a crop and irrigate it totally from groundwater to achieve maximum yield (Palanismai and Ramasamy, 1997). Option iii) is the most common, but use of expensive groundwater is kept to a bare minimum to prevent crop loss by irrigating only every 3 to 6 days. In this scenario, number of supplemental irrigations is correlated with final yield. The drawback that should be noted with supplementing tank irrigation with groundwater irrigation is that groundwater is at least partially dependent on recharge from seepage from tanks. They are hydrologically connected. Thus in very dry years/areas, both tanks and wells may become dry (Palanisami & Easter, 1987).

> Tanks commonly dry out before paddy has matured - if paddy and fish growth are synchronous, groundwater supplementation will be needed.

Decision making in use of tank water and/or groundwater is very complex, but one of the factors is the price ratio of rice : groundwater. Price of tank water has been shown by Palanisami and Easter (1987) to be less of an issue (in Tamil Nadu) since farmers are charged a fixed annual fee for use of tank water, compared to charging per hour of pumping of groundwater. Individual farmers thus have no direct incentive to conserve tank water, since if they do not use it, another farmer will, in a illustation of Hardin's 'tragedy of the common' scenario. Group management of tanks can lead to more equitable and sustainable use of limited resources, and less 'free-riding'. Tanks may be on private land with selfish or free use, on public land, built by the village, or on public land built by the Panchyat. Access and control of water will thus varying according to ownership. This will affect the suitability of the tank for aquaculture. According to Engelhart (1984), individual farm ponds (as opposed to tanks) for storing run-off are neither an economically nor technically feasible alternative to tanks. If run-off is to be stored then it must be from a catchment of greater than farm size, and thus it will supply a tank. This has implication for fish culture.

> Pricing of tank water does not encourage water conservation.

> One study asserts ponds are too small to store run-off; they must be tanks.

There are a number of factors important in use of tank irrigation, particularly when considering development of new tanks or modifications to existing ones. Tanks are shallow and can occupy as much land as they are able to irrigate, and their limited capacity means that they have little perenniality, and are dependent on annual rainfall (Palanisami & Easter, 1987). Tanks frequently also represent a community's only rabi season water source, and so new water uses which impact on existing users and existing multiple uses need careful consideration.

> There may be complex and competing demands on tanks during the dry season.

5.4. Socio-Economic Factors

Many of the water management options discussed are most successful if implemented at a collective level, e.g. soil and water conservation. To a large extent however, farmers willingness to become involved in such initiatives will reflect the likely benefits which they perceive will accrue to them directly and in the short term. Tenure status is thus an important factor, land-owners or those with secure tenure will have more incentive to improve the potential of their land. Will sharecroppers invest in water conservation or harvesting measures?

Exploratory study by Smith (1997) shows that those in the 'deficit' socio-economic class (SEC) have proportionately more upland than lowland, as do to a lesser extent self-sufficient households. Surplus households have large than average amounts of low and medium land. It is lowland that is better able to conserve moisture, and has better supply of supplemental water. It there has a longer potential cropping season and higher yield potential.

> Other socio-economic factors which need consideration include:
> - Tenure of tanks
> - Legislative frameworks for resource ownership/access
> - Differential access and rights of different SECs.

6. Principal Uses of On-Farm Water

6.1 Requirements for crop production

It is assumed that the principal objective of the majority of farmers in the project area will be the production of sufficient food grains for the farm-family to be self-sufficient. Generation of surplus for sale will be an important secondary objective, i.e. a subsistence-plus system. The principal use for on-farm water (as distinct from domestic water) therefore will be for production of the main crop. In semi-arid environments, the typical strategy for most soils[5] is to plant and establish a rainfed crop during the monsoon, ensuring anthesis occurs during conditions of favourable moisture supply, and then allow the crop to head-up and mature during the post-monsoon period, utilising moisture stored in the soil (see Figure 3).

The water requirements of the crop thus provides a baseline for the minimum quantity of water required on-farm. Of the common semi-arid zone crops, the ideal water requirement is shown in Table 6.

[5] Especially Alfisols but also ferruginous soils in general, though not Vertisols.

Table 6. Ideal water requirement of common dryland crops

Crop	Ideal water requirements (mm)	Sensitivity to water supply (ky value[6])
Groundnut	500 - 700	Low (0.7)
Maize	500 - 800	High (1.25)
Sorghum	450 - 650	Med-low (0.9)
Wheat	450 - 650	Med-high (1 - 1.15)

(after Landon, 1991)

This scenario is somewhat modified where wetland rice (paddy) is the principal crop, as it is in the project area, especially on low and medium land, where it occupies nearly all of the cropped area during the kharif (Hancock, *pers. comm.*). Water requirements for paddy production are affected by the need to supply standing water in the field. Paddy transpires about 5 - 8mm/day and percolation through the pan at the base of the paddy field varies between 1 - 10mm/day depending on soil and landscape characteristics (Greenland, 1997), though Tuong and Bhuiyan (1997) report percolation rates of up to 20mm/day. There is also direct evaporation from the water in the paddy field (Wallace & Batchelor, 1997). Water requirement is thus dependent to a large extent on duration of the growth period of the paddy. Transplanted modern varieties (MVs) maturing in 100 days thus require 540 - 1620mm, while traditional 130 days varieties require 720 - 2160mm. In addition to this cropping period demand, many cultivation systems require significant quantities of water prior to cultivation to soften soils that are hard after the dry season, and also for cultivation and transplanting. This may equate to another 300 - 700mm demand to water (Greenland, *ibid*).

The effect of these factors on the total water demand is illustrated in Figure 4. Thus for low demand crops, between 1020 and 1720mm is necessary, for high demand crops this increases to 2860 - 5000mm.

Tuong & Bhuiyan (1997) describe the components of the water requirement of paddy as:

Table 7. Water use in rice-based systems

LW	the amount of water needed to prepare the land
ET	the amount of water needed to meet the crop's evapotranspiration requirement
S&P	the amount of water needed to compensate for seepage and percolation losses

LW can be high because up to 45% of the water may enter deep rabi season cracks in the soil and by-pass the topsoil (Tuong & Bhuiyan, 1997). S&P losses are reduced through puddling, though uneven puddling and deep standing water will increase S&P. Walker (1997) has shown that most S&P occurs through lateral seepage into bunds and then vertical drainage into the water table. Deep water, poor puddling and wide bunds are three farmer-controlled factors that increase this element of S&P.

Seepage losses can be reduced through better puddling and good compaction of bund walls.

In terms of ET alone, the water productivity (WP) of rice is comparable to other cereal crops at 0.9 - 1.6 kg grain m^{-3} water used. However, when S&P are factored in, this drops to 0.37 - 0.69 kg m^{-3}, and if LW is also included it drops to 0.31 - 0.58 kg m^{-3}. Bhuiyan (1992) calculates that rice requires 1.14 m^3 water Calories $^{-1000}$ food energy produced; this compares with 0.69 $m^{3\ -1000}$ Cal. for wheat and 0.39 m^3 Cal.$^{-1000}$ for sorghum. The losses in the current wetland paddy systems thus result in poor use of on-farm water in terms of food production. Reduction of losses means more water for extra rice production or for other uses, such as fish production.

Research has shown that losses may be reduced through a number of measures (Tuong & Bhuiyan, 1997): the high LW losses due to deep cracks at the time of soil wetting may be avoided by dry shallow tillage soon after the previous crop has been harvested. Mechanical tillers also require less water than animal traction during wet cultivation. Shallower water depths save irrigation as percolation is less. Rice suffers a sharp yield loss if water stressed, and this occurs at soil water moisture contents just below saturation point (Bhuiyan, 1992). Thus the optimum depth of water should be between shallow submergence (5 - 7cm) and 'thin standing water' (1 - 2cm). Singh

Timely dry-tillage can reduce water used in cultivation.

Though water efficient, shallow water does not favour integration of fish.

6 ky value = ratio of relative yield decrease under moisture stress = (1 - actual yield/max yield) : (1 - actual ET - max ET).

(1997) found that, for IR-36, submergence deeper than 3cm (3.9% of plant height) caused a 0.76% decrease in yield for every 1% increase in depth.

Limited supplies of water be it from rain, surface or ground water have both direct effects on rice yield (due to stress as seen above) and indirect effects. The indirect effects occur due to changes in both use and response to other inputs, such as N fertilizer, labour for weed, and crop protection in water deficient crops (Palanisami & Flinn, 1989).

Flooding (deeper standing water) helps to control weeds and thus improves labour-use efficiencies, however where weeds are not a problem a so-called ‘saturated-soil regime’ with minimum water depth or even intermittent irrigation with alternate wet-dry periods of up to 3 days, but keeping the soil saturated, can improve water use by 23 - 50% or even 75% without affecting yield (Bhuiyan, 1992; Singh, 1997; Tuong & Bhuiyan, 1997), see Figure 5. In order to achieve these water use efficiencies through ‘water saving irrigation’ (WSI), accurate land levelling and skilful irrigation management is necessary (Greenland, 1997).

> Shallower water depth and/or intermittent irrigation is more water use efficient.

Production of seedlings for transplantation requires a further 50mm water. In transplanted systems, cultivation often commences when the nursery is sown, so that water is used conjunctively in the paddy field for 3 - 4 weeks for various cultivation operations prior to transplanting, and for seedling raising. Transplanting allows for better weed control, and facilitates puddling, which reduces seepage. Nonetheless, wet-seeded rice (broadcasting pre-germinated seeds) uses about 30% less water than the transplant nursery option since cultivation takes only about a week, reducing LW consumption/losses (Bhuiyan, 1992). A further option is dry direct seeded (DDS) rice which makes its early growth on rainfall, receiving supplementary irrigation only later in the season. In Malaysia, this was found to use 500mm less water than comparable transplanted rice systems (Tuong & Bhuiyan, 1997). The system is also common in Latin America. Since seed are sown on to a dry or moist seedbed that has not been puddled, savings on LW can be substantial. DDS is attractive where soils have a poorly permeable subsoil (to minimise S&P losses). Where DDS is combined with a short duration cultivar, an early harvest is facilitated, often permitting a second non-rice crop to be grown on residual soil moisture and late monsoon rainfall (Zeigler *et al*, 1995). The disadvantage of DSS is that poorer weed control can result, and in these systems an increase of herbicide has been detected. This may be detrimental to systems integrated with fish.

> Seeding systems (not transplanting) are more water efficient. DDS may increase herbicide use - a potential problem for integration of fish.

7. Options for Improved Supply and Use

7.1 Land Management Options

Important here is the conservation of available rainfall to meet the requirement of the crop. However, where rainfall in any one period is in excess of water demand in that period, the surplus can be conserved. This stored water can extend the growing season, often allowing the production of a second crop. Lack of attention to conservation of such surpluses means that most areas produce only a single crop each year (Katyal, 1997). Storage can occur through infiltration to increase soil stored moisture, or through run-off collection in ponds, tanks and reservoirs.

i) Watershed Management

A watershed is the dividing line between two catchments, but has come to mean the land within a specific catchment, above a certain point on its drainage stream (Doolette & Magrath, 1990). Watersheds are thus normally considered in terms of upper catchment (> 30% slope), and lower catchment (8 - 30% slope), nonetheless land, especially non-irrigated land, lower than this in the catchment cannot be ignored due to the hydrological connectedness of a watershed system.

The problems that watershed management tries to address are deforestation and loss of agricultural productivity due to erosion in upper catchments, and resulting downstream impacts of these in the lower catchment - sedimentation of reservoirs and irrigation systems, flooding due to excessive surface run-off, and reduce dry season stream flows. The excessive run-off from degraded catchments not only causes flooding, but also reduces the amount of rainfall entering storage in the soil profile and in groundwater aquifers, some of which would normally rejoin the surface water and contribute to dry season streamflow, which is highly important for crop production in dry areas (Magrath & Doolette, 1990).

Thus, watershed management aims to improve groundwater recharge, which is beneficial to both upstream farmers and downstream water users. However there is potential for negative impacts on downstream users too. In some places, farmers recognise the value of sediment and build traps to collect it on which they can farm the fertile soils. Similarly, many rainwater harvesting systems in dry areas depend on trapping run-off for cultivation (Barrow, 1987).

To effect environmental recovery in watersheds, a range of techniques are available. These include both structural and vegetative measures from the SWC portfolio to control erosion, such as earth banks and terracing, contour tillage, contour hedgerows and reforestation. Solutions need to be tailor-made to specific locations, often at the scale of the microwatershed (500 - 2,500 ha) (Magrath & Doolette, 1990). Whatever the solutions agreed upon, and however implemented (government intervention or local action), it should be recognised that the hydrographic conditions will be altered both upstream and downstream. Some quantification of the changes is needed to estimate how the potential for water-based development will be different, (see also Section 3.3; the perspective of the IIMI paradigm).

ii) Soil and Water Conservation (SWC)

Much previous SWC has been framed as 'sustainable', however this has been sustainability solely in terms of environmental protection, ignoring other dimensions such as economic viability and socio-economic acceptability. Benefits from SWC measures can take a number of years to become evident, particularly in terms of improving productivity. Farmers want to see an quick return for their investment, and thus there is a current move away from SWC towards 'better land husbandry' (Hudson, 1992; Shaxson *et al*, 1989), with a stronger emphasis on husbandry practices that improve productivity in the short term and offer soil and water conservation in the longer term as an additional benefit. Steiner *et al* (1988) list contour terracing, tied ridges, water harvesting and improved weed control as SWC measures that can increase productivity over the short term using few purchased inputs.

Many of these measures are in-situ water storage measures that act to increase infiltration close to where the rain has fallen. The objective is to maximise infiltration opportunity time (Katyal, 1997) by slowing the progress of, or preventing, run-off across the soil. In terms of crop productivity, this is beneficial, but it does not improve the options for integrating aquaculture into the system at that location. SWC thus has a different on-farm objective to the water capture options below. SWC aims to minimise run-off, so as to optimise or maximise it for on-site storage. The methods below focus on run-off not infiltration. Where excess water cannot be dealt with on-site, SWC uses grassed waterways and bunded *nalas* to remove surplus water in a controlled manner.

Improved upper catchment infiltration storage does not improve aquaculture potential at that location.

SWC occurs at two levels: i) on-farm actions, ii) landscape/catchment scale action. Farmers may use a number of complementary SWC technologies to improve soil physical structure to increase infiltration, reduce erosion and increase infiltration. These include mulching, stubble mulching, composting, manuring, leaving residues, deep tillage, conservation tillage, off-season tillage, fallowing, contour cultivation, tied ridges, contour bunds, contour trash lines, contour grass lines, contour hedges (agroforestry), and multiple cropping (Barrow, 1987). At landscape scale, government SWC Dept., projects, NGOs, etc can implement or promote technologies that span across numbers of farms. These include bench terraces and banks, grassed waterways, tree planting. These larger measures, often involving the building of structures that span several farms, follow the contour across the landscape. These have been found to be at odds with farmers views of SWC, and indigenous SWC is frequently integral with the plot boundary, rather than following the contour, as it can serve multiple purposes such as boundary marking and animal fencing (Kerr & Sanghi, 1992).

The proportion of water available for tank/pond storage (aquaculture) will be affected by choice of SWC +/or run-off collection

<u>7.2 Water Storage/Capture Options</u>

Where run-off can be safely directed and disposed of, then it can be stored and reused for irrigation or non-agricultural purposes (Tejwani, 1981). Two forms of capture are recognised - run-off collection and rain-water harvesting (RWH). The distinction is that the latter involves fallowing, compacting or otherwise treating a catchment area to improve the yield of run-off (Laryea, 1992).
There is also a scale issue here: RWH is often practised by individual farmers on single plots, run-off collection is normally a collective practice (though neither are exclusive). Katyal (1997) reports failures of water collection initiatives due to lack of group action.

Run-off occurs when precipitation exceeds infiltration; this varies according to soil type. Alfisols, which are usually crusted at the end of the dry season, yield more run-off early in the monsoon, whereas Vertisols, which enter the monsoon with deep cracking and thus have a larger soil storage capability, yield more run-off later in the season when they are saturated (Laryea, *ibid*). Nonetheless, El Swaify *et al* (1985) show that proportion of run-off from both these main SAT soil types is similar (Table 8), although run-off can be as high as 55 - 70 % of total monsoon rainfall.

Table 8. Water balances for SAT soils

	Alfisols	Vertisols
Runoff	26%	28%
Evap$^{\underline{n}}$ (from bare fallow)	-	24%
Deep percolation	33%	9%
Available for ET	41%	39%
Soil water (weeks crop growth)	17 weeks	26 weeks

i) Rain-water Harvesting [RWH] (in-situ)

RWH requires field modification to the catchment or apron in order to prevent infiltration and maximise run-off. This may utilise a membrane, a sealant or compaction. Run-off may be collected in a reservoir or directed to a infiltration area. DFID work in Tanzania has had success with mini-catchment RWH where individual plots are divided into a bare fallow apron and a cropped infiltration area on the lower part of the plot. Farmers may be reluctant to forgo cropped area for fallow in order to increase soil stored moisture however. In relation to aquaculture potential collection in a reservoir is a preferable option.

ii) Run-off Collection (ex-situ storage)

India has a long tradition of agriculture based on run-off collection. It is the basis of the extensive non-systems tanks in Tamil Nadu, Andhra Pradesh and Karnataka (see Section 4.3, Water storage). The catchment area is not modified in these systems. The success of run-off collection in tanks and ponds depends on both technical matters, such as seepage rates in the tanks (recommended to be below 20mm day^{-1}), and social ones, such a system for collective catchment area management and equitable distribution of water in the command area (Laryea, *ibid*).

iii) Groundwater

Supplies of groundwater are available in the project area. Some, such as the Artesian springs are seasonal. These offer a cheap opportunity to extend the cropping period, to fill up tanks and ponds for fish culture, etc. Participatory research should explore the trade-offs in different uses of this resource.

7.3 Fish-based Options

The options under this heading are covered only very briefly since they are the subject of a more detailed workshop paper: "Integrated aquaculture in small-holder farming systems - A review of current practices" (CIFA, KRBP-E, IoA, 1998).

Two primary forms of integrated agriculture-aquaculture are relevant in this project: fish integrated into crop fields - the so-called 'rice-fish' system, and fish culture in irrigation structures - this is mainly tanks and multiple use ponds in this project. These options are the hub of the research project. It is implicit that other options should be aim to maximise the possibilities for aquaculture. This may be through improving run-off collection or reducing the extraction from tanks/ponds for other uses. If fish are considered as 'a crop', then water can effectively produce two crops (paddy and fish), radically affecting the water productivity (WP) calculations in Section 6.1.

Fish-based options are the hub of this project

One of the limiting factors in aquaculture in the project area is shortage of fry (Haylor, *pers. comm.*). Where water for integrated aquaculture is limiting, fry production rather than production of eating fish per se is a viable option, which could utilise limited or seasonally available groundwater.

i) Rice-Fish Systems

Fish may be cultivated in paddies either simultaneously or in rotation with rice (Lightfoot *et al*, 1992). Due to water shortages, the synergistic use of water in the paddy in the simultaneous system is more appropriate in the project area. Paddies require modification for fish culture as the fish require deeper refuge areas, in which it is not possible to grow rice. These may occupy up to 15% of the paddy area, thereby potentially reducing rice production (Little & Muir, 1987). Work in Bangladesh has demonstrated the profitability of rice-fish integration however (Kamp *et al*, 1996). Lightfoot *et al* (1992) report rice yield increases of 5 to 50% across Asia, with a few instances of yield reductions. Pesticide use must be stopped or fish-kill losses will be high as many rice insecticides are piscitoxic. IPM is used instead, and rice yields are maintained. With a similar rice yield but reduced expenditure on inputs, overall profit is increased. The profit from selling the fish adds further to profitability of the system. Rice-fish and IPM are two steps in developing a more closely integrated management system for rice-based farming systems. Lightfoot *et al* (1993) and Wouters (1994) describe a number recycling flows of organic material used as feed and fertiliser that lead to more integrated and sustainable systems in rice-crop systems. This view of rice-fish as part of the whole farm system rather than a stand alone technology is supported by Edwards in McClellan (1991). These systems are not only economically better than rice-only systems, they are also more stable and less risk-prone.

ii) Aquaculture in Irrigation Systems

In the project area, this form of aquaculture will mostly take the form of tank aquaculture/pond aquaculture. For details see the integrated aquaculture workshop paper.

7.4 Agronomic Options

i) Cropping Pattern

As shown above, rice is one of the least efficient users of available moisture. Price control means that there is a high demand for this crop, but it may not be the most productive option for all farmers, especially in rain-fed systems where water is limiting. Research can help select crops and cropping patterns which make most productive use of water. Technologies which have been developed include varieties and species of crops to plant, making best choice of planting date, and intercropping systems (Singh, 1989; Paul, 1997). Smith (1997) reports that KRIBP-E farmers recognise the moisture potential of different landscape positions and grow different rice varieties accordingly: Pankaj (120 - 135 days to maturity) on lowland, Kalamdani, Sri Kamal and Dondha (90 - 110 days) on medium land, and Gora (75 - 85 days) on upland. ICRISAT research in the Bangladesh Barind Tract has successfully introduced chickpea as a drought-adapted crop that can be grown in what is normally the fallow rabi season (ICRISAT, 1996). Within the remit of the current project, such research would have to be more than just agronomic, reflecting how these technologies would affect the possibilities for integrating fish into the production system.

ii) Trees

Trees serve a useful function in the upper catchment as they break the fall of raindrops thus reduce raindrop impact at the soil surface and subsequent splash erosion (Tejwani, 1981). However trees also intercept rainfall, and prevent some 30 % of precipitation ever reaching the ground (Newson, 1992). This maybe an important balance to investigate in areas where rainwater harvesting and run-off storage are in use. The ability of trees to reduce erosion is important in controlling the siltation of tanks.

> Trees reduce erosion but also intercept rain.

Trees, and other perennial species generally have deeper root systems than annual crops, and can abstract soil water from deeper horizons. Trees can capture that moisture which would have normally been lost to drainage[7]. The water available to trees is thus greater than for crops, and trees are a useful way of obtaining an economic product (fuel, fodder, fruit) from otherwise too dry areas, allowing supplemental water to be focused on field crops. Trees can also be part of rain-water harvesting systems - Smith (1997) reports use of micro-catchments by KRIBP-E to establish multipurpose trees.

Though tree crops, such as coconuts, do respond to irrigation, these are less demanding of water than annual crops. Fatimson and Rao (1996) report that in Tamil Nadu, farmers are moving out of irrigated paddy into mango and coconut as they require less irrigation. The economics of food/marketable commodities per litre of water are worth investigation. However market opportunities may not exist in the same fashion in the project area.

> Trees can yield more economic product per litre water than paddy.

iii) Fallow

[7] Plantation blocks of trees, especially Eucalypts, can affect groundwater recharge in this way - extracting more water than falls as precipitation - water mining. (Calder *et al*, 1992).

Increasing the area under irrigated cropping can be detrimental if it leads to reciprocal increases in neglected dry land fallow. Gopal and Kumar (1995) report that in semi-arid Andhra Pradesh, the availability of cheap irrigation plus other policy measures and incentives, like cheap loans, have promoted irrigated rice production. This has led to lower rice prices, and thus less interest from consumers for foods from dry land crops like millet and sorghum. This has led in turn to increased areas of dry land fallow which become degraded without management, because marginal dry land farmers migrate to work as farm labour in irrigated areas. Similar negelct of land leading to increased areas of poor quality fallow are reported by Fatimson and Rao (1996) in Tamil Nadu. Gopal and Kumar therefore call for programmes to improve the productivity of marginal farmers' rainfed farming through SWC and watershed management. Integration of fish into wetland rice should take care not to exacerbate this trend.

8. Research for Water Management in Rainfed Farming Systems in N.E. India

Two Consultative Group on International Agricultural Research (CGIAR) initiatives are relevant to rainfed farming in N.E. India. The research under these programmes may generate new options for the systems under study. The programmes are the CGIAR System-Wide Initiative on Water Management (SWIM)[8], and the Rice-Wheat Consortium for the Indo-Gangetic Plains (RWC)[9].

SWIM is a two-stage process, initially producing state-of-the-art papers on each of seven key areas, and then undertaking targeted research in these areas. The papers are due in early 1998. SWIM is managed from the International Irrigation Management Institute (IIMI), and the seven areas are mainly focused on irrigated systems, but have relevance to the project area. They are:

- Measuring the Productivity of Water
- Productivity and Prevention of Resource Degradation in Irrigated Agriculture
- Water Efficient Irrigation for Rice-Based Systems
- Alternatives for Improving On Farm Water Use Efficiency in Water Scarce Areas (*the most relevant to this project*)
- Intersectoral Water Allocation in River Basins: Impact on Agricultural Growth and Environmental Sustainability
- Multiple Use of Water in Irrigated Areas at the Local Level
- Improved Water Utilization in a Watershed Perspective

ICLARM is involved with a SWIM project on Valuing the Multiple Uses of Irrigated Areas. The ICLARM programme on Integrated Aquaculture-Agriculture Systems is also highly relevant to this project since its objective is 'to improve small-scale farm productivity through participatory research on the introduction of multipurpose water bodies'. Its projects that are of relevance include:

- Reviews on Inland Aquatic Resources Systems
- Development of Sustainability Indicators for Integrated Agriculture-Aquaculture Farming Systems
- Research for Development of Sustainable Aquaculture Practices in three rice ecosystems

RWC aims to locate specific areas most seriously threatened; identify biological, physical and socio-economic causes of the problems; and develop, test and promote the implementation of strategies that will result in greater sustainability and higher system productivity. Its four main themes are:

- Integrated Nutrient Management (INM)
- Integrated Pest Management (IPM)
- Tillage and Crop Establishment (TCE)
- Water Management (WM)

It will be outputs from the last of these themes that will be most relevant to the project.

8 http://www.cgiar.org/iimi/swimra.htm
9 http://www.cgiar.org/rwc/obj.htm

Abrol (1997) reports that RWC recently identified researchable issues in water management for rice-wheat systems including:

- Conjunctive management of ground and surface water resources.
- Enhancing 'on-farm' water use efficiency by developing practical water application methods, schedules and appropriate water management techniques for rice and wheat for specific water supply situations.

RWC emphasised that water management research should occur across the spectrum of farm, irrigation system, and policy levels (cf. the IIED model).

9. Summary and Conclusions

In concluding, it must be noted that the weight of evidence from many developing countries, including India, is that better and more sustainable management of natural resources occurs where resource users act collectively (Pretty, 1995; Farrington & Lobo, 1997). The properties of water mean that sustainable water management is best approached at a large (greater than field) scale. Carruthers (1992) states that "water development is an area where participation and empowerment can have real meaning". Thus the options for better on-farm water management identified in this study, must be set in the context of watershed management and collective actions.

The paper has identified a number of options for improved on-farm water management from both the sub-continent and Africa, from both research efforts and farmers own technologies. These options are necessarily at a fairly high level of generality, they need to be informed by the local context and conditions. Ideas from local farmers need to be allowed to "trickle-up" to provide practical farm-scale insights into water management in the project area (Carruthers, 1992).

9.1 From Options into Activities

As has been shown in this paper, the project covers an area that is spatially diverse and temporally variable - an heterogenous physical environment. Furthermore the farming systems are complex, diverse and risk-prone (CDR). It should be clear from the participatory research exercise to which this paper contributes that single off-the-shelf 'package' solutions are not suitable in these circumstances. This final section of the paper outlines a system whereby the diversity of farming systems and environmental situations can be broadly classified into like groups for whom there are sets of options that can be further tested and developed through the participatory research process. Thus sets of options and activities are given as loci for participatory research; they should not be seen as prescriptive, but rather as topics which might usefully be considered in relation to water management. Because of the "systems nature" of water management, upstream and downstream cause and effect need to be taken into account in aquaculture development - these options provide a framework for that process.

i) Principle Objectives for Better On-Farm Water Management

The overall objectives for farmers in project clusters are detailed in the paper "Current Household Priorities in KRIBP-E Project Clusters, with a focus on West Bengal" (KRIBP-E, 1998 [this workshop]). This section deals specifically with objectives for water use. On the assumption that project farmers recognise water as a serious production constraint, if the supply could be improved, what would be their objective for use of that better supply?

> There is a need to undertake participatory research to establish farmers' objectives for better water management.

Fundamental here is the debate over the basis for decision making in farmers' choice of crop. The essential choice is water demanding rice versus dryland crops. How will the introduction of fish change the choice? However farmers' rationale is based on more than water, also highly important (if not more important) are the price of rice and the social status gained from being a rice producer rather than a small grain producer. The cropping pattern supports the perception that improved rice production would be one of main, if not *the* main, reasons for farmers wanting improved water supply. However there are many other reasons for improving on-farm water management:

- More secure rice production
- Better yield of rice
- Rabi cropping
- Increased surface water storage - for multiple use
- Increased surface water storage - for aquaculture
- Integration of fish culture into the production system
- etc

There is therefore a need to undertake participatory research to establish goals for better water management and classify farmers accordingly. This could commence with a brainstorming to capture the multiple perspectives on water management objectives.

ii) Assessing Water Use Possibilities

It is suggested that the next step in assessing options for on-farm water management is an assessment of the hydrological and agricultural conditions of the farm. Table 9 defines five categories of farm water resource status. In Table 10, the various land and water resource factors are itemised according to the water use type with which they are a best fit. These tables related to the water resource physico-technical potential as described by Turton & Bottrall (1997). However, it assumes that socio-economic and politico-instutional factors are constant.

Table 9. Category of water resource status

No.	Category	Type of water management option
1.	Ample cheap water - perennial surplus - maximise gains from the resource	Storage and multiple use for aquatic and terrestrial production
2.	Sufficient water with seasonal surplus	Maximise use of surplus with short cycle crops
3.	Sufficient water - but limited by access or cost	Collective or high value crop approaches to water use
4.	Shortage - seasonal deficit	Soil & water conservation
5.	Severe shortage - maximise conservation	Soil & water conservation; efficient cropping systems

Table 10. Categorisation of farm's land and water parameters

Parameter	Water resource category	Comment
1. Sources of water		
• Rainfall		
◊ High (> 1250mm)	1	High potential
◊ Medium (800 - 1250mm)	2 - 4	
◊ Low (< 800mm)	4 - 5	Dryland
• Ground water		
◊ Seasonal	2 - 3 /4	Record length of season with sufficient water
◊ Perennial	1	
◊ Artesian spring	1 - 2	
◊ STW/LLP	1 - 2 /3	
◊ DTW	3	
• Surface Water		
◊ CPR (e.g beel, river)	1 - 2, 4	Record perennial/ephemeral
◊ Private tank/pond	3	
◊ Public tank pond	1 - 2, 4	
• Conjunctive use of S & G	1 - 4	
2. Irrigation management		
(if uses irrigation)		
• Irrigation objective		
◊ Life saving	4 -5	
◊ Supplemental	2 - 4	
◊ Total	1 - 2	
Level of control of supply/access		
◊ Controlled	3	
◊ Unregulated	1 - 2 (4 - 5)	
Cost of water		
◊ High (pay-per-use, etc)	3	Typical of tubewells
◊ Low (annual fee, none)	1 - 2	Typical of tanks
3. Land resources		
Landscape position		
◊ Upland	4 - 5	
◊ Medium	2 - 4	
◊ Lowland	1 - 2	
Soil type		
◊ Coarse or compacted	4 - 5	
◊ Fine/clayey	1 - 2	

Once farms, or more probably clusters of households, are broadly categorised according to their priorities for water resources development and their land and water resource base, options and activities for that development can be identified from Table 11.

Table 11. Options and Activities for water resources management and development.

Options	Activities	Category most suited to	Development actions
1. Classification			
• Classify water resource base	Water resource audit (Individual/Community)	All	
• Identify farmers' objectives for water management		All	Brainstorm, and matrix rank options.
2. Technical/bio-physical			
• Water Conservation ◊ Reduce waste ◊ Increase resource capture In-situ (surplus to *nalas*) Run-off collection Rainwater harvesting	•} Assess relative benefits of increased soil stored moisture } with surplus going to tanks via *nalas* or dedicated run-off areas } to maximise tanks storage.	4 - 5	On-farm trials
• Better use (increase efficiency)	•Assess relative merits and acceptability of water efficient paddy cultivation methods, such as DDS, very shallow flooding, compacted bund walls. •Appraise cropping pattern for new opportunities for high water use efficiency/short duration rabi crops/intercrops.		Semi-structured interviews
• Reuse/Storage	•Assess options for tank/pond development. •Develop best practices to prevent sediment transfer to ponds. •Explore competing and complimentary uses for Artesian spring water.	1/ 2 -3 1 - 2	
3. Organisational/Social			
• Individual vs. Collective actions	•Undertake preference ranking exercises on individual vs. collective water management actions.	2 - 4	
• Upstream vs. Downstream impacts	•Undertake a systems review of all micro-catchment water management activities. Where are the net gains and losses?	All	

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11. List of Abbreviations & Local Terms

nala	Seasonal stream
CRIDA	Central Research Institute for Dryland Agriculture
NARS	National agricultural research system
ICRISAT	International Crop Research Institute for the Semi-Arid Tropics
KRIBP-E	Kribhco Rainfed Indo-British Project - East
IIMI	International Irrigation Management Institute
IIED	International Institute for Environment and Development
SEC	Socio-economic class
DDS	Dry direct seeded
RWH	Rain water harvesting

Studies for the workshop which are associated with this paper:

- Current farm household production objectives and priorities for technological change in relation to incorporating fish production into the farming system in identified research sites. (KRIBP-E)
- Rain-fed farming systems of India's eastern plateau: Products, production estimates, on and off-farm resources and their use - A baseline study. (KRIBP-E)
- Freshwater aquaculture in West Bengal: Production statistics, species, systems - A baseline study. (CIFA)
- Integrated aquaculture in small-holder farming systems - A review of current practices. (CIFA, KRBP-E, IoA)
- On-farm water management - A review of options. (Barr)
- Farmer participatory research - An appraisal of current best practice. (Lawrence)

12. Annex 1. Maps

Map 1. Chotanagpur Region

Map 2. Orissa High;and Region

Map 3. Lower Ganga Plain

13. Figures

Figure 2. Schematic of an idealised hydrological cycle in a dryland production system.

Figure 1. The conditions for sustainable agriculture.
(after: Ptretty, 1995)

Figure 3. Growth of cereal crop in relation to moisture availability.
(after Gibbon & Pain, 1985)

Figure 4. Water used for wetland rice production
(after Greenland, 1997)

Figure 5. Traditional and modern, intermittent irrigation of rice (in Japan).
(after Greenland, 1997)