An approach to valuing ponds within farming systems for aquaculture

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1. Introduction

According to Morris, Weatherhead, Dunderdale, Green & Tunstall (1997), water is an unconventional economic good because it is:

- a 'fugitive' and re-usable good,
- a public good and often under common property regime,
- a stochastically supplied and distributed resource,
- subject to economies of scale in provision,
- essential to plant and animal life, with no substitute,
- associated with many non-market environmental qualities and values.

In the context of arid and semi-arid climates, where water resources are scarce and where multiple uses of water have to co-exist to support a variety of life systems, competition for the products and functions of water resources (see Box 1) is likely to be intense and to involve problems of opportunity costs and externalities (Hodge & Adams 1997).

Opportunity costs may be defined by the 'sacrifice' made, and its related forgone income, in allocating a scarce resource to a particular purpose rather than another (Pearce & Turner 1990; Lipsey & Harbury 1992). For example, at the farm level, integrating aquaculture within irrigation systems may lead the farmer to face two different 'dilemmas' during the dry season when water scarcity is felt more strongly:

- Either use pond water to irrigate vegetables/fruits/rice crops OR keep it to stock fish for later consumption.
- Either use feed or some sort of fertilisation to enhance pond culture OR use 'untreated' pond water for livestock and household use. (Pant & Demaine 1998 with reference to Thailand).

If the farmer makes the right choice, its financial consequences are likely to be positive, since the foregone benefit of the non-adopted option, or 'bad' choice, should be lower than the financial benefits of the 'good' choice. In theory, it should be possible to attain a point of equilibrium where the benefits of all water uses are maximised. However, as will be detailed further, a high number of factors and uncertainties compose the 'choice' function and render decision-making a highly complex process. One of these difficulties relate to current land use patterns, in particular when these are unplanned. For example, the planting of deep-rooted perennials close to water bodies might increase the rate of water loss during the dry season. Eucalyptus has been planted extensively as an economic source of timber and pulp and is often planted as boundaries. Such species do not require 'watering' but are very important in the overall farm surface/ground water balance. In addition, if surface water bodies are sited in areas with higher ground waters, they may have much more water available for longer in the year. This illustrates the importance of considering the OFR as an element of the whole ecosystem and not in isolation from biological, geographical, geological, hydrological etc. components.

Negative externalities, or uncompensated losses of welfare, associated with water quantity and quality left in a system after extraction and/or increased irrigation-induced salinity levels, are likely to be borne by people who "have not contracted to accept them, nor will receive compensation for them" (Hodge *et al*. 1997). Some freshwater fish species are found to perform good growth rates in saline environments, however, many crop yields are affected adversely by salinisation (Agnew & Anderson 1992). Thus if irrigation externalities remain non-internalised due to the existence of high transaction costs (i.e. costs of gathering the necessary information, establishing contracts, reinforcement etc.), that is if the cost of land rehabilitation or of measures required to keep salinity levels low are not included in water 'bills', farmers who do not practice aquaculture may be the ones bearing these costs the most heavily.

Conversely, surface irrigation may also have positive externalities through the recharge of the aquifer underneath the field, which in turn, may be used for irrigation purposes (Briscoe 1997). As both salinisation and aquifer recharge are likely to occur simultaneously, the natural ecosystem will be able to stand an optimum level of externality defined by the marginal economic cost due to salinity, the marginal benefit of recharging the aquifer and the optimal point of salinity (S*), as shown on Figure 1 at the end of the document. Another positive externality would be the possibility to introduce and grow black tiger shrimp (*Penaeus monodon*) in inland saline areas, instead of using sea water for its acclimatisation.

Box 1: Products and functions of water resources

Products	Functions
- Fisheries and other aquatic plants and animals - Other wildlife resources supported (but not dependent upon) water habitats - Drinking water supply - Water supply for other uses (e.g. bathing, washing, cooking, religious uses etc.)	- Geomorphological agent fashioning the shape of the earth - Vital input to biophysical resources, groundwater recharge/discharge - Means of transport of materials and nutrients - Means of dissolution (disposal) of wastes - Component of productive processes (agriculture, industry, energy) and support for recreation and tourism - Micro-climate stabilisation - Integral part of nature and focus of environmental interest.

Developed from Pigram 1997 and Dixon & Padman 1997.

Recognising the existence of opportunity costs linked to the use of water implies the recognition of the "intersectoral competition" for water resources (Meinzen-Dick 1997) not only at a large scale between cities and rural areas, but also at the local and household/farm level. The difficulty arises in 'costing' the multiple uses of water for livestock consumption, domestic water supply, non-agricultural activities (e.g. cottage industries), environmental benefits and aquatic production. Intuitively speaking, it is likely that the *value* of these uses, although usually remaining un-costed because of direct consumption and use for subsistence, will be higher than the financial and economic gains brought by irrigation for purely agricultural purposes (*ibid*.). In addition, integrating aquaculture within irrigation systems involves the simultaneous use of water, land, labour, fertilisers and credit, leaving farmers facing 'dilemmas' and opportunity costs related to the use of each of these uses for crop irrigation or aquaculture enterprises. Choices made by farmers to select one use over another will themselves be dependent on factors such as household size, farm typology[1], sex and age of the decision-maker and his/her perception of risk associated with the use of one resource over the other. Decisions made by farmers for one use of their water supply rather than another can therefore not be explained by profit maximisation theories only (Chancellor 1997). In the context of developing countries, they may be more correctly explained by risk minimisation and auto-consumption and have to take into account market imperfections, household relationships, and the social dimension and implications of the decisions made (Strosser & Rieu 1997).

2. Review of existing costs and benefits studies on the use of on-farm reservoirs (OFR) in small scale farming systems.

As mentioned previously, two of the dilemmas faced by farmers when water scarcity is problematic relate to the competition between water requirements for crop production or fish production, and to the use of fertilised water for crops and/or fish (i.e. costed use) or keep it clean for human use (drinking, bathing, etc. i.e. non-costed use).

Moya, de la Viña and Bhuiyan (1994, with reference to Thailand) found that water used for irrigation of crops was given the priority over fish culture as water storage becomes limited during the dry season, farmers preferring to eat under-sized fish rather than risking to compromise their rice crops. This paper presents a comparison between on-farm reservoirs (OFR) users and non-users (i.e. pure rainfed farmers), with costs of production and net benefits, along with cost and benefit ratios for different types of irrigation systems. They found that fish culture returns were about US$210 per year, twice the costs of constructing an OFR and five times the value of the forgone crop cultivated on the area used by the OFR. In this particular instance, this means that the opportunity 'benefit' to do fish culture in a defined

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[1] "Farm typology" is defined by the combination of (1) the farm characteristics, i.e. owned area, land tenure status, family labour, tractor and oxen ownership and tube well ownership. (2) the physical environment, i.e. soil and irrigation water quality, degree of salinity which may be indirectly measured with compared crop yields. (3) the access to water resources, i.e. tube well ownership and adequate irrigation water supply at the farm level. (4) a risk aversion factor which may be expressed through the number of crops in the cropping pattern used (Strosser 1997)

OFR area is higher than the opportunity 'cost' of growing rice on a patch of land of equal size. Regarding opportunity costs and benefits linked to the use of water, Syamsiah, Suprapto, Fagi and Bhuiyan (1994) showed that, in Indonesia, the loss of crop production from a 100 m2 land used for an OFR is negligible (equivalent value of US$7.0) compared to the benefits brought by the overall increase in rice production, the possibility to grow vegetables and fruits in the second dry season and fish during the wet season. Both studies therefore suggest that having an OFR will bring benefits in terms of both increased fish and crop production when these are carried out *separately*. However, competitive uses of water and their related opportunity costs, along with fertilisers opportunity costs, will occur at the farm level. One may therefore be a limiting factor to the full production of the other and the aim of the present study is to assess the extent to which one will be a limiting factor, and if a balance is achievable between both productions using the same OFR.

Complementary to Moya *et al.* (1994)'s study can be added data of farm costs and benefits for wet and dry season rice and for fish production for OFR adopters (Fujisaka, Guino, & Obusan 1994) which show that farmers with OFR benefited from the addition of fish culture in combination with two-season (dry and wet) rice production. This study also highlighted the fact that, high input and low input fish culture resulted in similar yields, thus high input fish culture resulting in lower outputs. Farmers rearing fish with high inputs were reluctant to release water in their rice fields during the dry season, which in turn resulted in lower rice yields, and meant that farmers were loosing on both fronts. Their practice of aquaculture is thus inefficient and requires a multi-disciplinary approach to integrate it successfully in OFRs. This suggests that a simple decision support model which takes into consideration both fish and crops requirements in terms of water and fertilisers has to be designed to improve the rationale behind farmers' choices of water allocation. In such water-short environments, the species of fish chosen will be of high importance, not only for the financial returns that may be expected from them, but also for their biological adaptations to water shortages. In this context, air breathing fish (e.g. Hybrid *Clarias* catfish nursing rather than growout of carps etc.) may be preferred. The importance of the choice of fish is developed in section4.

In Eastern India, the use OFR for supplementary irrigation of rice fields has increased yields significantly. In lowland areas in particular, over 60% of OFR construction costs could be recovered in one year through benefits such as control of water levels in rice fields (less flooding and irrigation when required), drainage improvements for vegetables grown after rice, water for vegetables and fish cultures (Pal, Rathore & Pandey 1994). In midland areas, if US$225 per year of net returns from the OFR, its construction costs (US$400-600 + interest) could be recovered in 3 to 4 years (*ibid*.). In the Hazaribagh District, Bihar, it was found that the cost of a 2-ha OFR (US$350 per ha) could be compensated in 4 years with the additional return from wet season rice alone (yield increase of 0.8 t/ha due to irrigation (Paul & Tiwari 1994). The timing of water use during the agricultural cycle in terms of matching the needs of the different crops is crucial for the overall productivity and efficiency of the OFR use. This is detailed in the following section.

3. Use of OFRs for agricultural purposes

Given the arid or semi-arid areas in which small-scale irrigation takes place, it does not appear rational to plan to use irrigation water to grow crops during the dry season when high rates of evaporation, seepage and percolation make the culture of flooded rice inefficient and unsustainable (Guerra, Watson & Bhuiyan 1994). The purpose of many irrigation systems is therefore to provide supplementary water to crops cultivated during the wet season and to extend its length both before and after the rains, represented in Figure 2 (at the end of the document) by zones [A] and [B].

Although OFRs do not need to be 'full', i.e. to have reached their maximum capacity, to support fish culture, fish growth is higher when water is plentiful. If there is a market demand for small fish (e.g. Bangladesh), fish raised during the monsoon months will only have to reach the preferred market size (i.e. small). This thus means that competition for water between agriculture and aquaculture will be somehow limited. However, if the preferred market size is for larger fish, it is unlikely that the rainy season will be long enough to support the complete fish growth. Months 'outside' the wet season, in zones [A] and [B], will be required to complete the growth cycle using extra water provided by OFRs. At the same time, OFRs will also be fulfilling their role of supplementary water provision for crops. During this time, competition for water resources will therefore reach a peak, and so will the opportunity costs of water use. However, typically prices are lowest when waters are receding and wild fish are most easily caught which makes zone [B] not the most favourable time to sell cultured fish. The most valuable role of OFRs for aquaculture will be in their possibility to hold fish to a period after this surplus, commanding higher fish prices. While matching specific market requirements, there will also be a need to investigate how fish and crop growth cycles can be 'spread' over the year in order to reduce the intensity of water requirements for both activities, and thus reduce the negative effects one use of water may have on the other. In this context, the selection of crop and fish species will be of crucial importance. However, the potential socio-economic impacts of the introduction of 'new' species on communities, along with the target groups' perception of innovation, their motivations and fears to adopt new technologies will also have to be investigated.

3.1 Opportunity cost of land use

The opportunity cost of land use relates to the 'dilemma' of digging an OFR in an area which could otherwise be cultivated. If fish are added to the pond, this leads, further down the line, to comparing the value of high quality product ($/unit weight, produced through fish) and low value product (produced through grain crops). The former, richer in crude lipids and proteins is typically more valued than grain crops, but larger numbers of people can be supported on staple, cereal crops which are also typically exportable. Hence restrictions put on fish pond construction in some areas where governments want to maintain rice production.

The aim of the spreadsheet presented below (Table 1) is to compare the yields and returns of two farms of equal sizes (3ha), one (farm 1) using a portion of its land as an OFR, the other one (farm 2) not, when fish culture is not practised.

Table 1: Comparison of yields and returns provided by an OFR farm and a non-OFR farm

	Farm 1 (OFR user)			**Farm 2 (non-OFR user)**		
	Wet season	Dry season	Total	Wet season	Dry season	Total
Total farm area (ha)			3			3
OFR surface (ha)			0.14			0
Cultivable area (ha)			2.86			3
Area cultivated (%)	100%	39%		100%	0	
Area cultivated (ha)	2.86	1.12		3	0	
Yield (t/ha)	2.8	2.3		2.5	0	
Production (t)	8.0	2.6	10.6	7.5	0	7.5
Value of output ($/t)	148	148		148	148	
Gross returns ($)	1185	380	1565	1110	0	1110
Variable costs ($)						
Fertiliser ($/ha)	34	34		33	33	
Tot. fertiliser cost ($)	97	38	135	99	0	99
Pesticide ($/ha)	8	8		7	7	
Tot. pesticide cost ($)	23	9	32	17.5	0	17.5
OFR digging costs ($/m3)			0.39			0.39
OFR capacity (m3)			2670			0
Total digging costs ($)			1041			0
OFR life (years)			15			15
OFR cost/year ($)			69			0
Total variable costs per year ($)			236			116.5
Net returns per year ($)			1328			993.5

Data used:

Average area occupied by OFR in Philippines: 0.14 ha approx. (Moya *et al*. 1994; Undan, Tabago, Collado, Jr. & Manabat 1994). If we assume that the total farm area (3ha) includes an OFR, then 2.86 ha are left for crops.

Cultivable land farm 1 = 2.86 ha
Cultivable land farm 2 = 3 ha

Rice yield under irrigation conditions (OFR users) =5.1 t/ha (2.8t/ha during WS + 2.1 t/ha during DS)
Rice yield under rain fed conditions (OFR non-users) =2.5 t/ha (2.5 t/ha during WS only) (e.g. Philippines, Maglinao, Vergara, Belen & Jovellanos 1994)

Value of output: US$ 148/t of rice (e.g. Philippines, Maglinao *et al.* 1994)

Digging costs of an OFR: $0.30/m3 (e.g. eastern India, Pal *et al.* 1994)

This table shows that even though an OFR reduces the cultivable farm area, it still increases the farm net returns by 33%.
It would be interesting to 'run' the table to find the equilibrium point, i.e. when too much land is occupied by water and the pond water (still without fish) does not provide extra value. At this point, fish may be added to the OFR. This suggests that transforming low value land (in particular land prone to flooding) into a reservoir/pond to growth fish would enable to increase the value of poor quality land. It also suggests that it may be worth comparing high value land and low value land for the sitting of OFRs.

The same kind of model should be elaborated for fish production (aquaculture water requirements and length of crop and fish growth cycles given the seasonal natural of water storage). Costs and returns may be evaluated at a later stage with different results obtained from the running of the models.

3.2 Crop yield response to irrigation:
General work of irrigation economics (Carruthers & Clark 1981) comprising functions of crop responses (incremental yield) to irrigation (incremental water supply) can serve as a basis for the development of simple models. Figure 3 at the end of the document illustrates crop yield response to water inputs.
Based on basic resource economics (Neher 1993), the increase of yield ($G(y)$) is a function of the level of water input (w). Given the susceptibility of some crop species to water logging, $G(y)$ will reach a maximum when w = w^M, declining after this value has been reached. The optimal water input is obtained when the derivative function of $G(y)$ is equal to zero, that is when:

$$\frac{dG(y)}{dw} = G'(y) = 0 \cdot$$

The value of w solving this equation is w^M , also called 'stationary point': $G'(w^M) = 0$.

Although linear functions are simplifications of reality, they have been used in models estimating the marginal value and hydrological impact of agricultural irrigation (O'Callaghan 1996). Such functions do not include factors such as water evaporation, plant transpiration, sporadic rainfalls etc. and assume that the timing of water input is unimportant, i.e. if water is applied once or throughout the growing season. However, provided that these constraints are borne in mind, these models provide a measure of the marginal response of a particular crop to a certain level of irrigation and a checking base of the economic returns per crop per hectare under irrigation or rain-fed conditions.
In the context of OFR, work has been carried on the elaboration on decision support models to maximise crop returns using on-farm irrigation systems. Sayco, Angeles and Bhuiyan (1989) designed a simple linear programming technique of water allocation to different crops to maximise yields and returns without consideration to the seasonal nature of rainfall. From this, Galang and Bhuiyan (1994) proposed a decision support model composed of four sub-models estimating: 1. The water supply reliability, 2. The seasonal water supply, 3. The reservoir operation simulation, 4. The crop area allocation, to optimise economic returns from resource allocation (i.e. water) in farms with rainwater storage facilities. Their model aimed at maximising net returns for cropping rice (1), soybean, peanut and mungbean under several limiting conditions, such as limited water supply (2) or limited cultivable area (3), and limited capital (4), as shown below:

$$Max\ P = \sum_{i=1}^{n} RiXi \qquad (1)$$

subject to

$$\sum_{i=1}^{n} Wi_1 Xi \le W_2 \qquad (2)$$

$$\sum_{i=1}^{n} Xi \le B \qquad (3)$$

$$\sum_{i=1}^{n} Ci_1 Xi \le C_2 \qquad (4)$$

where
Π = total net return (profit) in US$
Ri = return per unit area of the ith crop
X_1, X_2, X_3, X_4 = area (ha) of soybean, peanut, mungbean and rice respectively
Wi_1 = water requirement (m3/ha) for crop i
Ci_1 = capital requirement (US$/ha) for crop i
W_2 = seasonal water supply (m3)
C_2 = total available capital (US$)
B = total farm area (ha)
n = number of crops = 4 in the present case.

In Strosser's (1997) farm stochastic linear programming model, the water constraint includes the use of irrigation water and its related additional costs. In Pakistan, farmers irrigate their crops once a month on average, so the month can be considered as the temporal unit for water requirements.

$$\sum_{i} (iwr_{it}.X_t) - TW_{St} - TW_{Pt} \le cws_t$$

$$\forall t \in \{Jan, Feb, ..., Dec\}$$

Where, X_i = area (ha) of crops selected in the cropping pattern,
Iwr_{it} = irrigation water requirements ($m^3.ha^{-1}$) for crop i and month t
Cws_t = canal water supply (m^3) available at farm for month t
TW_{pi} = quantity (m^3) of tube well water purchased per month t
TW_{si} = quantity (m^3) of tube well water sold per month t

Irrigation water requirements for crops at various times of year and period of growth, given a defined level of rainfall, can be obtained from the CropWat FAO software. Water requirements for the Chistian Sub-division of Pakistan are provided in table 2.

Table 2: Irrigation water requirements (met at 100%) for crops grown in the Chistian Sub-division of Pakistan

Month	J	F	M	A	M	J	J	A	S	O	N	D	Total	No. months
Early cotton	0	0	0	0	359	981	837	1414	1294	1045	247	0	6177	7
Middle cotton	0	0	0	0	0	846	486	1272	1294	1172	512	0	5582	6
Late cotton	0	0	0	0	0	394	239	953	1276	1197	527	0	4586	6
Rice	0	0	0	0	710	3400	1550	1723	1511	548	0	0	9442	6
Sugarcane	0	83	396	1062	1706	2069	1002	1116	1030	1002	598	221	10285	11
Kh. Fodder	0	0	0	0	0	986	789	1355	1074	231	0	0	4435	5
Early wheat	424	658	535	0	0	0	0	0	0	0	122	252	1991	5
Middle wheat	199	613	1018	939	0	0	0	0	0	0	0	99	2868	5
Late wheat	75	311	1004	1514	343	0	0	0	0	0	0	0	3247	5
Rb. Fodder	336	488	750	360	0	0	0	0	0	753	703	476	3866	7
Total	1034	2153	3703	3875	3118	8676	4903	7833	7479	5948	2709	1048	52479	

Developed from Strosser 1997.

Because of the importance of rice, sugarcane, kharif fodder and rabi fodder for subsistence, it can be assumed that farmers will meet 100% of the water requirements indicated by CropWat. However, for the other crops, farmers may practice deficit irrigation and meet, for instance, only 75% and 60% of the water requirements for these crops (wheat and cotton). Table 3 shows the ranking of crops by decreasing water requirements, when these are met at 100, 75 and 60%; those for rice, sugarcane, kharif fodder and rabi fodder being met at 100% in any case.

Table 3: Ranking of crops by decreasing water requirements, when these are met at 100, 75 and 60%.

100%	75%	60%
Rice	Sugarcane	Sugarcane
Sugarcane	Rice	Rice
Middle wheat	Rb. Fodder	Rb. Fodder
Rb. Fodder	Middle wheat	Middle wheat
Early cotton	Middle cotton	Middle cotton
Middle cotton	Late wheat	Late wheat
Late wheat	Late cotton	Late cotton
Late cotton	Kh. Fodder	Kh. Fodder
Kh. Fodder	Early wheat	Early wheat
Early wheat	Early cotton	Early cotton

Results of the ranking are similar when plants water requirements are met at 75% and 60%. However, the stress to plants induced by water shortages is likely to affect crop yields. If economies of water are realised by practising deficit irrigation, one may make sure that the resulting loss in yield is balanced by an increased value of water through the introduction of fish culture for example.

As shown in table 2, the number of months during which crops require water vary considerably from one species to the other. If irrigation is provided by an OFR of definite capacity, these two factors are important for the planning of multi-cropping. This is illustrated in Figure 4 hereafter.

Garg & Ali (1998) developed a two-level optimisation model for the Lower Indus Basin to schedule the crops sowing dates so that the peak water requirements for the crops are more evenly distributed over the year, and hence larger areas can be irrigated with the same reservoir or canal capacities. This is simply illustrated in Figure 4 with for example, the farming of rabi fodder and late cotton.

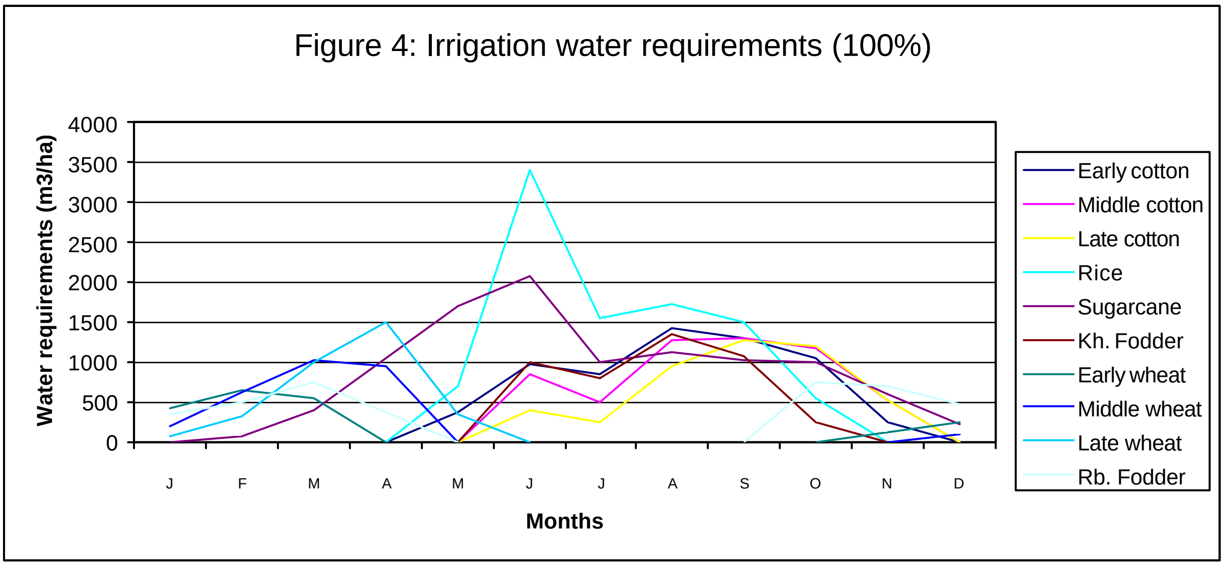


Figure 4: Irrigation water requirements (100%)

3.4 OFR in cropping systems

Water requirements for crops are not even throughout their growth period and throughout the year (Table 2). OFRs capacity also depends on rainfall, runoff, seepage etc. Although the seasonality of OFRs may be their greatest constraint, one may take advantage of it by making a more intensive and profitable use of the 'secondary' resources they provide (e.g. nutrient-rich sediments) during the dry season, when their water capacity is at its lowest. Dike cropping of high market value vegetables on the edges of ponds is an example of use maximisation of traditional reservoirs (Korn 1996). Regarding the use of slurries (higher water content) and sludge (higher dry matter content), two different uses may be made of them, both with different costs (labour costs and/or requirements for suitable equipment). First, they may be used *in situ* during the dry season, when water has receded and the exposed nutrient- rich sediments are planted with high value vegetable crops for example, using water from the 'puddle' left at the bottom of the reservoir (Figure A at the end of the document). The second option may be to move sludge and slurries by pumping from the bottom of the reservoir to its edges to practice dike cropping (Figure B at the end of the document). In the first case, only human labour is required and costs related to the use of suitable equipment to move the mud are null. In the second instance, costs will be increased since both labour and equipment/machinery will be required to do the operation of moving sludge and slurries and planting of crops). However, this option enables to cultivate higher value crops when the reservoir is still full, during the wet season, i.e. to extend the cropping season, and therefore, assuming that there is a market demand for vegetables during the wet season, increase and spread financial returns over a longer period. The OFR design is therefore crucial to enable:

- the maximisation of slurries and sludge use at the minimal cost
- the facilitation of year-round fish culture and fish catch at the minimal cost.

Some examples of OFR designs are presented in Figures C and D at the end of the document.

The use of OFRs as a supplementary source of irrigation water proved to increase yields significantly and to enable the culture of post-rainy season vegetables with the remaining OFR water (Pal *et al*. 1994). Some study results are depicted in Table 5.

Table 5: Grain yield (t/ha) and returns (US$) provided by the culture of crops under rainfed and OFR irrigation conditions:

	Rainfed		With OFR		Source
	Yield (t/ha)	Returns (US$)	Yield (t/ha)	Returns (US$)	Eastern India Pal *et al.* 1994
Rice (1)	1	np	3.4	33.2 (3)	
Soybean and pigeonpea (1)	0	np	2.56	317.9 (3)	
Gram (2)	0	np	1.1	66.5 (3)	
Mustard (2)	0	np	0.8	32.1 (3)	
WS rice	5	304.9	4.9	298.8	Indonesia Syamsiah *et al.* 1994
DS rice	2	121.9	1.92	117.1	
DS seed water melon	0	0	0.4	195.1	
Banana (bunch)	0	0	0.04	19.5	
Rice local variety	2.38	np	3.5	np	Bangladesh Islam Md., Siddiqui, Hassan, Md., Islam, Md., Musa & Kar 1994
Rice modern variety	2.9	np	5.1	np	
WS rice	2.5	162.5	3.0	822.0	Philippines Moya *et al.* 1994
DS rice	0	0	2.3		

(1) Rainy season cropping; (2) Post-rainy season cropping; (3) Returns above variable costs due to OFR. np = not provided.

3.4 Crops cultivated:

Most of the major crops are grown on irrigated land. The application of animal manure tends to be restricted to cash crops and the more specialised foods grown around the homestead (Norman, Pearson & Searle 1984).

Table 6: Main crops grown and their uses in Karnataka (India):

	Consumption	Market	Fodder	Fuel	Land type
Cereals					
Sorghum (*Sorghum bicolor*)	***	*	**		IL & DL
Pearl millet (*Pennisetum americanum*)	***	*	**		IL & DL
Maize (*Zea mays*)		***		*	IL
Wheat (*Triticum aestivum*)	**	**			IL
Pulses					
Red gram (*Cajanus cajan*)	*	*	*	*	IL &DL
Green (*Phaseolus radiatus*)and horsegram (*Vigna radiata*)	*		*		IL &DL
Oilseeds					
Groundnut (*Arachis hypogaea*)		***	**	*	IL
Thill (?)	*	*		*	DL
Sunflower (*Helianthus annuus*)		***		*	IL &DL
Cotton (?)		***			IL
Vegetables	**	***			IL

Importance: * = least, *** = most

For livestock consumption and fuel, only hay or husks are used.

Irrigated land (IL) yields 2 harvests (kharif and rabi), dry land (DL) only one (kharif).

Kharif = the first growing season (June to October); Rabi = the second growing season (November to March).

Vegetable crops include aubergine, chilli, cucumber, garlic, okra and tomato.

Source: Integration of aquaculture in farmer-managed Working Paper No. 5 (July 1998).

In Tamil Nadu, dominant wet crops grown are paddy, turmeric, sugar cane and banana because of the water availability and the higher market prices (J. Robson, pers. com.).

Table 7: Biological characteristics of the main tropical crops

RICE (*Oriza sativa and O. glaberrina*)	
Main characteristics	3 classes: upland rice; wet or padi rice, grown in water < 1m deep; deep-water rice, grown in water 1-6 m deep.
Growing season	140 days average.
Salinity resistance	? (Farmers plant rice on saline soils as a mitigation measure (Kuper 1997).
Susceptibility/tolerance	Sensitive to temperature. Water availability particularly important during the period of anthesis and grain filling (later phases of growth): deficit during this time will affect grain yields.
MAIZE (*Zea mays*)	
Main characteristics	Has a substantial place in Asian cropping systems as a 2nd crop in association with legumes or vegetables following a 2nd wet-season rice crop
Growing season	In a maize/upland rice/cassava crop cycle, quick maturing maize is planted in the early wet season (September), cassava is inter-planted 4-6 weeks later. Maize is then harvested in the following January (130 days as average crop growth period), rice in February and cassava in June
Salinity resistance	Soil salinity has to be inferior to 2 dS m^{-1} in the top 50 cm (at a temperature of 25 °C)
Susceptibility/tolerance	Susceptible to water logging (more than sorghum)
SORGHUM (*Sorghum bicolor*)	
Main characteristics	Important crop in some irrigated cropping systems and can subsist with irregular water supplies
Growing season	Average crop growth period for sorghum is 110 days
Salinity resistance	Suitable soil salinity has to be inferior to 4 dS m^{-1} in the top 50 cm (at a temperature of 25 °C)
Susceptibility/tolerance	Tolerance to water deficit but also stands water logging better than maize, which makes it a preferred crop to maize on clayey soils in high rainfall areas or low topographic sites
PEARL MILLET (*Pennisetum americanum*)	
Main characteristics	Adapted to grow on low fertility soils, but will absorb large amounts of nutrients when fertilised or grown on richer soils. In India, pearl millet is found in intensive irrigated cropping systems, in conjunction with grams, forage sorghum and wheat (Punjab) and with groundnuts, rice and sugar cane (Tamil Nadu).
Growing season	Average crop growth period for pearl millet is 100 days
Salinity resistance	Resistance to salinity: germination is retarded but established plants are able to reach maturity on dilute (1%) sea water and produce yields as high as with irrigation water
Susceptibility/tolerance	Susceptible to water logging.
GROUNDNUT (*Arachis hypogaea*)	

Main characteristics	Commonly found rainfed summer crop in wet-and-dry climates. In south and south-east Asia, groundnuts may be a wet-season substitute for rice, or more commonly a dry-season crop following rice, often under irrigation conditions. .. In India, they may be cultivated in conjunction with pigeon pea (*Cajanus cajan*) and cotton
Growing season	100 to 160 days are necessary between emergence to maturity
Salinity resistance	Suitable soil salinity has to be inferior to 4 dS m^{-1} in the top 50 cm (at a temperature of 25 °C)
Susceptibility/tolerance	Yields are function of soil water availability and increased yields have been reported in irrigated environments
SOYBEAN (*Glycine max*)	
Main characteristics	Usually grown as a sole crop in sequence with other crops, but sometimes inter-cropped. In S-E Asia, important role as a secondary crop in intensive cropping systems based on wet rice.
Growing season	?
Salinity resistance	?
Susceptibility/tolerance	End-season water deficits reduce all yield components (pod, flower and grain). Sensitive to soil acidity.
CHICKPEA (*Cicer arietinum*)	
Main characteristics	India = 70% world production. Adapted to rainfed soils of moderate fertility. May be grown as a sole crop but is often mixed with wheat.
Growing season	90-110 days at Hyderabad (latitude 17ºN) 140-180 days at Delhi (latitude 28ºN). Often sown as an early dry-season crop in the wet-and-dry tropics.
Salinity resistance	?
Susceptibility/tolerance	Susceptible to diseases and water excess
BANANAS (*Musa spp.)*	
Main characteristics	Grown in the wet, wet-and-dry and cool tropics. Bananas and plantains growing around villages are fertilised with various forms of organic waste which can increase yields significantly. Multiple use of the plant (fuel, fertiliser, roofing, feed for livestock, food for humans, etc.)
Growing season	Planting at the start of the wet season. 6-8 months from planting to bunch emergence in Malaysia, 9.5-13 months in New Guinea. Then 100-120 days from bunch emergence to harvest. Total: 8.5-11 months in Malaysia, 12-16 months in New Guinea. Irrigation reduces the time to bunch emergence (365 days average).
Salinity resistance	Moderate tolerance (up to 0.5 g/l). Plants and fruits affected when levels rise below this value.
Susceptibility/tolerance	Susceptible to lodging and water deficit (shallow roots)

From Norman *et al*. 1984

In addition, turmeric requires 10 months to reach maturity, sugar cane about 12 months (J. Robson, pers. com.).

The length of growth of crops in mixed or multi-cropping systems is not only important for the investigation of its compatibility with fish farming in terms of competition for water, but it is also of importance in terms of labour availability. In areas where two seasons of paddy are grown in large quantities, labour is in high demand over a more extended period. Labour requirements for different crops (expressed in hr/ha) are presented in Table 8.

Table 8: Labour requirements for the main crops (Chistian Sub-division, Pakistan)

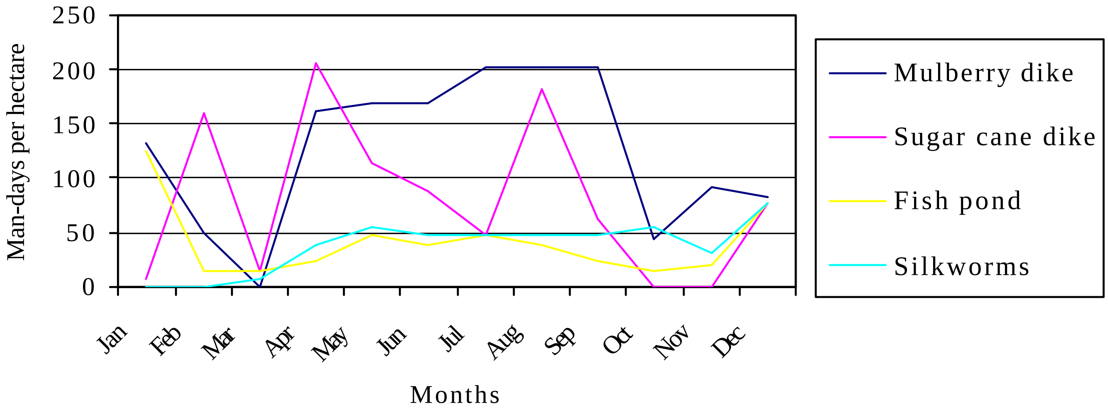
Crop	Total labour requirements (hr/ha)
Rice	520
Sugar cane	1025
Cotton	440
Kharif fodder	700
Wheat	180
Rabi fodder	1300

(Strosser 1997)

As underemployment is a major constraint for many landless people in rural areas months, the opportunity cost of labour invested in aquaculture rather than agriculture is likely to be important, because fish farming is a labour-demanding activity in itself and involves a high level of risks, especially in the starting phase of the activity. Figure 5 illustrates the labour requirements for the cultivation of a dike-pond system in China which components are fish culture, mulburry and sugar cane dike cropping, along with silkworm culture (Ruddles &Zhong 1988).

The cultivation of mulberry is the most labour intensive and spread throughout the year, compared to the culture of sugar cane which peaks during dike preparation, planting and harvesting (February to May) and in August when several management tasks have to be performed. Annual pond maintenance (ponds refilled and stocked with fingerlings) for fish culture in December and January is the highest labour requirement, although a higher number of men-days are required in May for more pond maintenance (draining of excess water during the wet season) and harvest in July and August. Not only labour requirements are different for each activity, but their costing is also likely to be different since, as indicated by Ruddle *et al.* (1988), time consuming tasks requiring a low energy input may be performed by children, women or other family relatives (possibly elderly). The real cost of the time of these categories of people is likely to be incorporated in the final product price. However, division of labour between age categories and sexes and its costs has to be investigated to ensure that the trade-offs and costs implied by the introduction of fish farming in irrigation systems are not borne unfairly by disadvantaged groups (women, young kids).

Figure 5: Yearly labour requirements (man-day/ha) of a dike- pond system in the Nanshui Brigade, China.



Developed from Ruddle *et al*. 1988.

3.5 Problem of salinisation and implications

Salinisation is one of the many problems faced by irrigation systems around the world and is partly caused by an excessive use of water (Agnew *et al*. 1992). The use of saline water for irrigation affects yields since some plants and crops are more sensitive or resistant than others to saline environments (Table 7). Yield response to saline water has been studied for a number of crops (Hussain, Al-Jaloud, Al-Shammary, Karimulla & Al-Aswad 1997: e.g. of barley (*Hordeum vulgare L*.); Chopra & Chopra 1997: e.g. of wheat (*Triticum aestivum*)). In this context, farmers are faced with economic choices related to:

- the optimal use of irrigation water of a given quality,
- the reuse of drainage water (i.e. the "non-consumed fraction of the irrigation water already diverted" (Willardson, Boels & Smedema 1997),
- the potential reduction in income linked to the use of saline drainage waters, optimal rate of mixing good quality water with saline irrigation water (Datta, Sharma & Sharma 1998).

Part of this decision can be rationalised by referring to crop production functions under various conditions. A computerised salt-tolerance database management programme, SALT-DATA has been developed to estimate the crop growth response as a function of soil salinity (Ulery, Teed, Van Genuchten & Shannon 1998) and thus decide which crops are best to be grown in a particular area. However, farmers have long been using their experience and indigenous knowledge to develop mitigation strategies to the problem of salinisation on agriculture. These can be divided in four categories and are summarised hereafter (after Kuper 1997).

Water management:

- Maximise canal or reservoir water quantity
- Minimise tube well water use
- Selection of tube well with the best quality water
- Mix tube well and canal/reservoir water
- Improve intra-farm water allocation
- Increase frequency of irrigation
- Leaching prior to sowing

Crop choice:

- Plant priority crops in non-saline fields, secondary crops in saline fields
- Leave saline fields fallow
- Plant rice
- Plant salinity resistant and salinity tolerant crops
- Minimise fallow periods

Cultural practices:

- Land levelling
- Removal of the top layer
- Add sand
- Hoe to break the soil surface crust

Biotic and chemical amendments:

- Use of gypsum, sulphuric acid, farm yard manure, fertilisers and plant stems.

One can ‘intuitively’ estimate that the measures and their costs for the rehabilitation of water and land which have become saline are heavy to support by an average small-scale farm or a cluster of farms if irrigation reservoirs are operated in group. Even more so when areas under saline conditions are increasing: an average of 14.2% of the farms operated area in the Chistian Sub-division of Pakistan are under saline conditions (Strosser 1997). This has to be combined with the existence of water logging and the fact that not enough water is available to irrigate all land, leading therefore to poorer lands being left uncultivated (J. Gowing, pers. com.).

It was found at an earlier stage of this study that the opportunity cost of digging an OFR on cultivable land was less than using the same land for agricultural purposes (Table 1). This will be even more true for saline uncultivated lands. A mitigation measure which was not mentioned above and which has the potential to give value to poor saline lands and bring tangible benefits to farmers is to transform these in – saline – reservoirs and to stock them with *salt tolerant freshwater fish species*. In the past this has been the justification for the introduction of aquaculture in areas suffering low agricultural productivity due to salinisation problems, or though it may also be regarded by some as the replacing of one problem (land degradation) by another i.e increasing inland surface salt/brackish waters and their ecological impacts.

4. Use of OFRs for aquaculture purposes

4.1 Fish in on-farm reservoirs

Aquaculture as one of the common multiples uses of a water body has been reported in a few studies (Meinzen-Dick 1997, Dayanandam 1998, Palanisami, Balasubramanian & Mohamed Ali 1997). Studies found in Bhuiyan (ed. 1994) demonstrate mainly the potential of OFRs to increase agricultural production when used for irrigation purposes. Although the integration of fish in these reservoirs is mentioned with its potential to bring extra returns to farms with access to reservoirs (Table 9), aquaculture seems to remain a secondary use of non-irrigation water. There may be many reasons why farmers do not stock fish, however reasons for non-adoption of aquaculture have not been studied.

Table 9: Annual gross margin of fish culture (US$/farm) on farms with reservoirs

Farm size (ha)	Reservoir size (ha)	Annual gross margin of fish culture (US$/farm)	Location	Source
3.3	0.149	209.5	3 provinces of Central Luzon, Philippines, 1985	Moya *et al.* 1994
3.3	?	99 (90)	Central Luzon, Philippines, 1985 (1986)	Maglinao *et al.* 1994
?	0.17	136	Central Luzon, Philippines, 1992	Fujisaka *et al.* 1994
0.5	0.1	19.4 (*)	Indonesia	Syamsiah *et al.* 1994

(*) Total variable costs are included in this figure.

Table 9 indicates that research to date has not addressed the key issue of simultaneous use of irrigation water for agriculture and aquaculture. Only Undan *et al.* (1994) studied the financial viability of OFRs under several cropping patterns. They showed that, although an OFR with a minimum life of 5 years can be paid for in 3 years with the farming of rice and fish only, it will take only 2 years with a [rice + fish (tilapia) and rice] combination and 1.2 years with a [rice + fish and watermelon] combination. The association of high value vegetable and fruit crops such as water melon can increase financial benefits significantly (net present value of 56US$, 548US$ and 2524US$ for each combination respectively).

It was indicated previously (Figure 2) that competition for water resources provided by OFRs between aquaculture and agriculture will be more intense at both ends of the rainy season. Water requirements for various crops at different times of year, along with their growing period, has already been indicated. Table 10 presents similar data for the various fish species encountered in Asian countries to enable a complementarity between crops and fish, given their specific water requirements, to be established, in the context of scarce and un-evenly distributed water resources.

Table 10: Duration of culture, stocking densities and preferred marketable size of fish species commonly found in the South Asian continent

Species	Feeding regime	Salinity resistance	Growth		Breeding (B), stocking (S) and harvesting (H) times	Stocking densities	Flesh quality and marketable size
			Year 1	Annual average			
CARPS			Slow growing				
Common carp (*Cyprinus carpio*)	"scavenger of the pond"	Up to 10-11 ppt, sometimes grow better in ~ 5ppt. Animal wastes (by decreasing order of efficiency: poultry, duck and sheep/goat) could be utilised to fertilise brackish fish ponds (Garg 1996)	50g adv. fry may reach 300g in 4 months	500-700g	B: Jan. - April		
Chinese carps:							
Grass carp (*Ctenopharyngodon idella*)	Herbivorous, microvegetation						
Silver carp (*Hypophthalmichthys molitrix*)	Plancton (phytoplancton)		500-600g. Fish can grow 10g/day				
Bighead (*Aristichthys nobilis*)	Macroplancton						
Indian carps					Spawn 4-5 times a year between March-Sept. Condition: reach maturity before monsoon, density = 1000kg/ha and fed a good diet.		
Catla* (*Catla catla*)	Surface + column feeder (plancton)		50g. adv. fry may reach 450-500g in 4 months	500-750g	B: mid-April- mid July		Important food fish
Rohu* (*Labeo rohita*)	Column feeder in ponds (decaying vegetable matter)			250-400g	B: mid-May – Late Sept.		Popular culture fish
Mrigal* (*Cirrhina mrigala*)	Bottom feeder, algae, higher plants and detritus.			250-400g	B: March – Sept.		Important culture fish

Calbasu* (*Labeo calbasu*)	Bottom feeder, organic debris.		Up to 700g	25-30 m	B: June-Sept.		Popular food species
CATFISH					S: spring, H: harvest in Oct./Nov., after 7 months.	3700-4900 fish/ha for 0.5-0.6kg growth at the end of the season.	0.5 to 1.4 kg, although many harvested at 0.45-0.6 kg.
Asian catfish (*Clarias batrachus*)**		Can adapt to fresh and brackish waters with low oxygen content and to poor environmental conditions. In eastern India and Bangladesh, partly improved swamps are used to grow Clarias in combination with another catfish (*Heteropneustes fossilis*), the climbing perch (*Anabas testudineus*) and the snakehead (*Channa spp*.)			1. S: March-April, culture for 3-4 months. H:: July. 2. S: July –September for 2nd culture. May be delayed until Feb. or March.	~100 fish per m2.	
African catfish (*Clarias lazera*)					4.5 months from 95g stocking weight to 380g, 7t/ha/yr	1/m2	
Pangas (*Pangasius pangasius*)				May reach 700-800g in 1 year.		5/m2	

Tilapia (*Oreochromis spp.)*		*O. spilurus spilurus* can be successfully acclimatised to sea water (36.6 permill) after a gradual acclimation period of 48h, even as a newly released fry (0.03 g) (Jonassen, Pittman & Imsland 1997). In Addition, hybrids from O. mossambicus incorporates their tolerance to high salinity (for temp. .>25°C.) (Lahav & Ra’anan 1997)	Fast growing. 5g fingerlings may reach 150-200 g in 4 months		2 or 3 crops/yr, after each harvests ponds drained completely.	3000-5000/ha Broodstock (100-450g) = 0.1 fish/m2. Fish = 2 to 5/m2 Stocking only: 200-500kg/ha Stocking + fertiliser: 1000-3000kg/ha Stocking + feeding: 3000-6000kg/ha. Yields of 1100 kg/ha w/o suppl. Feed; 1900 kg/ha w/ suppl. Feed in 4-5 months.	200-300g

* Known as major carps, cultured together in traditional pond culture.

** Average yield in Thailand is 29-32.6 t/year in a 1600m2 pond

(after Pillay 1990; J. Robson, pers. com.; IoA WP No.8 1998; Beveridge & Haylor 1998; M. Beveridge, pers. com.; Hepher & Pruginin 1981; Egna, Boyd & Burke 1998).

In Tamil Nadu, fish prices for the most frequently encountered freshwater species in urban and rural areas are presented in Table 11. The wholesale price may be either the farmgate price or that paid to the middle men depending on whether producers have direct access to stall owners. On average, buying prices are about 30% higher than selling prices (J. Robson, pers. com.).

Table 11:Fish prices in urban and rural areas of Tamil Nadu, India, summer 1998.

Species	Wholesale price (Rs/kg)		Selling price (Rs/kg)	
	Urban	Rural	Urban	Rural
Rohu (*Labeo rohita*)	30	N/A	35-43	N/A
Catla (*Catla catla*)	30	N/A	35-43	40
Tilapia (*O. mossambicus*)	N/A	N/A	15-20	10-30 (1)
Auery ?	70	N/A	100	60-70
Snakehead catfish (*Channa spp.)*	80	N/A	100	80
Etraplash ?	N/A	N/A	40	35

Source: J. Robson, pers. com. (1) Fluctuations of prices between villages may be a result of availability or simply an error on the behalf of the respondent.

Existing on-farm irrigation structures used for aquaculture in the Raichur District, Karnataka (south west Indian peninsular, representative of arid and semi-arid tropics) include:

- Farm ponds, seasonal water storage, irrigation of high value crops (i.e. vegetables), with high levels of silt, usually individually owned, small in size and numerous.
- Embankments/surface ponds (emergency irrigation, perennial in nature), the most common water storage used in India, used for groundwater recharge, seedling nursery irrigation along with other community uses. They can be both individually and community-owned.
- Low earthen dams, community-owned and used for ground water recharge, protective irrigation along with other community uses.

This indicates the variety of existing structures and the variety of uses and functions, and ownership status under which they are operated. This diversity also suggests the dangers for research to generalise issues and situations. Hence the need to develop a broader model (e.g. linear programme) than those found in the current literature, which would include not only physical and biological factors (land use, climate, hydrology, engineering, fish and plant biology etc.) but also social, cultural and legal factors (traditional livelihoods, religion, credit distribution and wealth, land ownership and access, etc.).

Table 12 presents the average OFR capacity in various locations in Asia.

Table 12: Average OFR storage capacity:

Location	Average depth (m)	Average area (m2)	Volume (m3)	Reference
Central Luzon, Philippines 1986	2.6	1490	3874**	Moya *et al*. 1994
Central Luzon, Philippines 1990	1.2	1115*	1400	Undan *et al*. 1994
Central Luzon, Philippines 1991	1.7	1590*	2737**	Undan *et al*. 1994
Hazaribagh, Bihar, India	1.3 (Min: Nov.) 3.1 (Max: Jul.)	7084	9209 (Min: Nov.) 21960 (Max: Jul.)	Paul *et al*. 1994
Saroil, Rajshahi District, Bangladesh	-	-	290***	Islam *et al*. 1994

* at full capacity

** calculated

*** OFR excavated to collect runoff water.

4.2 Fertilisers use and opportunity costs

Experiments were carried out to study crop responses to irrigation using fertilisers. They showed that irrigation combined with other inputs such as fertiliser (N), crop protection and high yielding varieties could increase the total yield by over 40%, against 10% when applied separately (Carruthers *et al*. 1981).

5 t/ha of manure/compost (dry matter) applied to the land will produce 4 t/ha of grain (rice, maize, wheat, millet), whilst when applied to a pond, it will produce 1 to 4 t/ha of fish (polyculture) (Little & Muir 1987). Although the input is similar, outputs are different in nature since grain production brings more energy and fish production more protein to consumers. In Bangladesh, farm households produce on average 1 t of rice bran, 6 t of cow dung and 880 kg of kitchen wastes (Ahmed & Abdur Rab 1992). Most of these are used as animal feed (58% of total rice bran production and 89% of kitchen wastes) and as fertiliser in crop fields (80% of total cow dung available). The proportion of household by-products used for aquaculture is marginal. Although they present an important potential as fish pond inputs, their use for aquacultural purposes is likely to have an opportunity cost in terms of forgone crop yield due to the preferential use of fertilisers in ponds rather than in fields. However, it was demonstrated that, non only fish growth will improve in ponds fertilised by waste, but that the nutrient rich effluent from the fish pond can be further reused as a land fertiliser to grow several types of crops (Shereif, Easa, El-Samra & Mancy 1995). In addition, using the 'dilute' fish pond water to irrigate fields (process called as 'fertigation') also proved to nearly double crop yields (Little *et al*. 1987). This would therefore suggest that opportunity costs related to the use of fertilisers is very limited. However, the complementarity of both cultures in their growth cycles (put in a simplistic way, fish grow first, and crops follow irrigated by fertilised pond water) is unlikely to happen in the context of arid to semi-arid climates and given the households' food and earnings requirements.

In Karnataka, the main use of cow and buffalo, ox and goat manure is as organic fertiliser. However, manure is an important on-farm resource used in multiple ways with therefore multiple opportunity costs when used for a defined purpose, as shown in the Table 14.

Table 14: Various uses of livestock in Karnataka, India.

Livestock	Major use	Lesser use
Cow & Buffalo	Milk Organic fertiliser Manure for fuel	Sellable asset
Ox	Draft work (ploughing, pulling carts…) Organic fertiliser Manure for fuel	Sellable asset Manure for house construction
Goat	Milk Meat Organic fertiliser	Sellable asset
Sheep	Meat	Sellable asset
Chicken	Meat	Sellable asset

Source: IoA WP No. 5 1998.

Farm animal waste output has been quantified (Little *et al.* 1987), presented in Table 15.

Table 15: Quantification of animal waste output

	Pigs	Hens	Ducks	Cattle	Horses	Sheep
Kg wet waste/animal/day	8	0.7	1	30	24	2.1
% faeces	45			70	70	66
% urine	53			30	30	34

The production of 10 t of fish/ha/year may consume up to 75 t of duck manure, or 454 t of pig manure, or 550 t of cattle manure per hectare (wet weight) (Korn 1996 with reference to China).

The recommended level of input in a 1000 m2 pond (e.g. 20 × 50 m) is 10.5 kg of chicken manure per day (wet weight) and 80 kg of cattle manure per day (Little *et al.* 1987), i.e., with the above figures:

29,200 kg of cattle manure/1000m2/year would produce 58.4kg of fish/1000m2/year, and

3,832.5 kg of poultry manure/1000m2/year would produce 511kg of fish/1000m2/year.

If the effects on production of both cattle and poultry manure can be cumulated, the total annual fish production will be 569.4 kg/1000m2 pond or 5,964 t/ha/year, rounded up to 6,000t/ha/year.

If stocking of the same pond is done with fish capable of growing to a harvest weight of 300g (= 0.3kg), this represents two crops of 300 kg/1000m2 annually. 300/0.3 = 1000 fish in pond (1000m2) at harvest time. Allowing for mortalities, e.g. 10%, the initial stock in this pond was:

1000 × (100/90) = 1111 /1000m2.

Water requirements for this size stocking density are (m3 water/t of fish):

'Static' earth pond production of air breathing fish (e.g. *Clarias* catfish, Thailand)	50 - 100
Semi-intensive pond culture of tilapia and common carp (Israel)	500 - 1000

(Little *et al.* 1987).

1111 fish of 50g each (= 0.05kg) stocked in the pond = 55.5 kg or 0.0555 t of fish in the pond.

Given the above water requirements, we can obtain:

'Static' earth pond production of air breathing fish (e.g. *Clarias* catfish, Thailand)	2.775 m3 to 5.55 m3 required for one crop of 1111 fish
Semi-intensive pond culture of tilapia and common carp (Israel)	277.5 m3 – 555 m3 required for one crop of 1111 fish

Figures do not have to be doubled to obtain the ~ 600kg/1000m2/year as fish crops come one after the other. A 20 × 50 (=1000m2) pond should be 0.6m deep minimum (= 600m3) to satisfy these requirements and enable the growing of 600 kg of fish per year approximately. This means however that this pond water is used for aquaculture only, which is unlikely to be the case in the real world. Other uses of water will be for human consumption and uses, for livestock and for irrigation purposes (IoA, WP No.5 1998).

4.3 Salinisation and aquaculture

Salt tolerant fish species have been described in Table 13. Some species of carps (common and Chinese), along with tilapia and catfish, can tolerate brackish water and could therefore be used in OFRs affected by salinity. However, in spite of their utility in this respect, tilapia *O. mossambicus* and hybrid magur (*Clarias garapenus* × indigenous *C. batrachus*) have been banned by the central government of India because of the threat they pose to wild fisheries (IoA, WP No. 6 1998).

The potential for aquaculture using saline groundwater has been studied for several locations, including Pakistan and India, by Shearer, Wagstaff, Calow, Stewart, Muir, Haylor & Brooks 1997. For the development of aquaculture in the Sind Province of Pakistan, where saline groundwater is already pumped out and disposed as part of a dewatering scheme, it was concluded that existing technical (water systems) and environmental (salinity and temperature) conditions would appear to favour the traditional culture (extensive to semi-intensive) of tilapia. However, this species commands a lower market price than carp which could not be produced under these conditions, and this may stand against the commercial viability of tilapia culture in this area.

In the Junagadh district of the state of Gujarat, India, severe groundwater degradation has occurred, affecting irrigation agriculture and drinking water supplies. Groundwater salinisation is responsible for the farmers' return to rainfed farming systems and changes in crop irrigation and culture practices. Although it is concluded that there is a potential for the development of aquaculture in this area due to water availability and suitable environmental conditions, the report questions the potential for using groundwater for aquaculture production. Market and cultural constraints (vegetarian population therefore uncertain market for any aquaculture products) and economic constraints (saline land is not abandoned, but returned instead to rainfed agriculture, therefore still possesses an economic value, albeit reduced) may weigh in favour of the non-adoption of aquaculture in this area.

The overall study concludes that the potential for aquaculture using saline groundwater is often quite good from a technical point of view. However, the two case studies described above show that, in spite of providing farmers with the option of remaining on land where salinity problems impede agriculture, economic and social constraints have to be evaluated in their own rights and incorporated in the overall feasibility assessment.

Integration of aquaculture within OFR systems used for irrigation purposes: economic issues surrounding water allocation

5.1 Water allocation

Although the culture of fish is 'non-consumptive' in nature, fish need a minimum of water to survive and grow. Thus, in zones [A] and [B] (Figure 2), water allocation can be illustrated by the curve in Figure 6 at the end of the document (J. Lingard, pers. com.). This curve also represents the opportunity cost of using one extra unit of water for fish or rice.

Table 16 illustrates the concept of optimum allocation of water resources, by taking the example of a 1ha of water used for simultaneous production of fish and 1 ha of rice. In this example, it is assumed that fish yield remains unchanged with 100, 90 and 80 units of water. From then on, it is assumed that yields decrease by 10% for every 10 water units removed. Similar assumptions for rice production are made: yield remains unchanged with 100, 90, 80 and 70 units of water. However, yields decrease by 10% for each 10 units below.

Table 16: Water allocation for rice and fish production and related gross value of production (variable costs are not taken into account).

Wf	Wr	Qf (kg)	Qr (kg)	Pf (Rs)	Pr (Rs)	Total f+r (Rs)
100	0	2,700	-	189,000	-	189,000
90	10	2,700	1,068	189,000	13,352	202,352
80	20	2,700	1,187	189,000	14,836	203,836
70	30	2,430	1,319	170,100	16,485	186,585
60	40	2,187	1,465	153,090	18,316	171,406
50	50	1,968	1,628	137,781	20,351	158,132
40	60	1,771	1,809	124,003	22,613	146,615
30	70	1,594	2,010	111,603	25,125	136,728
20	80	1,435	2,010	100,442	25,125	125,567
10	90	1,291	2,010	90,398	25,125	115,523
0	100	-	2,010	-	25,125	25,125

Wf = water units allocated for fish production
Wr = water units allocated for rice production
Qf = quantity of fish produced (based on yield obtained in case study, section 5.2)
Qr = quantity of rice produced (based on yield obtained in case study, section 5.2)
Pf = price of 1kg of tilapia = Rs70 in Kandi, India 1998 (J. Robson, pers. com.)
Pr = average price of 1kg of rice = 12.5Rs in Tamil Nadu, India 1998 (Rs9/kg at harvest time, Rs16/kg during Yala), J. Robson, pers. com.).

Table 16 suggests that the higher value of the overall production is when 80 units of water are kept for fish production and the remaining 20 units used for rice culture.

According to Palanisami (1995), the use of traditional irrigation technology (e.g. unlined canals with no maintenance) is not efficient, i.e. uses more water supplies compared to improved technology (lined canal to minimise water losses), and results in a reduction in profits.
In this context, questions to address are:
→ What is the cost for farmers to attain a better level of input efficiency (i.e. more water in his field), that is what are the maintenance and lining costs of canals and reservoirs?
→ Could these costs be balanced by the following increase in yields?
→ If the farmer cannot afford to maintain his reservoir properly, then the introduction of fish farming and its returns may contribute to 'make up' for the value of the water wasted by the traditional irrigation technology.

5.2 Example of a cropping system with the integration of aquaculture

Data on cropping rotation is provided in Table17 for East Java.

Table 17: Intensive rice/sugar cane/upland crop rotation (East Java)

Year	Months	Period (months)	Crop
1	January – May	5	Rice
1-2	June – December	Up to 18	Sugarcane
2-3	January – May	5	Rice
3	June – December	6	Upland crops (*)

Source: Norman *et al.* (1984)
(*) Upland crops = cotton, sorghum, pearl millet, wheat, maize, groundnuts, etc.

Water requirements for tropical crops were described in Table 2 and are briefly summarised below (Table 2A). Early cotton and middle wheat have been chosen arbitrarily as upland crops.

Table 2A: Monthly water requirements (m3/ha) (met at 100%) for crops grown in the Chistian Sub-division of Pakistan

Month	J	F	M	A	M	J	J	A	S	O	N	D	Total	No. months
Early cotton	0	0	0	0	359	981	837	1414	1294	1045	247	0	6177	7
Rice	0	0	0	0	710	3400	1550	1723	1511	548	0	0	9442	6
Sugarcane	0	83	396	1062	1706	2069	1002	1116	1030	1002	598	221	10285	11
Middle wheat	199	613	1018	939	0	0	0	0	0	0	0	99	2868	5
Total	199	696	1414	2001	2775	6450	3389	4253	3835	2595	845	320	28772	

(Strosser 1997).

A typical farm size with access to an OFR (but OFR not included in the total farm area) may be described as follows:

Average farm size with OFR:	3.63 ha.
Average reservoir capacity:	2670m3 (from Table 12).

We assume that:

i) the total farm area is cultivated, i.e. 3.63ha.
ii) rice = 50% of the farm cultivated area = 1.65 ha
iii) sugarcane = 30% of the farm cultivated area = 0.99 ha
iv) early cotton = 15% of the farm cultivated area = 0.495ha
v) middle wheat = 15% of the farm cultivated area = 0.495ha

It is also assumed that the OFR is full (100% of its capacity is reached) during the monsoon season [December – January – February – March]. In [October - November] and [April – May], the OFR is filled at only half (50%) of its capacity. In [June – July – August – September], the OFR is filled at only 20% of its capacity (based on seasons and rainfalls in Indonesia, Syamsiah *et al.* 1994).

Can the OFR meet the crop water requirements each month under the above assumptions?

Table 18: Monthly crop water requirements (m3/ha) compared with OFR capacity throughout the year

Month	J	F	M	A	M	J	J	A	S	O	N	D
Early cotton	0.0	0.0	0.0	0.0	118.5	323.7	276.2	466.6	427.0	344.9	81.5	0.0
Rice	0.0	0.0	0.0	0.0	1171.5	5610.0	2557.5	2843.0	2493.2	904.2	0.0	0.0
Sugarcane	0.0	82.2	392.0	1051.4	1688.9	2048.3	992.0	1104.8	1019.7	992.0	592.0	218.8
Middle wheat	65.7	202.3	335.9	309.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.7
Total	65.7	284.5	728.0	1361.3	2978.9	7982.0	3825.7	4414.4	3939.9	2241.0	673.5	251.5
Rainfall (m3/ha)	2400	2500	2200	1400	1300	700	800	300	500	1100	1100	2300
ORF capacity (m3)	2670	2670	2670	1335	1335	534	534	534	534	1335	1335	2670
Total water provision	5070	5170	4870	2735	2635	1234	1334	834	1034	2435	2435	4970
Difference (m3)	5004	4886	4142	1374	-344	-6748	-2492	-3580	-2906	194	1762	4719
Surplus (lost m3 extra water that cannot be contained in the OFR)	2334	2216	1472	38.8	-1679	-7282	-3026	-4114	-3440	-1141	427	2049

N. B.: Rainfall figures are for Indonesia, in Syamsiah *et al.* 1994, and are approximate.

Under the above assumptions, water requirements for the present crops cannot be met from May to September, with the complete use of both OFR and rainfall waters.

The next question to address is

→ which fish species growth can be satisfied given these constraints (seasonality of OFR, variable water excess)?.

If it is assumed that livestock and other human uses of water are not fulfilled from this particular OFR and given the crop combination chosen, this table therefore suggests that fish culture can be carried out from October to April included, i.e. 7 months approximately. Consequently, this means that only 7 months are available for fish growth and this will partly determine the choice of fish species. The chosen size of fingerlings for stocking may be function of the amount of time available for the fish to reach a marketable size, of the quantity of water available during the period of growth, but also of the

farmer’s budget for the purchase of fingerlings. In this context and given the information provided in Table 10, tilapia can be chosen for the case study due to its fast growth characteristics.
2 scenarios:

1. tilapia is stocked in October, when the OFR capacity is 194m3.
2. Tilapia is stocked in December, when the OFR capacity is 2670m3 (OFR full).

Calculation of fish production under scenario (1):
There are 194m3 of water left in the OFR over a surface of 1400m2, which implies that there are only approximately 14cm of water at the bottom of the OFR. However, we can assume that the OFR bottom is on a slope so that water is collected in one corner during the dry season. For reason of simplicity, we may assume that the 194m3 are spread over a 1m deep area of 194m2, that is only 14% of the OFR area are under water.
Assuming 5g tilapia fingerlings may reach 150-200g in 4 months at a stocking density of 2 per m2 (Table 10). 388 fingerlings thus socked in the 194m2 OFR. Allowing for an average mortality rate of 10%, approximately 350 fingerlings reach maturity. They are harvested when they weigh 0.15kg after 4 months of growth, i.e. in January. The total harvest is therefore of 0.15×350 = 52.5kg, yielding 2.7t/ha.

Calculation of fish production under scenario (2):
In December, the OFR is (over-)full (2670m3). At a density of 2 fish per m2, 5340 fingerlings may be stocked in the 2670m3 OFR. Allowing for a mortality rate of 10%, 4806 fish will be harvested after 4 months of growth at a weight of 0.15kg, making a total harvest of 721kg of fish.

Under the above parameters, crop and fish production may be as follows (Table19):

Table 19: Year production and returns of a 3.63ha farm using OFR irrigation water for simultaneous culture of crops and fish.

CROPS	Cotton	Rice	Sugarcane	Wheat	Total crops
Average yield (t/ha)	1.24 (1)	2.01 (2)	75 (1)	1.88 (3)	
Area cultivated (ha)	0.495	1.65	0.99	0.495	3.63
Production (t)	0.61	3.32	74.25	0.93	79.11
Total average variable costs (US$/ha, WS+DS) (4)	540	600	1000	330	
Fertiliser and pesticides (US$/ha)	40	40	40	40	
Seeds (US$/ha)	150	150	150	150	
Labour (US$/ha)	350	410	810	140	
Total variable costs (US$, WS+DS)	267	990	990	163	2411
Value of output (US$/ha) (5)	?	394	?	?	
Value of output (US$)	757	650	1422		
Average gross margin (US$/ha) (6)	439	354	426	?	
Gross margin (US$)	490	-340	432	?	582 Min. (7)
FISH	Tilapia stocked in October			Tilapia stocked in December	
Production (kg)	52.5			721	
Total variable costs (US$) (8)	895			895	
Farm price of tilapia (US$/kg) (9)	2.8			2.8	
Value of output (US$)	147			2018.8	
Gross margin(US$)	-748			1123.8	
Net farm margin crop + fish (US$)	-166			1706	

Notes:

Conversions from Rupees into US$ have been based on 24.3 Rs = US$1.

(1) Strosser, 1997. Average yields for the command area of the Fordwah and Azim distributaries, Chistian Division, Pakistan.
(2) Norman *et al*. 1984. Average tropical yield of paddy rice.
(3) Ruddle *et al*. 1988. Regional average yield for the Zhujiang Delta, China.
(4) Approximate figures based on Maglinao *et al*. 1994, Moya *et al*. 1994 (total variable costs for rice production of ORF users in 6 rainfed villages in Central Luzon, Philippines, 1985) and Strosser 1997 (labour requirements for cotton, rice, wheat and sugarcane production in the Chistian Division Pakistan).
(5) Maglinao *et al*. 1994, Moya *et al.* 1994. Average value of rice production of OFR users for the wet and dry seasons users in 6 rainfed villages in Central Luzon, Philippines, 1985.
(6) Strosser 1997. Average gross margins when irrigation requirements are met at 100% in the Chistian Division, Pakistan (figures for cotton and sugarcane only). Value of output for cotton and sugarcane have been calculated from the value of the gross margin.
(7) This figure is a minimum since the gross margin of wheat is unknown and not incorporated in the sum.
(8) Dayanandam 1998. Total variable costs include costs fort transport and 5250 fingerlings, feed costs for 4 months, watch and ward for 5 months and miscellaneous expenses, fish rearing in tanks, Tamil Nadu, India.
(9) J. Robson, pers. com. Market price of Tilapia in Kandi, Tamil Nadu, India, 1998.

5.3 Shortfalls of the spreadsheet model presented and potential for further investigations

This case study, however simplified is the reality it presents, is nevertheless indicative of the double use (crops and fish) that may be made of rainfed OFR water. No consideration has been given to the problem of salinisation which is particularly present in Pakistan (an average of 14.2% of operated farm land is under saline conditions in the Chistian Division, Pakistan, Strosser 1997). Costs to pump water out of the reservoir into the field are not available and have not been included in the variable costs. In addition, costs of water per unit used would have to be added if irrigation water was pumped from a wider tank system. The practice irrigation deficit, change in the cropping pattern or combination of selected species along with a change in fish species cultivated and their density are as many variables that can be tested in the above spreadsheet model to optimise the year-round multiple use of irrigation water. Energy and proteins along with financial returns may also be calculated for both cultures since the project aims at improving livelihoods through better subsistence and food security.

Nutritional benefits of various crops are provided by Norman *et al.* (1984), Engle, Balakrishnan, Hanson & Molnar (1997) and Little *et al*. (1987) with economic considerations comparing fish and crops outputs.

Other non-costed water uses for households (e.g. drinking water, cooking water, house cleaning, bathing water, water for religious and laundry purposes) and for livestock (Jehangir, Mudasser, -ul-Hassan & Ali 1998) have not been included in the case study either. The cost of tube-well water may give an indication of the value of these uses to the economist and was investigated for various water uses (i.e. drinking, industry, commercial and agricultural purposes) by Palanisami & Murali (1995) in Tamil Nadu. However, their intrinsic value is likely to be higher because of the cultural and life-supporting role in communities, albeit difficult to estimate by people for the fact that water and its uses may be 'taken for granted' by the users themselves (who have probably never been asked to put a monetary value to these). The importance of the perceived value will therefore weigh in the farmer and household decision prioritisation over water use. It may therefore be interesting to investigate the economist' s decisions made through the elaboration and use of a 'rational' decision model taking into account physical, biological and economic factors, in comparison with the farmer's own decision 'model', based on his experience, traditional use of land and water, culture and own prioritisation of livelihood needs. The contrast of both decision frameworks would provide the project with a more realistic picture of the opportunities and constraints related to the integration of fish farming in irrigation systems. This in turn may facilitate the better formulation of development policies and sensitive targeting of primary and secondary stakeholders, in particular deprived groups, i.e. women, who are also at the focus of the project.

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FIGURES

Figure 1: Optimum level of externality (from Pearce and Turner)

Sayco, T.B., Angeles, H. L., Bhuiyan, S. I. (1989) Optimal cropping decisions for rainfed rice farms with small on-farm reservoirs. Paper presented at the IRRI Saturday Seminar, 14 Oct. 1989. Los Baños, Philippines.

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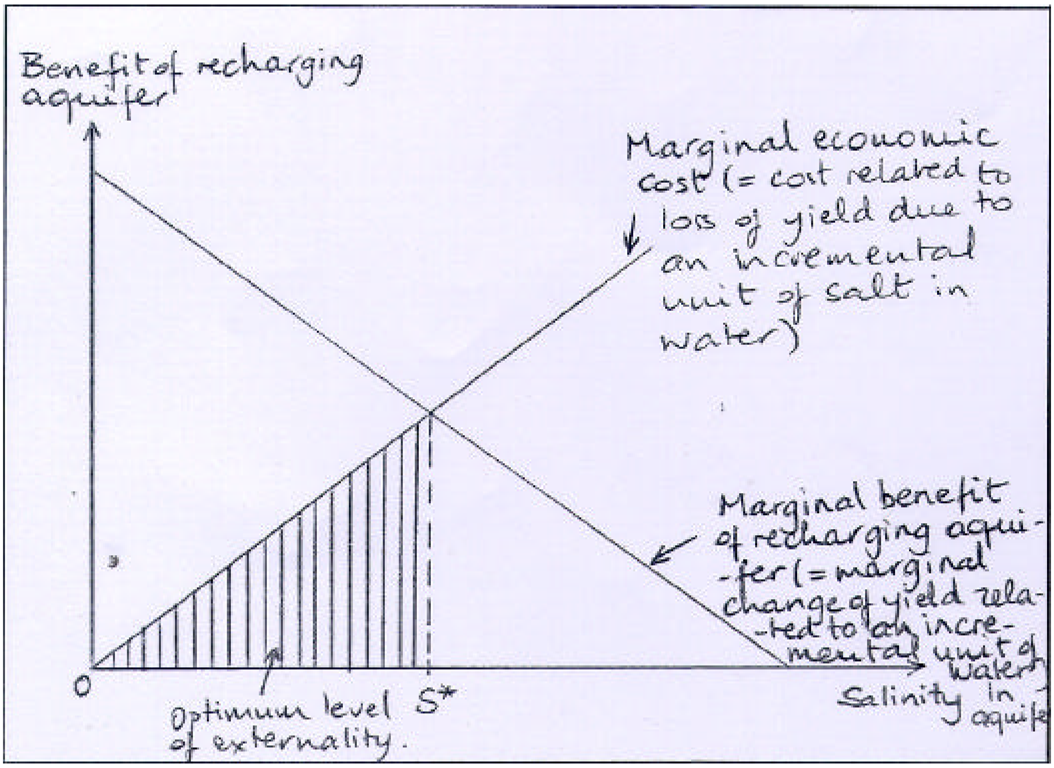


Figure 2: Water provided by rainfalls and OFRs throughout the year.

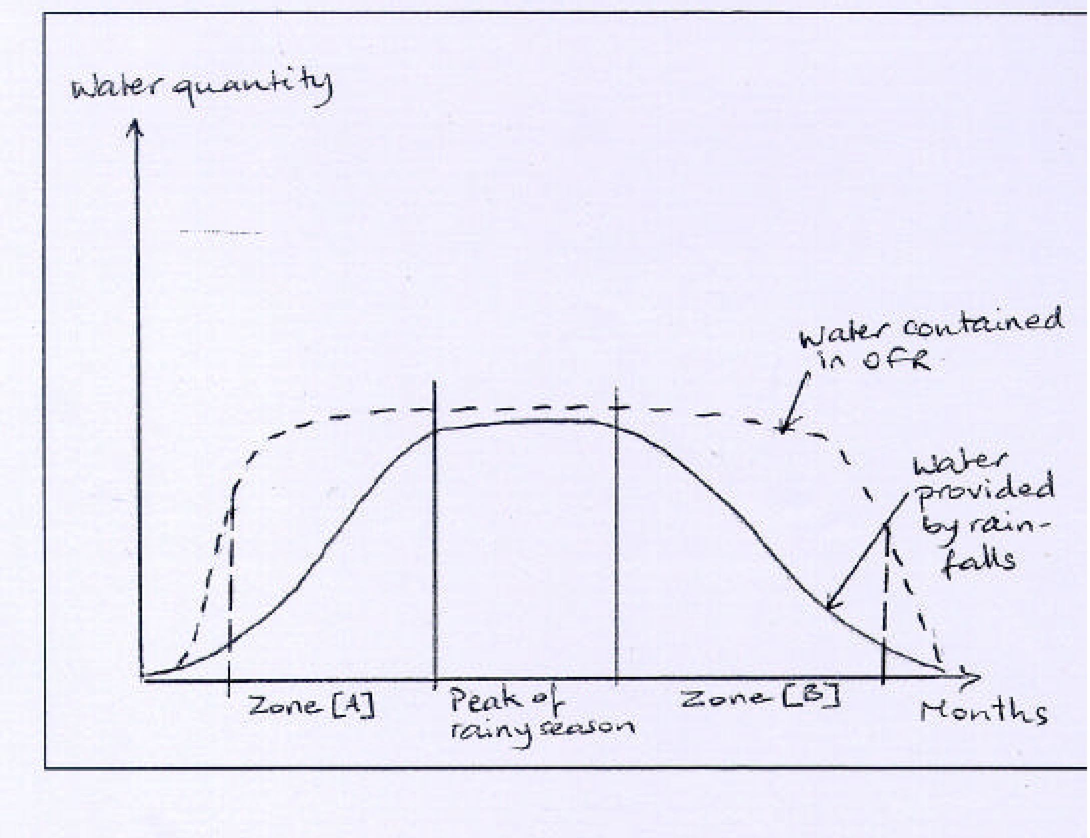


Figure 3: Yield response to water inputs

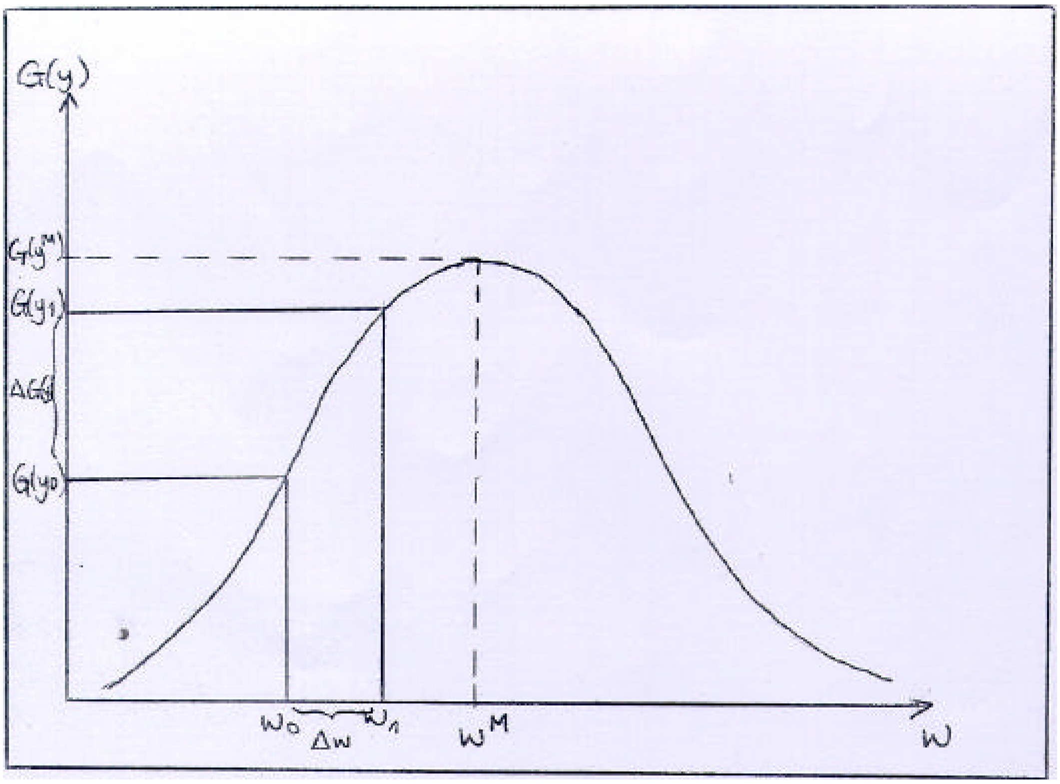
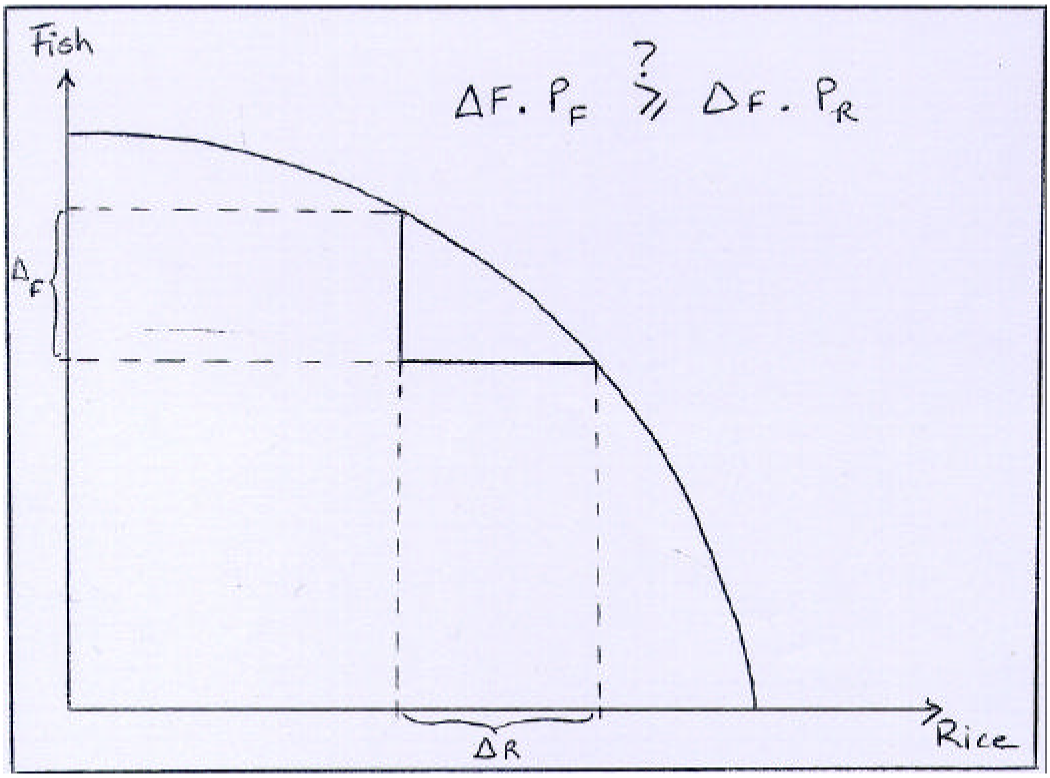
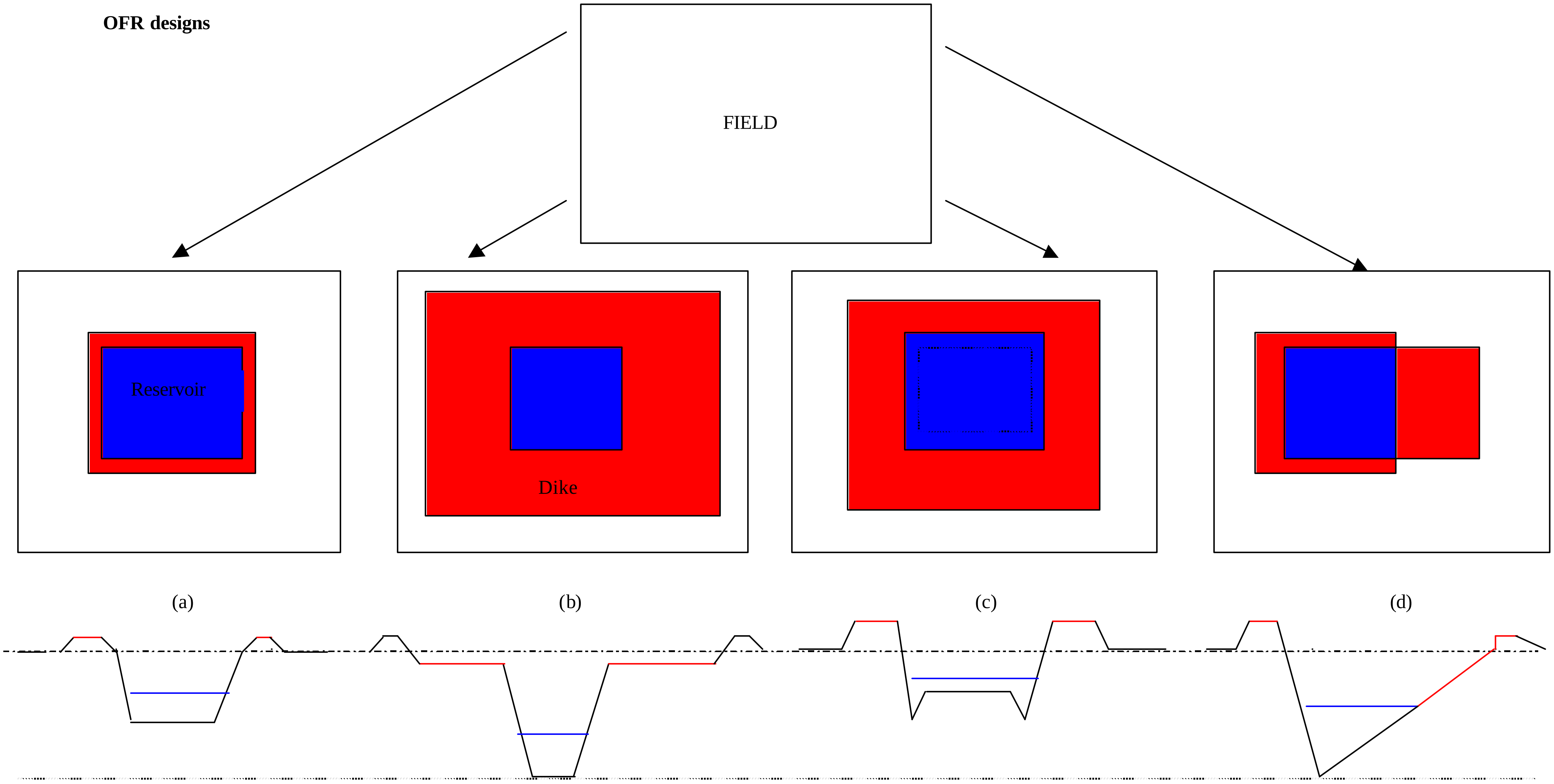


Figure 6: Production possibility curve for fish and rice using a defined quantity of water



OFR designs



Prevalence aqua/crops	aqua	crops	equal	equal
Construction Costs	***	*	**	**
Cost of slurries + sludge use	***	**	**	**
Use of water for aqua during DS	**	***	*	***
Use of water for crops during DS	*	***	**	**