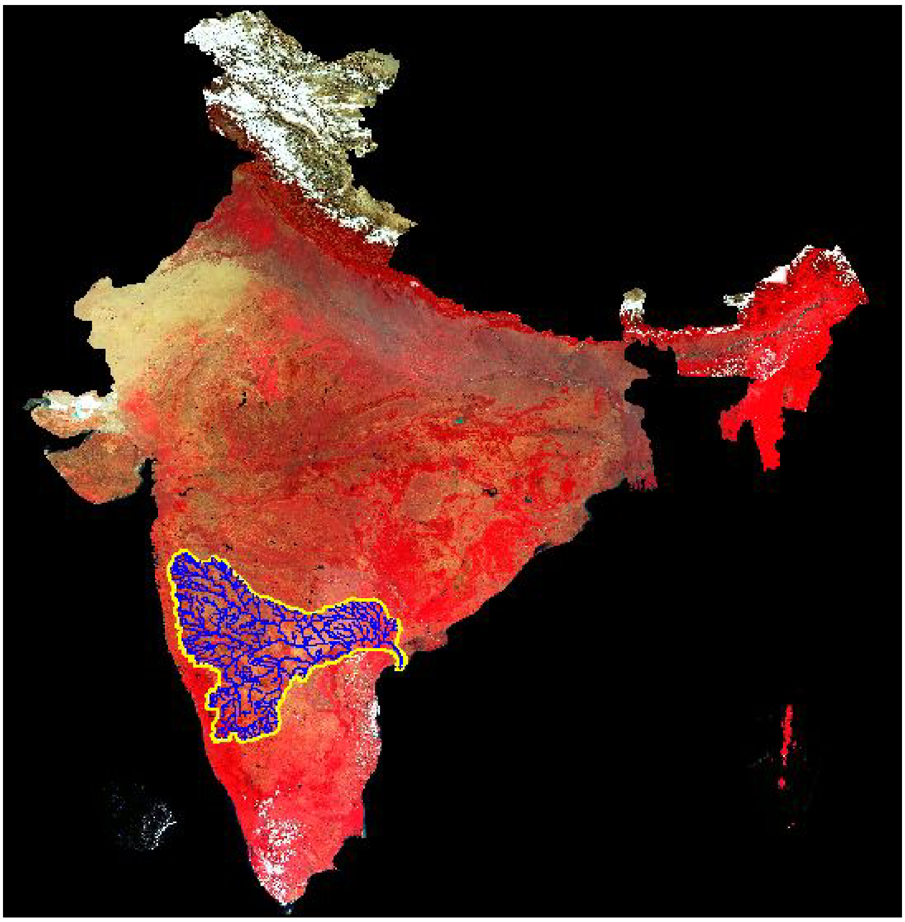
# Land, Water and Ecosystems Management in the Krishna River Basin

**Phase 1 (May 2006-March 2007) – DRAFT VERSION**

**Various authors**



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# Land, Water and Ecosystems Management in the Krishna River Basin

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**Wageningen UR, Wageningen.**

ABSTRACT

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There is no doubt that the water authorities in India have to think and to work towards allocative water management strategies to ensure long-term judicious land and water development and management. Allocative water management strategies offer great opportunities to significantly improve the water productivity in agriculture and in other sectors. It also offers opportunities in combating environmental degradation and in the reconstruction of degenerated natural resources.. This report presents a problem analysis and a first inventory and assessment of the opportunities and implications of allocative water management in terms of (economical) water benefits, agricultural benefits and ecological benefits. The report also presents tools for strategical and operational allocative water management and details on institutional aspects.

The project activities were discontinued in 2007. This report describes the activities executed from May 2006 to March 2007 and is aimed as initial knowlegde base and starting point for further investigations.

Keywords: Adaptive water management, water allocation, water productivity, Krishna River, farming systems, coastal ecosystems, water institutions.

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# Contents

## Preface

In May 2006, the BO Cluster International Cooperation and International Agreements requested Wageningen UR to conduct the project Land, Water and Ecosystems management in the Krishna River basin, in the framework of Bilateral Project Activities.

The DLO institutes Alterra, PRI, LEI and WI were commissioned to execute the project. A project proposal was composed, presenting details on the problem statement, objectives, approach, activities, timeframe and outputs.

In the proposal a project duration of 4 years was envisaged (2006-2009). However, in October 2006 the BO Cluster management decided that the financial support to the project would be discontinued in 2007.

As a result, only the project outputs that were planned for 2007 were achieved. To avoid that the obtained information would be lost (or become inaccessible) a report was composed presenting the contributions of the individual DLO institutes.

The present report gives an overview of the results to date. The various contributions have, however, not been processed nor synergized, nor (internally and externally) reviewed, which implies that there may not be consensus on all details.

The present report should, therefore, be considered as an inception report and/or initial knowledge base for further research, rather than a conclusive document.

Wageningen, Herco Jansen (contact person)[1], May 2007

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# PART A: INTRODUCTION AND RATIONALE

# 1 Introduction

*Herco Jansen, Bart Snellen*[2]

## 1.1 General outline

India is the world's major irrigating country with the major share of the water resources being used for irrigation. The demand for water from both the agricultural and the non-agricultural sectors is growing rapidly, causing an increased pressure on available water resources. In many areas overexploitation of the resources and environmental degradation are already manifest. The national and state governments of India, therefore, face huge challenges in water management.

In addressing water scarcity issues, there is currently no (clear) prioritization of water allocation. In the case of water scarcity the Irrigation Department envisages equitable distribution among the water users. This practice of "sharing the scarcity" (rather than reallocation of water to water uses that generate a high value per unit of water) results in low irrigation productivity, low yields, low cropping intensity and reduced opportunities for diversifying agriculture.

Allocative water management implies prioritization in water allocation (at catchment level) and the establishment of discriminate service levels for the different water uses. This will result that farmers will optimize their farming system according to the service level of water supply (reliability of water supply), which will lead to an increase of the agricultural productivity. The gains from such water reallocation can be immense if there are significant differences in the value per unit of water consumed across farming systems.

In addition to a productivity increase in agriculture, allocative water management strategies offer great opportunities in combating environmental degradation and even in the reconstruction of degenerated natural resources.

The project "Land, Water and Ecosystems management in the Krishna River basin" envisages to show the potential benefits of allocative water management as a possible (future) alternative of the present water management practices (paradigm shift: *"prioritization rather than equity"*). The hypothesis that a change in water management practices can lead to a significant increase in overall agricultural productivity, whilst offering opportunities for environmental reconstruction, is being investigated.

This report presents the (preliminary) results obtained in Phase 1, executed from May 2006 to March 2007. Phase 1 of the project was financed by the Dutch Ministry of Agriculture, Nature and Food Quality in the framework of bilateral project activities for policy support to the Cluster International Cooperation and International

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Agreements. Additional financing was provided through the Andhra Pradesh Water Management Project (AP-WAM), financed by the Government of India and the Food and Agricultural Organisation of the UN. In addition there has been synergy with activities by the International Water Management Institute (Hyderabad) and with PhD research at Wageningen University.

## 1.2 Objectives

The goal of the project "Land, Water and Ecosystems management in the Krishna River basin" is *judicious land and water development and management in the Krishna River Basin.*

The purpose is to support the LNV policy (and policies in India) on socially, economically and environmentally sustainable use of water, with focus on decision support in water allocation, improved water productivity in agriculture, and combating (deltaic) environmental degradation.

## 1.3 The Krishna River Basin

Allocative water management can only be effectively implemented if land and water resources are managed at (sub) catchment level. Although the project envisages to develop *generic* methodologies and tools (i.e. that can similarly be applied to other areas, or upscaled for larger areas), these methodologies and tools will firstly be applied to a selected "pilot catchment", in order to show their applicability. The existing water management problems and the ongoing WUR/DLO activities on water management in the Krishna river basin (see also Section 1.1) make this area a very suitable case for such a river basin study. To ensure relatively rapid results/outputs a further delimitation to selected subcatchments was made (see Section 1.4).

The Krishna River has its origin near the west coast of India and its delta is located in the State of Andhra Pradesh at the east coast. The watershed comprises an area of 250,000 km$^2$, being equivalent to approximately 8 % of the surface area of India as a whole. At present, the governments recognize problems in the basins related to:

- Lack of information for land, water and ecosystem management (Box 1);

*Box 1*

*At the scale level of (sub)catchments, the responsible executive water management agencies do not have adequate information and tools for setting the right priorities in water allocation policies, and for the planning of land and water interventions, being both strategic (spatial planning, the construction of infrastructures, etc) and operational interventions.*

*Water allocation to the different water uses and within the same sector (agriculture) is not optimum, not only in times or situations of water scarcity, but also when the water is abundantly available. There is also no good insight in repercussions of land and water policies and interventions on ecosystems and other water uses, which often manifest themselves hundreds of kilometers downstream.*

- Lack of (financial) incentives and accountability mechanism for providing reliable irrigation services by irrigation agencies and for efficient water use by farmers (Box 2);

*Box 2*

*In relation to the abovementioned lack of information (at the appropriate level) and proper prioritization in water allocation, it is presently not possible to establish discriminate service levels for water allocation. Discriminate "service levels" are required to ensure maximum water productivity, especially in situations of water scarcity. Cost recovery mechanisms (based on the "profit principle") can only be successful if –at the end of the day- water authorities are made accountable for their services. The willingness to pay and efficient water use by farmers is strongly related to the accountability of the service-providers.*

- Low water productivity in the agricultural sector, both in irrigated agriculture and in (partly) rain-dependent agriculture (Box 3);

*Box 3*

*In the case of unreliable irrigation water supply farmers tend to opt for low-productive, low-investment and low-risk crops and farming systems. The productivity will increase if the risks (of water shortage) can be better assessed and if the irrigation water supply would be less erratic. A more reliable irrigation water supply will promote investments by farmers and thus enhance productivity. In addition, crops and crop varieties can be improved, so that productive crops that are well adapted to the different risk levels of water (and salinity) stress are grown.*

- Upstream agricultural practices and other land and water interventions resulting in deterioration of (deltaic) ecosystems, salt water intrusion and salinisation in the deltas;

- Adverse impacts of large-scale introduction of aquaculture on coastal ecosystems.

## 1.4 Approach and activities

***Study area***
On the basis of scientific, policy relevance and practical criteria a further delimitation to selected subcatchments was made (see also Section 8.3). The (entire) sub-catchments that discharge into the Krishna River between the Nagarjuna Sagar Project and the Prakasam Barrage of Vijayawada were selected as study area. This area covers approximately 36000 $km^2$.

***Water uses***
Allocative water management implies prioritization of water allocation to the most productive water uses. In the project the focus will be on the different agricultural water uses (*farming systems*). It is thus assumed that the water uses "drinking water" and "industries" should a priori get a higher priority in water allocation than agriculture[3] (their present water use is also minor in comparison with agriculture). The water use by other uses (e.g. recreation, energy supply, transport) is not considered at this stage.

***Focus of activities***
In 2006 activities have been undertaken to outline the concepts for quantitative river basin analyses, current farming systems, water valuation, institutional instruments in water allocation, coastal zone productions systems, and stakeholder analyses. A database with (spatial and temporal) land- and water data has also been prepared.

***Information for land, water and ecosystem management (see also Box 1 of Section 1.3)***
Allocative water management requires that the water management entities have adequate information on the hydrological system (at the appropriate level) and on the repercussions of any management intervention. Such information requires a hydrological system analysis and a monitoring system. The project activities have been aimed at developing a general applicable methodology with minimum data collection, which is not location-specific and which does not require primary data.

***Farming systems and water productivity (see also Box 3 of Section 1.3)***
Allocative water management implies discriminative service levels for irrigation water supply, related to the productivity of farming systems. Various existing and potential farming systems have be identified and described in terms of input use and (financial) output. A first classification has been made on the basis of secondary information on cropping and farming systems. Thereafter a detailed survey was started for selected areas.

In the study area, the reliability of water is, generally, the dominant factor for the farming system. The eventual objective of the data search and survey was, therefore, to identify and quantitatively describe (including productivity) feasible farming systems, for different service levels (i.e. levels of water reliability).

3 It is noted that with this limitation (potential) impacts such as pollution are ignored. If appropriate, the implications of impacts for water allocation may be addressed at a later stage of the project.

***Water valuation***
Given the objectives of the project, the economic components have been focused on elaborating a methodology that is capable of assessing the private economic impacts of water (re)allocation. The sustainable financial management of irrigation infrastructures was not within the scope of the project.

At a later stage, the returns of irrigation water for different farming systems will be further quantified.

***Institutional issues***
Allocative water management can have large social and political implications. The project will not address how these can be overcome, however the critical institutional issues in water reallocation and enforcement have been inventoried. Possible instruments for allocation and reallocation of water rights have also been identified.

At a later stage, possible incentives for reliable and accountable irrigation services will be elaborated.

***Salt water agriculture***
Allocative water management may lead to the introduction of entirely new, innovative farming systems. In the project special attention will be paid to salt water farming systems. The coastal zone of the Krishna River estuary has been studied in more detail and existing and potential problems resulting from land and water management (upstream) in the catchment have been identified. Local stakeholders were involved and new concepts and development options have been discussed and assessed.

## 1.5 Project organization

The project was executed by a multidisciplinary team of Dutch experts from Alterra, LEI, PRI and WI, and Indian experts from ANGRAU and IWMI. The various activities were rationally distributed over the various institutes.

The division of roles and responsibilities was:
- Alterra: project management and expertise on planning & decision support in integrated water resource management, irrigation institutions, irrigation performance, remote sensing, holistic modelling, GIS.
- LEI: water economy and water valuation, water institutions, water rights, incentives in water demand management.
- PRI: farming systems in relation to water reliability, water productivity (in irrigated and rainfed agriculture), crop vulnerability to water (and salinity) stress, salt water farming systems
- WI: multi-stakeholder processes, integrated coastal zone management.

The partners in India involved in the project were:

- Acharya N.G. Ranga Agricultural University, Andhra Pradesh, India: Liaison with local organisations, modelling, GIS, surveys/data collection and processing, farming systems.
- International Water Management Institute (Hyderabad).
- Swaminathan Foundation: Stakeholder meetings, knowledge on restoration of coastal ecosystems.

It is planned that a workshop is organised in India in 2007 to discusse the results and recommend on follow-up.

## 1.6 Structure of this report

The report is subdivided in 3 parts:

- Part A: Introduction and rationale
- Part B: Referential framework (problem analysis)
- Part C: Towards judicious land and water development and management in the Krishna River basin

Chapter 2 starts with the rationale of allocative water management, its prospects and implications.

As the focus of the project is on water allocation for irrigated agriculture and ecosystems, it was considered appropriate to study the development of irrigated agriculture in India, the problems that emerged, the interventions made, the perceptions and beliefs of the planners and designers, etc. Chapter 3 (Part B) presents an analysis of the objectives of the Indian irrigation sector and how these objectives evolved in time.

In Part C the contributions by the various partners to the knowledge base on judicious land and water development and management are presented. As the financing of the project was rather unexpectedly interrupted these contributions have not yet been reviewed nor synergized. The information should, therefore, be considered as an initial knowledge base for further research.

# 2 Prospects and implications of allocative[4] water management

*Herco Jansen*[5]

## 2.1 The need for allocative water management in the Krishna basin

When dealing with increasing water scarcity, water management institutions, generally, show the following sequence of action[6]:

1. Supply Management. Interventions by water managers are aimed at getting more water, which is mostly accomplished by water transfer and storage. Supply management generally implies (sometime large) infrastructural works, such as barrages, storage reservoirs, new irrigation schemes, supply canals, pipelines, pumping / booster stations, well fields / boreholes, etc. The goal of supply management is ***to get more drops*** ("*get more water*")
2. Demand management / end-use efficiency. Interventions are aimed at water saving technologies and strategies. The goal is to get ***more crop per drop*** ("*do more with the water*"). Improving end-use efficiency may imply technical interventions, such as efficient irrigation systems or crop varieties, constitutional interventions, such as the charging of water, institutional / management interventions (including training), aimed at better (agricultural) practices.
3. Demand management / allocative efficiency. Interventions are aimed at the reallocation of water to water uses that generate a high value per unit of water. Improving allocative efficiency may imply the withdrawal of water rights from irrigation schemes that produce low revenues per unit of water. It, therefore, implies strategic decisions on water use. The goal is to get ***more jobs per drop*** ("*do other/better things with the water*").

Water management institutions generally prefer supply management as the first option, as water supply interventions are the easiest to implement and also cause the least social disruption. However, the improved supply of water will also cause increased demand, which then results in a vicious cycle that again more water supply infrastructure will be needed, which obviously becomes more and more costly and more and more environmentally detrimental. As water is principally considered as a free good, emphasis on supply management also poses the risk that irrigation performance and the management needs do not receive due attention.

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4 In the international literature the expression 'adaptive water management' is generally used. As adaptive water management has a broader scope, while 'allocative water management' focuses on the general water scarcity issue, the latter expression is used in this report.

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6 See FAO, 2000; Turton, 1999; Snellen et al, 2005; and others

Water demand management can result in social and political stress. The introduction of water saving technologies is still relatively easy, but –for example- the charging of farmers for irrigation water is often declined. In India many farmers subsist in a rather marginal financial situation, which does not allow them to pay (substantially) for water[7]. The average landholding in India is only 1.57 ha (Ministry of Agriculture, 1996), with 59% of the landholdings being less than 1 ha (data of 1990-1991). Another aspect is that the charging for water implies that the service-providers (Irrigation Department) become accountable for their services, which would entail additional obligations and a shift in their daily routines.

In India the Irrigation Department has initiated some activities directed to water demand management, such as the introduction of organizational reforms (through Water Users Associations) and training programs. However, the emphasis of the Department is still on *supply management*, which is illustrated by various large infrastructural projects presently being planned or executed, including the construction of huge storage reservoirs and large inter-catchment water transfers.

In almost the entire country there is no (clear) prioritization of water allocation in times of water shortages. In times of water scarcity the Irrigation Department envisages *equitable distribution* among the water users. This practice of *"sharing the scarcity"* results in low irrigation productivity, low yields, low cropping intensity and reduced opportunities for diversifying agriculture.

Allocative water management may require that the present technical infrastructure, mode of operation and institutional framework be thoroughly adapted, however the main obstacle is that reallocation of water to the most productive water uses is socially and politically extremely complex. It may imply that the food needed by growing populations will need to be imported and paid for by the industry, the services sector and highly-productive agricultural enterprises that produce for the (world) market. Allocative water demand management will require social restructuring and entails risks of tension and conflicts within the country, within states, and between sectors and population groups with different stakes in a new socio-economic environment.

Yet there is no doubt that the water authorities in India have to think and to work towards allocative water management strategies to ensure long-term judicious land and water development and management. Allocative water management strategies offer great opportunities to significantly improve the water productivity in agriculture (by introducing alternative, more productive farming systems) and in other sectors. It also offers opportunities in combating environmental degradation and even in the reconstruction of degenerated natural resources.

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7 Studies show, however, that for many farming systems the financial benefits of water are high, so that these farmers could easily bear water charging. Note also that if water benefits are very high then the effect of water charging as demand management measure is also limited.

## 2.2 Prospects of allocative water management for agricultural production

Allocative water management implies prioritization in water allocation and the establishment of discriminate service levels for the different water uses. Once that there is a service agreement between the water management organisation (Irrigation Department) and the (group of) farmers, farmers will optimize their farming system according to the service level of water supply (reliability of water supply). It is expected that farmers are prepared to run more risk and invest in more productive farming systems if the water supply is more reliable. Farmers will be prepared to select high yielding but water sensitive varieties, put more effort in land preparation, plant more intensively, and invest in high quality seeds, fertilisers and pesticides.

Allocative water management can, therefore, result in a significant overall increase of the agricultural productivity. The gains from water reallocation can be immense if there are significant differences in the value per unit of water consumed across farming systems. For example, rice that receives an unreliable water supply rarely generates more than $0.025 per cubic meter of water, while horticultural crops that receive a very reliable supply may generate 100 times that value. In times of scarcity water would then be (firstly) directed to the horticultural farms. The horticultural farmers will have no problem to compensate the less productive rice farmers with (say) $0.2 if they can use all of the water, which would mean that both farmers are better off (Hellegers, 2006).

At a larger scale (macro-scale) allocative water management envisages the same effect, i.e. higher revenues from agricultural production. This will be achieved if the increase in agricultural productivity from new, high-productive farming systems exceeds the decrease in productivity from the low-productive farming systems.

## 2.3 Prospects of allocative water management for ecosystems

The prioritization in water allocation and the establishment of service levels for water supply should be largely based on the value per unit of water used by the various farming systems. Once that these values are known, there is also good insight in the potential of restoration of ecosystems by abandoning low-productive (polluting) farming systems in areas with good ecological prospects or farming systems that impact on existing ecosystems.

For example, in a situation that 80 percent of the farming systems only contribute 20 % of the area's revenues from agriculture, there would be a great potential for a change in land use, for example towards the development or rehabilitation of nature, which would also offer new prospects of economic development (e.g. tourism, fishery).

Allocative water management may (should) eventually lead to a decrease of water use by agriculture, down to a long-term sustainability level. In such a situation water for agriculture will only be allocated to high productive farming systems. The total revenues of these (limited number of) farming systems will exceed the present revenues from the agricultural sector.

# PART B: REFERENTIAL FRAMEWORK (PROBLEM ANALYSIS)

# 3 The Indian irrigation sector's objectives [8]

*Bart Snellen*[9]

## 3.1 Irrigation reform in India

There is a huge literature on institutional reform in irrigation, in India (e.g. Gulati et al, 2005: *Institutional Reforms in Indian Irrigation*, with more than 200 references) and elsewhere (e.g. www.inpim.org). As stated in a World Bank report on *Institutional Reform Options in the Irrigation Sector*, 'in most cases the principal driving force for institutional reform is poor O&M and the inability of the government to mobilize funds, either directly or indirectly, for even deficient service provision' (World Bank 2004). This is also the case in India: by the mid-1990's, the revenue collected from water charges was less than 10 percent of the total O&M expenses (Gulati et al, 2005, p.19). The principle solution prescribed is that of transferring management tasks from the irrigation agency to the users; this process is addressed as Irrigation Management Transfer (IMT) or Participatory Irrigation Management (PIM), the term used by the International Network on PIM, hence www.inpim.org.

The literature on IMT/PIM suggests that the major problems in irrigation are institutional and therefore can be resolved through institutional reform. This paper argues that the irrigation sector in India faces three major and inter-related problems that may well originate from inappropriate institutional arrangements, but require more than institutional reforms to resolve:

1. *Too much land has been developed for perennial irrigation*; there is not enough water to provide adequate irrigation services to the currently developed command areas;
2. *Irrigation infrastructure precludes productive use of water*; current designs of large-scale systems give managers no alternative but haphazard distribution of irrigation water and prevents irrigators from using water – both irrigation and rainwater! - effectively and efficiently;
3. *Irrigation professionals lack the attitude, knowledge, and skills to provide water services to agriculture and protect the land and water resources.*

Dealing with these problems requires a drastic reform of Indian irrigated agriculture that goes far beyond the institutional reforms advocated by many researchers in this field. A better understanding of the root causes of these problems is gained by looking into the history of irrigation development in India. The first section will focus on Northern India, the second on East India and the Krishna Basin.

8 The title as submitted by the author was "The Indian irrigation sector's forgotten objectives"

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## 3.2 Irrigation development in Northern India

### 3.2.1 General outline

The first major study on the effect of colonial canal irrigation on agrarian conditions is by Elizabeth Whitcombe (1972). The introductory chapter describes the pattern of agriculture that existed at the time of the start of the works on the Ganges Canal in 1847. It explains in great detail how farmers used crop diversification to reduce the risk of crop failure caused by inadequate rainfall (both shortage and excess): they would grow a variety of crops on different locations.

The combination of a wide range of crops grown on a wide range of soils ensured that at least some crops would make it to harvest, even under the most adverse rainfall conditions. Farmers also practiced irrigation on a limited part of their land, using wells and small ponds in natural depressions that would fill with rainfall. Irrigation water generally needed to be lifted from the source, which required considerable labour and animal power.

According to Whitcombe, the introduction of canal irrigation 'caused pronounced environmental and economic disruption' and also 'disrupted the [farmers'] former pattern of work':

- production of food crops was downgraded in favour of commercial crops; this increased vulnerability of cultivators in dry years, when the canals – contrary to expectations – could do little to 'decrease the ravages of [rainfall] scarcity';
- overcropping, due to ease of canal irrigation compared to wells, leading to disruption of fallowing cycles and loss of soil fertility;
- canal irrigation attracted pastoral casts into crop cultivation, thereby reducing the availability of draught animals and manure, resulting in yield reduction;
- waterlogging of low-lying land, due to turning large quantities of water over an almost slopeless plains landscape, worsened by water channels obstructing natural drainage;
- saline deposits over land's surface, due to capillary rise of salt-laden water from subsoil;
- increase in malaria, due to expansion of mosquito breeding sites;
- disruption of well irrigation, due to instability of earthen wells after increase in groundwater table.

Whitcombe's verdict about the negative impact of canal irrigation on the peasant community stirred economist Ian Stone into undertaking a comprehensive analysis (Stone 1984). He finds that the adverse effects of canal irrigation have been greatly overstated and points out the positive effects of canal irrigation on the productivity of labour: 'The spread of canal irrigation created labour shortages which led to the adoption of a chain of labour saving devices and which gave the highest possible returns to direct cultivation.'

### 3.2.2 Discussion: Whitcombe versus Stone

A reviewer of Stone's book raised the question why the study had taken so long (12 years) and answered it himself: 'Successful analysis depends on a detailed appreciation not only of the political history of the period and of the specific context in which irrigation development took place; it also demands a full appreciation of the geographical, economic and social systems which provided the context of that development' (Bradnock 1986).

What strikes me as missing in Bradnock's list of important issues, is the *agricultural* context, which took such a prominent place in Whitcombe's study and received hardly more than some footnotes in Stone's publication. I think an important reason for Stone's positive stance on canal irrigation is his lack of appreciation for the way farmers had adapted their cultivation practices to the conditions of erratic rainfall.

This brings us to a key message of the present paper, which is that the primary purpose of irrigation is that of reducing farmers' exposure to risks resulting from inadequate rainfall. The success of irrigation development should therefore be evaluated in terms of two criteria:

1. The reduction of farmers risks from inadequate rainfall;
2. The resources (both natural and capital!) employed to achieve this reduction.

It is not easy to quantify these criteria in economic terms. Whitcombe perceived the shift towards commercial crops at the expense of food crops as an increased risk, because the chance of crop failure of the commercial crops – leaving the farmer without income and food - was much greater than the chance of not being able to harvest any of the food crops. But how to compare the value of an assured food supply with the value of a potentially higher but less secure income? She was also concerned by the adverse effects of canal irrigation on the natural resource base; the loss of this natural capital comes on top of the investment cost, but calculating the loss involves more than simple arithmetic.

Performance assessment is much easier when we adopt the indicator commonly used by the developers of canal irrigation in British India, which is based on:

1. The increased revenue from land taxes and water charges;
2. The capital invested in building the works.

*Table 1. Financial returns of major canals in the Doab (1895-1900)*

| Canal | Number of years in operation | Area irrigated (1000 acres) | Return on capital (%) |
|---|---|---|---|
| Upper Ganges | 46 | 949 | 9.5 |
| Lower Ganges | 22 | 774 | 4.0 |
| Agra | 26 | 228 | 5.6 |
| Eastern Jumna | 70 | 286 | 26.6 |

Source: Stone (1984)

Data on financial returns similar to those in Table 1 is available for all major irrigation works built in British India. By 1921, total capital investment in productive irrigation amounted to £ 57 million and the total command area to 57 million acres, producing an average return on capital of 9%. The reputation of the chief engineers in charge of the early irrigation works depended largely on the financial results. Stone's book contains an appendix with the career outlines of the most important engineers.

It is not my intention to suggest that Stone has chosen the easier method of performance assessment out of convenience, nor that he has sided with the British engineers rather than with the Indian peasants. On the contrary, Stone has gone to great length to explore the reasons behind the choices made by the farmers, analysing the impact of canal irrigation on availability and use of labour, the issues of land tax, water charges and pricing of agricultural commodities. Stone's book is very informative about farmers' predicaments in dealing with merchants and canal irrigation operators. The chapter on the protection against famine also gives the story from both sides: the colonial administration as well as the local peasantry.

Whitcombe versus Stone, therefore, is not about Indian peasants versus colonial rulers and irrigation engineers. Rather, it is about agriculture versus irrigation. Or more precisely: an interpretation of irrigation *serving agriculture*[10] *and the natural resource base on which it depends* versus irrigation engineering serving a purpose of its own.

In my view it is the second interpretation – irrigation mainly serving irrigation - that is the main cause of the abject condition of irrigated agriculture in India today. A footnote on p. 225 of Stone's book shows that this is by no means an original idea:

> '*Up to now, irrigation in India has been looked upon largely as an engineering problem.....but the real value of irrigation depends largely upon a proper appreciation of the needs of the crops irrigated*.' (Howard & Howard, 1917).

Howard and his wife both worked as botanists at the Agricultural Research Institute in Pusa (Bihar), founded by Lord Curzon[11] to promote scientific agriculture. The Howards studied the effects of rainfall and irrigation on soil structure and yields for various climates, soils, cropping patterns and practices. A main theme of their work was soil aeration, which they considered a neglected subject in India:

> *'The necessity for irrigation, the attention paid to dry farming methods and to water conservation, all tend to concentrate the attention of the investigator on questions related to water and, at the same time, to obscure the importance of the air supply to the roots…'* (Howard, 1953).

10 N.B. *Serving agriculture* here is more than contributing to income from agricultural production; it is also about understanding, using, respecting and maintaining the non-marketable part of the resource base on which agriculture depends: crops, soils, rainfall, as well as people.

11 Governor General and Viceroy of India (1899-1905)

In one of their on-farm experiments, they found that land prepared with a spring-tine cultivator and a single irrigation applied before sowing produced yields that were 30% higher than those obtained with the traditional practice with 7 or 8 irrigation applications. On the basis of this type of results, the Howards called for an overhaul of the systems governing the use of irrigation water and its payment:

> '*The importance of this matter to India needs no argument..... It is true that* ***the difficulties involved in overhauling a vast system of perennial irrigation constitutes a formidable undertaking****.* On the other hand, if, as appears to be the case,* ***much more can be made of the present water supplies, it is obviously to the advantage both of the cultivator and of the State that modifications should be introduced into the existing systems. The centre of the subject is the plant and the physiological processes involved in its growth. If perennial irrigation interferes with its growth, it will have to be modified****.* The difficulty in making an advance in matters such as the improvement of an existing irrigation system is to begin. If the most is to be made of irrigation water, it is obvious that the cultivator must be a willing partner in the undertaking and that* ***the water will have to be charged for according to the amount used****.* At present [1917 !] the usual method in India is to levy a water-rate according to the area watered, a proceeding often condemned by members of the Irrigation Department itself.'* [* my emphasis] (Howard 1953).

Sir Albert Howard is remembered as the founding father of Organic Farming[12], not as the great reformer of irrigated agriculture in India. His call of 1917 for an overhaul of India's large-scale irrigation systems has not been acted upon and irrigation has continued '*to be looked upon largely as an engineering problem*', until the present day. It seems justified to say that over the years, irrigation engineering, agriculture, nature and science have drifted apart even further.

### 3.2.3 Nature, agriculture, irrigation and science

It is not surprising that Sir Howard's plea for an overhaul of the large-scale perennial irrigation systems fell on deaf ears:

- It did not correspond with the *world view* of the British irrigation engineers,
- It went against their immediate interest of *expanding canal irrigation*;
- It would have required a totally different *irrigation design* (infrastructure and operational rules).

***World view***

The Howards applied their scientific insight in plant physiological processes interacting with the soil and atmosphere to improve local agricultural production. This was predominantly subsistence farming, with limited options for increasing the level of external inputs, especially inputs requiring cash. So the Howards developed a

[12] http://journeytoforever.org/farm_library/howard_memorial.html

keen eye for agronomic practices that made beneficial use of the natural environment; the resulting world view could be described as '*working with nature*'.

In contrast, the education of British engineers prepared them for 'victorious success in *subduing nature*' (Gilmartin 2003). Development and expansion of canal irrigation provided engineers with the opportunity to win two victories over nature:

1. harnessing and controlling the rivers
2. subduing the monsoon.

The engineers were actively engaged in the first battle: river engineering and canal construction. This prepared the ground for the second battle – making the land productive irrespective of rainfall – where the engineers saw a limited role for themselves, leaving the initiative largely to the cultivators.

Besides it being the more glorious part, in the early stages of irrigation development there were perfectly valid reasons for the British engineers to concentrate on river engineering and canal construction, rather than on distribution and application of irrigation water. They had observed that the agricultural lands adjacent to rivers were more productive and the population more prosperous. Hence, it would suffice to divert some of the river water into an artificial river (called *canal*) for the cultivators to reap similar benefits. Also, especially in the more arid regions, there was no scarcity of land. This meant there was little point in making every effort to optimize agricultural productivity per unit of land.

From the very start, irrigation engineers were encouraged to spread the canal water as thinly as possible, in order to maximize the size of the command area, thereby maximizing the potential revenue. As a productivity index, the term 'duty' was introduced; it indicates the number of acres of cropped land that can be brought to maturity with one cubic foot per second (cusec) running continuously throughout the growing season. The duty was also used in calculating the required capacity of the irrigation canals.

> *"Duty" was thus a fundamental measure of the ultimate goal of irrigation science – the extraction of productive capacity from water* (Gilmartin 2003).

Over time, profitability of canal irrigation gradually diminished and eventually turned from a source of income to the permanent drain of public funds that it is today. The dramatic changes in profitability do not appear to have had much effect on the engineers' world view, in the sense that until the present day there is still a strong preference for expanding canal irrigation.

### *Expanding canal irrigation*

British canal-building activity in India started in 1817 in Northern India. The first schemes were mostly rehabilitated and extended versions of indigenous works. The first purely British work was the Ganges Canal, with 650 miles of main and branch lines, which took from 1836 to 1854 to complete and required an investment by the government of £ 2.15 million. To enable implementation of even larger schemes, the hydraulic engineer Sir Arthur Cotton advocated commercial irrigation companies and financing through government-backed loans. This approach proved a costly experiment (see section below on Krishna river basin) and was abandoned in 1866.

Since then, irrigation works were implemented by a public agency. An annual sum of around £ 0.5 million was earmarked for irrigation out of ordinary revenue. For expansion of canal irrigation, an additional sum of roughly £ 2 million per year could be obtained through loans from London, provided that the schemes could be expected to be 'remunerative.' The 'productivity test' required that the projects after 10 years from their date of opening would yield an income equal to the interest on their construction cost (Stone 1984).

Project revenue depended on water charges and land tax. The irrigation authorities, however, were very much constrained in setting water charges, as the Imperial administration also sought *indirect* returns from irrigation in terms of political stability and social welfare. As a result, water charges were very much lower than the value of the irrigation water to the producer. The policy of low water charges was another disincentive for the irrigation professionals to take an interest in the effects of irrigation on agricultural productivity. Instead, it added to their tendency of evaluating the effect of their work predominantly in terms of area brought under irrigation. This tendency was further boosted by Richard Strachey, Inspector-General of Irrigation during 1866-9, who announced a new policy aimed at 'extending irrigation generally and so far as is possible in a manner that shall to the utmost guard against the worst effects of severe drought'.

For Northern India, the 'normal standard' adopted in the 1870's was that 42.5% of the cultivable area within a village should receive irrigation water. 'In practice, the guidelines were impossible to adhere to, but the principle was clear; equity was to be an important guide in the establishment of the distribution system; as many villages as possible were to be served, with a view to maximizing protection rather than production.' (Stone 1984)

The pressure on the irrigation engineers to expand the irrigated areas may serve to explain their lack of interest in the agronomic experiments of the Howards. From the perspective of maximizing the 'protected' area, however, it is a pity the engineers have not listened: the experiments of the Howards not only indicated how to increase crop yield per unit of land, but also per unit of water. Taking up the advice of the Howards would have enabled the irrigation engineers to expand the irrigated area even further.

Besides limited interest in agronomy, there are two more reasons that may explain why the irrigation engineers did not care much for Howards' point of view:

1. The Howards preferred rain water over canal water. This largely follows from the importance they attached to adequate soil aeration. They believed that rainfall contains more dissolved oxygen than canal water, which explains part

of their preference. The other part is their concern about the effect of over-irrigation on soil aeration. Hence their recommendation to make optimal use of rainfall and reduce canal water applications. It is quite understandable that this message is not immediately appreciated by a profession that is founded on selling canal water.
2. The irrigation infrastructure developed for the distribution of canal water was incompatible with the mode of operation suggested by the Howards. This aspect will be discussed in the next paragraph.

***Irrigation design***

The early irrigation projects built by the British consisted merely of an inlet from a river into an earth canal running parallel to that river and often ending in the same river from where it departed. The engineers' main concern was to keep the canal stable. Having no previous experience with irrigation canals, this was mainly a matter of trial and error. Only in the last decades of the 19th century, the engineers developed mathematical formulas which allowed them to calculate the maximum allowable slope of the canals. These formulas were mainly based on empirical data, rather than on hydraulic theory.

The canals carried water continuously, with variations in flow depending on water levels in the parent river. Hence, there was no relation between canal supply and irrigation demand; surplus supply would simply return to the river. This made perfect sense in the early stages of development, with abundant supply of river water and limited irrigation demand. In spite of advances in hydraulic theory and infrastructure that provided more control over flow sizes, both at the headworks and at canal offtakes, the feature of continuous flow in the main canal remained. This was done in order to maintain a flow velocity that is high enough to prevent siltation. Again, this mode of operation can be quite efficient as long as there is not much variation in irrigation demand, as is the case in regions with negligible rainfall.

It is not compatible, however, with a mode of operation that seeks to make maximum use of natural rainfall, as this would require a system that can cope with large fluctuations in irrigation demand. In addition, the suggestion of the Howards to charge water on a volumetric basis could not be followed-up; not only for lack of discharge measurement structures, but also because the distribution system did not offer the option of either storing surplus water and using it at another time or redirecting it to another place where it could be beneficially used. The 'overhaul of the perennial irrigation systems' recommended by the Howards would indeed have required a complete revision of the irrigation design and operational practices.

### 3.2.4 Discussion: Irrigation and its potential role in building social capital

Elizabeth Whitcombe's verdict was that canal irrigation '*caused pronounced environmental and economic disruption*' and also '*disrupted the* [farmers'] *former pattern of work'*.

Sir Albert Howard complained that '*irrigation in India has been looked upon largely as an engineering problem*'.

Stone contradicts Whitcombe and concludes that irrigation stimulated economic development.

The above mentioned authors all wrote before the issue of Bruntland's Report of 1987 on Sustainable Development, which advocated economic development in harmony with social and environmental objectives. In short, the need to balance the three E's (*Economics, Ecology, Equity*) or three P's (*People, Planet, Profit*).

Reflecting this line of thought, the new field of '*ecological economics*' aims at obtaining an optimal mix of man-made capital, natural capital and social capital. Another new specialized field is '*institutional economics*', which besides the cost of production also considers the cost involved in making agreements – and living up to them - between economic actors. In the field of natural resources management, the belief that science and technology provides the means to control nature has been replaced by '*adaptive management*': as we now know that we cannot accurately predict the outcome of our interventions, we need to monitor their effects and be ready for taking corrective action.

Howard criticized the builders of canal irrigation for paying too little attention to natural capital; Whitcombe evaluated the effects of canal irrigation on social capital from the point of view of diminishing natural capital; Stone regarded the shift from subsistence agriculture towards a market-orientation as positive, also in terms of contributing to social capital[13]. This difference of opinion shows that there are different criteria for valuation of social capital; perhaps as many as there are worldviews.

Just like social and natural capital are not really new concepts, the same can be said of *adaptive management*: the early history of canal irrigation in India is very much one of building up experience through trial and error, or learning by doing. What strikes me as most unfortunate is that this capacity for adaptation seems to have largely disappeared. Unfortunate too, is that this loss has occurred so early: in the 1870's, when it became official policy in Northern India that 42.5 % of the cultivable area within a village should receive irrigation water. Stone's comments on this policy: 'In practice, the guidelines were impossible to adhere to, but the principle was clear; equity was to be an important guide in the establishment of the distribution system; as many villages as possible were to be served, with a view to maximizing protection rather than production' (Stone 1984).

Adaptive management requires monitoring of the effects of one's actions, recognizing undesirable outcomes and taking corrective action. Imposing impossible guidelines on a group of professionals kills every incentive for a critical evaluation of the outcomes of one's actions and for taking corrective action. If the situation is

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[13] This is perhaps best illustrated by Stone's words: *'irrigation was 'absorbed' according to the priorities and complexities of the peasant system.'* (p. 194)

allowed to continue, the professional has no option -apart from resigning from the job- than to learn how to cover up the gap between official policy and the actual results. In stead of solving problems, he becomes apt at ignoring or hiding them.

Stone, apparently, was less dismayed by the '*impossible guidelines*' than I am, possibly because he found that at least '*the principle was clear*' and '*equity was to be an important guide*'. In my perception, the equity principle was just as impossible to achieve in practice, for various reasons:

1. **Irrigation design**
   Proportional distribution of incoming flow is technically relatively simple; it has been accomplished with local building materials in traditional irrigation systems that proved sustainable over centuries. The irrigation systems built by the British in Egypt also used the concept of proportional distribution. This functioned well enough until the introduction of the transportable diesel pump undermined an essential feature of the design. This feature was the need for cultivators of lifting the water from the distribution canals. Lifting was done by camel driven waterwheels, with limited pump capacity that became even smaller with falling canal water levels. Installation of waterwheels was subject to license. Equitable water distribution in the Egyptian systems was feasible, therefore, through an appropriate mix of hardware (proportional distribution in main canals, water level in distribution canals below field level, waterwheels with inbuilt capacity reduction under conditions of water scarcity) and software (licensing of lifting devices, policing against lifting without license).

   Canals in British India initially had to compete with irrigation wells. A major 'selling point' of canal water was that it did not require lifting from the source. Hence, water level in the distribution canals was above field level. Irrigation engineers used hydraulic infrastructure that was based on proportional distribution, in the main canals as well as at the inlet of the distribution canals. Although these structures were made of concrete and steel, they were easily bypassed by digging through the embankment, rewarding the illicit digger instantly with a supply of water in excess of his proportional share.

2. **Social capital**
   Traditional irrigation systems would rely on a combination of locally-made infrastructure that was effective in operation but not tamper-proof and social control for checking such tampering. In these systems, the software – or social capital – compensates the vulnerability of the hardware. The required social capital may result from past experiences with mutual assistance or from joint efforts in developing irrigation infrastructure.

In British India, for a short time, the right to construct an outlet from the main canal was sold to any interested party, leaving the construction and operation of the water distribution to local initiative. Rather than resulting in building up of social capital by jointly building and operating of the infrastructure, this resulted in speculation – where the right to use the outlet was constantly transferred at a high premium – and gave 'powerful rural elements an unduly pervasive and lasting influence over the manner in which water was distributed' (Stone 1984).

In an attempt to regain control, this practice was abandoned in the post 1860's period, with the agency built irrigation system being extended to the village level. For reasons explained in the above paragraph, however, the hardware used was by no means tamper-proof. Moreover, the 'powerful rural elements' could simply redirect their influence and manipulate the water distribution at the village level.

In conclusion, neither the hardware nor the software used in canal irrigation in India could realistically achieve equity in water distribution. Yet, equity has been upheld as a guiding principle and remains official policy until today.

## 3.3 South and East India, Krishna Basin

### 3.3.1 General outline

Under colonial influence, water was diverted from its role in the survival economy and nature's economy and was transformed into a source of revenue and taxes, or as an input to commodity production for the generation of profits. The introduction of market forces in the water economy of the country created new conflicts over water resources between the market and survival economies[14].

More than half of the total area under government-owned perennial canal irrigation in British India in 1945 was in the northwest, which is predominantly arid to semi-arid. Another 25 percent was located in the wetter south (Kumar 1982). The relatively wetter conditions in the south provide better opportunities for rainfed agriculture and rainfall dependent water technologies.

> *'Large-scale water projects which work against nature's water economy and people's sustenance requirements have been designed by destroying water technologies which were ecologically more sustainable and socially more just.' (Shiva 1991)*

Shiva describes different types of indigenous water harvesting and irrigation technologies, corresponding to variations in rainfall, soil and topographical conditions. Among them is the impressive tank system of South India, which has survived over centuries. It consists of several hundred and in some cases over a thousand reservoirs linked together. While Shiva states that in some regions 'these tanks still play a central role in irrigation even today', she also indicates that the 'immunity [against famine] was eroded following the deterioration of these irrigation works, which was primarily a consequence of breakdown in economic and social systems which ensured maintenance of the water systems.'

[14] Source: Shiva, V. 1991.

In his account of irrigation developments in the Krishna Basin, Wallach says that when the British came into this part of India in the early $19^{th}$ century, they 'found a ravaged countryside' with most of the indigenous irrigation works – however impressive - in ruins or on the verge of collapse. He gives accounts of pre-Raj famines, e.g. that of 1832 when 'two-fifth's of the people in the [Krishna] delta would perish with the failure of the monsoon.' (Wallach 1985).

### 3.3.2 Early success

The British restored some of the ancient works as well as building new canal systems. Sir Arthur Cotton, after reconstructing systems at the mouth of the Cauvery and Godavary rivers, persuaded the East India Company to develop irrigation canals in the Krishna delta. As the Company was not sure whether the farmers -who were used to rainfed rice cultivation- would be willing to buy canal irrigation water, the command area was made about ten times larger than could be irrigated with the available supply. It turned out that canal irrigation was indeed welcomed by the farmers; by 1878 around 500,000 acres of paddy were irrigated, which was eventually doubled after a number of expansions of the system.

The Indian Irrigation Commission of 1901-1903 wrote of Cotton's delta projects that 'it would be difficult to find in any country three works of similar magnitude or cost which have conferred the same degree of benefit upon the people and the state'. (Cited in Wallach 1985).

### 3.3.3 Early signs of trouble

Cotton returned to England in 1855 because of ill-health but continued to promote canal irrigation; not only because he felt that 'the sole cause of famine is the refusal to execute the works that will give us the use of the water that is at our disposal' but also because he insisted that a network of navigation canals throughout India was a much more appropriate technology for India than railways. The canals would have dual functions and produce double profits.

D'Sousa describes a scheme that Cotton managed to 'sell' to the East India Company in 1858. It combined navigation, irrigation and flood control in the Mahanadi delta (State of Orissa) and would yield a 30 percent return on investment (D'Sousa 2003). This time, however, the farmers had little interest in buying canal water; besides the delta's high rainfall, the cultivators had access to various traditional irrigation sources.

D'Sousa describes the colonial administrations moves aimed to 'divorce the cultivators in the delta from ownership and access to their means and conditions of production, in order to then confront them with canal irrigation as a commodity subject to the market imperative.'

These moves included:

- Act III of 1876, which empowered the East India Company with the right to regulate the delta's drainage. This enabled systematic destruction of small dams that cultivators would constructed to divert water from natural drains to their fields;
- Construction of drains that destroyed farmers ponds and emptied small streams from which farmers used to collect water;
- Alignment of irrigation canals in such a way that they would obstruct natural streams, which cultivators previously used for irrigation.

According to D'Sousa it was clear that 'the colonial administration sought to increase the spread of canal irrigation in the Orissa delta by forcibly foisting it upon a large number of cultivators.' He gives a vivid account of violent disturbances, of farmers collectively resigning from their canal irrigation leases and petitioning to the Collector against the canals.

The same author suggests another reason for the farmers not responding well to the scheme: the flood protection component interfered with farmers' deliberate practice of diverting silt laden river floods to fertilize their land with the fine clay. He refers to Sir William Willcocks – another celebrated irrigation engineer of the British Empire – who argued that a system of overflow canals previously traversed India's eastern deltas and irrigated vast stretches of land: it was a combination of the rich red water of the river and the rainfall that sustained the high agricultural output in the region for centuries prior to colonial rule. The deposition of silt, in addition to maintaining fertility also gradually raised the level of the flood plains, thereby providing a degree of protection against flooding.

### 3.3.4 Discussion: Irrigation, imperialism and capitalism

Elizabeth Whitcombe criticized the developers of canal irrigation in Northern India for disturbing the traditional practices by which the peasants protected themselves against the risks of inadequate rainfall.

D'Sousa presents a case where a poorly functioning canal irrigation and flood protection system replaced a traditional system that had proved to be sustainable over centuries. In D'Sousa's perception, this was not just the result of an over-ambitious canal builder, but a typical example of capitalism transforming nature in order to make a profit.

In a comparative study of British and Dutch colonialism, respectively in Burma and Indonesia, Furnivall (1956) concludes that capitalism was allowed to run more freely in Burma, whereas in Indonesia social constraints were imposed by the colonial government. Another major difference was that the Dutch kept most of the traditional social institutions, while the British brought all institutions under British law.

Willcocks' remarks about the benefits of irrigation with silt laden water are confirmed by Dutch agronomist Den Berger, who investigated the effects of silt loads of irrigation water on soil fertility and rice yields (Berger 1915). The defense of his PhD thesis was held at the Technical University in Delft, because the Agricultural school in Wageningen did not have academic status at that time (1915).

The thesis includes 12 propositions, two of which correspond with the recommendations made by Howard in the same year (refer to preceding section/chapter):

- Proposition VIII: 'The irrigation works in the Dutch Indies should be managed by agriculturists'.
- Proposition IX: 'It is recommended to collect irrigation fees from cultivators, local as well as European'.

### 3.3.5 Developments after Independence

> *'Still, after the record of British failure, the government of India might have looked back at the British irrigation works and wondered at the obstinacy that led the Raj to continue building projects that were crippled the day they were finished.'*
> *'India after 1947 did not ask these questions. The result was that no effort was made to prevent India from falling into a variation of the colonial trap. Instead of foreign masters who could not seek advice from villagers, India now developed a bureaucracy that was even more hierarchical and dismissive of the people it served.' (Wallach 1985)*

The projects in the Krishna Basin that Wallach refers to are what he calls 'high-tension' projects, which are designed to spread the available water thinly over a large area, in order to reach as many farmers as possible. This only works when each farmer takes less water than would be needed to cover the water requirements on all of his land. For Wallach, '*the real culprit'* responsible for the '*crippled*' projects referred to in the above quote, was '*the weakness of the political institutions needed to ration water*.'

Wallach quotes N.V. Gadgil, who was the first minister of public works under Prime Minister Nehru and told the parliament in 1950: "the main problem of this country as everybody knows is that of food" and "unless irrigation facilities are increased a hundred fold the problem of food is not going to be solved."

In the Krishna River Basin, the area under irrigation increased about five fold, due to impressive works such as Nagarjunasagar, proudly advertised as 'the world's biggest masonry dam'. Wallach comments: 'The dams and canals are splendid monuments, but as water-distribution systems they are rarely able to deliver water to more than half of their commands, or service areas. The problem is partly an engineering one, with leaky, undersized canals; more fundamentally however, the problem is political, for the government is unable to prevent farmers at the upper or head ends of the distribution system from taking so much water that the tail end runs dry. Despite a decade of efforts of stopping this kind of irrigation abuse, there is much pessimism.'

Wallach continues: ‘An irrigation engineer for FAO writes, “I have no suggested solution. It is becoming very difficult to live with any rational solution to water distribution.” Little has been published on the subject, perhaps because India has so much money, professional pride, and dreams of prosperity invested in the projects. Yet many irrigation engineers in India will admit privately that the waste of developmental funds is staggering. There is too much at stake for the problem to be tactfully ignored’ (Wallach 1984).

### 3.3.6 Localization and Irrigated Wet & Irrigated Dry

In 1984, the Government of Andhra Pradesh (GOAP) issued the Irrigation Utilization and Command Area Development (ICCAD) Act. It aims at spreading the benefits of irrigation as widely as possible. Irrigated areas are classified as "Irrigated Wet" (IW) and "Irrigated Dry" (ID) under a procedure known as "Localization". In IW designated areas, all crops may be grown but farmers grow mostly rice and sugarcane. In ID designated areas (usually lighter soils), rice and sugarcane are specifically banned under the provisions of the 1984 Act because farmers in the canal head reaches would prevent water from reaching the tail-end areas. Section 24(2) of the 1984 Act allows GOAP to alter the Localization designation of an area if it wishes to advance the technology of land and water management practices.

### 3.3.7 Andhra Pradesh Irrigation Project

In 1986, the World Bank approved funding for the second Andhra Pradesh Irrigation Project (AP II) for an amount of about US $ 300 million. It included rehabilitation of 234 000 ha in the Srimasagar Project (SRSP) which was also to be extended by 34 000 ha, and new development of 65 000 ha served by the Srisailam Right Branch Canal (SRBC). New water management principles were to be introduced ‘to implement GOAP’s policy of equitable and cost-effective delivery of available water to a maximum number of beneficiaries’ (World Bank 1997). All new and rehabilitated areas were designated as ID areas (see paragraph above) and would receive a reduced water supply. The project was cancelled in 1994, with only 52% of the budget spent. Its overall rating was highly unsatisfactory and the institutional development component negligible. AP II received the worst rating of 48 water resources projects in India in the World Bank portfolio in the period 1990-2000 (Pitman 2002).

In 1997, World Bank approved a US $ 150 million credit and US$ 175 million loan for AP III. The project would assist GOAP to complete the work started under AP II. The main stated project benefit of AP III was that ‘the project would reduce production variability and enable an increase in the production of high value crops estimated at about US $ 140 million per annum’ (World Bank 1997). The Staff Appraisal Report (SAR) envisaged ‘significant shifts from low value to higher value crops as a result of rehabilitation works and expansion of reliable canal irrigation to the whole command’. The increase in average farm income was estimated to be 360% in the new areas, 104 % in the rehabilitated areas and 197 % in the partially completed areas. In spite of these huge expectations, the agricultural component of the project was only a mere 2.5 % of the total budget.

### 3.3.8 Discussion

As in the colonial era, the GOAP and the Irrigation Department are eager to expand irrigable area by building new canals, even though irrigation water in the existing systems hardly ever reaches the tail ends. The World Bank assists in making it plausible that the additional irrigation water needed for the expanded area can be obtained by simultaneously improving the productivity* and the efficiency* of water use in the existing command. If effective, this combination results in more value being produced with less water.

This miracle can be accomplished if the large majority of farmers shift from rice to a less water demanding, higher value crop. The key to performing the miracle is more reliable irrigation services; this is perhaps best appreciated by comparing water management for rice cultivation with that of other crops. Rice is one of the few crops that tolerate – and sometimes even benefit from - submergence of their root system for a prolonged period of time. By simply maintaining a shallow layer of water in the field, farmers obtain optimal moisture conditions.

More importantly, this water acts as an on-farm storage reservoir, which offers farmers a degree of protection against unreliable irrigation services or inadequate rainfall. Farmers will only be prepared to give up this insurance when they are fully convinced that they can rely on the irrigation agency to provide them with timely and sufficient irrigation water. In addition, farmers need to adopt other water management and cultivation practices:

- **Need for more irrigation ditches**. When practicing rice cultivation with inundated fields, irrigation water can flow from field to field. If fields are not submerged, small irrigation channels are required to transport water. These channels take up land, which could otherwise be cultivated. This is even more problematic when farmers have to give up land for the construction of canals that distribute water to other farmers;
- **More effort in land preparation**. Even distribution of irrigation water in a non-submerged field requires greater accuracy in land leveling and/or preparation of irrigation furrows or borders;
- **More difficult to assess adequacy of on-farm irrigation**. In order to achieve optimal moisture conditions, farmers must apply a volume of irrigation water that is just adequate to replenish the rootzone of the plant to its maximum moisture holding capacity. Any excess volume applied will leach out nutrients, under-irrigation may lead to moisture deficiency before the next irrigation application is due.

  Farmers in AP generally do not have the means of knowing the moisture holding capacity of their field and the actual moisture content prior to irrigation. This means they cannot know exactly how much irrigation water to apply. Even if they could calculate the required irrigation volume, they have no means of measuring it.

The above doesn't say the miracle cannot be performed; the message is that it would require enormous efforts from the irrigation agency as well as from the farmers. Even more importantly, the two sides would need to be fully committed to engage in a mutual trust building exercise. One might have expected that the World Bank would have insisted on firm evidence of this commitment as a condition for providing financial support. Especially since achieving the production increase predicted in the SAR entirely depends on achieving the shift in cropping pattern from rice to high value crops.

The limited budget for the agricultural component and the fact that this component was only aimed at the farmers and not for giving agricultural education to irrigation engineers may suggest that this component was added just to give credibility to an extraordinary high estimate of agricultural production increase resulting from expansion of an irrigation system that is already facing water constraints.

Apart from increasing agricultural production, the shift towards non-rice crops was also expected to free up water, thereby reducing the water constraints. As explained above, this shift will only occur when irrigation services become more reliable. Apart from rehabilitation works, the SAR for AP II does not mention any upgrading of main system operation by the irrigation department for achieving more reliable irrigation services. This is highly surprising, because without reliable water supplies at main system level, it is absolutely impossible to achieve adequate distribution among farmers.

The Implementation Completion Report (ICR) for AP III became available in January 2005. The overall performance of the project was rated 'satisfactory', while the institutional development impact was rated as 'modest'. Under the heading 'Agricultural Support Services', the ICR states: 'Overall performance is considered satisfactory in view of the good performance of the research and demonstration undertaken by Acharya N.G Ranga University (ANGRAU). A total of 2782 research trials and 1054 small and large-scale demonstrations were undertaken and a broad range of agronomic and water technologies developed.'

ANGRAU has 41 research stations in the AP, many of them with their own irrigation facilities. This makes them independent from the functioning of large-scale public irrigation systems. Research trials conducted at those stations bear little- if any – relation with the problem of unreliable irrigation services in those public systems. The use of the term 'agricultural support services' again suggests that agriculture was not considered as the central objective of AP III.

The Project Preparation & Monitoring Unit was reported to have 'functioned satisfactorily providing timely information and reports. However, insufficient attention was given to independent project assessment and evaluation. The base-line survey, inordinately delayed and not completed until 2003, was based on secondary sources of data for a single season'. In spite of these shortcomings in data collection, the ICR authors managed to calculate the Economic Rate of Return, which was claimed to be 14.7% at project closure. The IRC provides tables showing an increase in the value of production, but does not discuss to what extent the shift from low to high value crops has taken place or whether irrigation services have become more reliable. It does mention that: 'two consecutive years of drought in 2002 and 2003 delayed release of water throughout the 65 000 ha command of SRBC, thereby delaying the project impact'. This information is given under the heading: 'Factors outside the control of government or implementing agency.' This brings up the question: "*What is the point in investing in large-scale irrigation systems if they don't protect farmers against inadequate rainfall?*"

In my view, the story of AP III confirms what is suggested in the title of this paper: that the irrigation sector seems to have forgotten what irrigation is all about.

### 3.4 Towards a solution: Change the way we think about water and agriculture!

*'Change the way we think about water and agriculture!'* is the first of 8 policy actions formulated by the Comprehensive Assessment of Water Management in Agriculture (Molden 2007). Instead of a narrow focus on rivers and groundwater, we should consider *rain* as the primary source of water. The implication is to give more attention to rainfed agriculture and supplementary irrigation. Resolving the problems in the Krishna basin requires a set of new paradigms to make agriculture regain its central place in irrigation development:

- Redefine the purpose of irrigation as reducing risks to farmers resulting from unreliable rainfall;
- Recognize rainfall as the primary water resource and the landscape as a major factor determining how much of the rainfall can be 'harvested' for beneficial purposes;
- Redefine the role of farmers from mere users of water, to 'processors of rainfall' whose actions have a large impact on water security in the river basin;
- Recognize the primary responsibility of agricultural engineers for developing solutions that provide basic food and water security through exploring the potential of 'green infrastructure' options, using their insights in interactions between rainfall, landscape, cropping patterns, agronomic practices and terrestrial and aquatic ecosystems in the river basin;
- Recognize the primary responsibility of civil engineers for developing 'hard infrastructure' for two main purposes: 1. Supplementing deficiencies of 'green infrastructure' in providing basic food and water security, and 2. Maximizing productive use of the water that remains after basic needs have been met.

# PART C: TOWARDS JUDICIOUS LAND AND WATER DEVELOPMENT AND MANAGEMENT IN THE KRISHNA RIVER BASIN

# 4 Rethinking irrigation

*Bart Snellen*[15]

***Preface***

This chapter is aimed at providing some solutions to the problems presented in Chapter 3. It is not specific for India and can, therefore also be seen as a supplement to the chapter on irrigation in *The Value of Rain* (Alterra-report 1325, 2006).

As I was working on this paper, IWMI published the report: *Water for food, Water for life,* which is the outcome of a 5 year international research project (*Comprehensive Assessment of Water Management in Agriculture*, CA), which involved some 700 researchers. The summary report gives 8 policy actions. The first one is:

> *Change the way we think about water and agriculture.*

Some quotes from the CA report:

- 'It is time to abandon the obsolete divide between irrigated and rainfed agriculture. In the new policy approach rainfall will be acknowledged as the key freshwater resource.' (p.19)
- 'We need to consider agriculture as an ecosystem and to recognize the importance of preserving the natural resource base on which agricultural productivity rests'. (p.19)

The recommendations of the CA seem to correspond largely with the ideas that I presented in *The Value of Rain* and the conclusions of Chapter 3. The CA report also has a chapter entitled *Reinventing Irrigation.*

The CA was, however, issued at the time of this report. It was considered appropriate to analyze the CA before presenting the final version of this chapter. The working draft of this chapter has, however, been distribute to a limited group of readers.

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# 5 Scope for improvement of overall water benefits by allocative water management

*Petra Hellegers*[16]

## 5.1 General outline

The purpose of this chapter is to present a methodology that is capable of assessing the private economic impacts of redistributing water. To illustrate how the methodology works, the Musi catchment, a sub basin of the Krishna River, is used as case study.

This chapter and the case are based on work done by Davidson et al. (2007). It is important to note that the analysis is based in part on information about farm input prices, crop yields and market values - all of which vary from season to season - but the sample data used just serve to highlight underlying issues. Problems are not resolved in this chapter. Rather, aspects of a methodology through which these problems could be addressed are presented (Section 5.2). In Section 5.3 the implications of water reallocation between competing claims in the Musi catchment are assessed to show whether there is scope for improving the overall benefits from water reallocation among the major water user. In Section 5.4 the potential role that water valuation can play in assessing the gains from more reliable water supply is discussed.

## 5.2 Methodology to assess the private economic impacts of redistributing water

To an economist it is important to measure the benefits that can be derived from controlling water, while accounting for the costs of undertaking such an act. Hopefully, but not necessarily, the benefits of such an act will outweigh the costs.

Two important and related economic elements need to be stressed. First, water is an input to a production process. If one is to assess the benefits of controlling water, then it is imperative to value the outputs or uses that are derived from water, not necessarily the water itself. Second, given that water is combined with other inputs to produce outputs, it is also imperative that the value that water adds to the outputs is determined separately.

In this study the aim is to measure the private economic effects of changing the distribution of water. What are measured are the economic surplus changes that result from changing what water is used for (see Figure 1). The supply and demand

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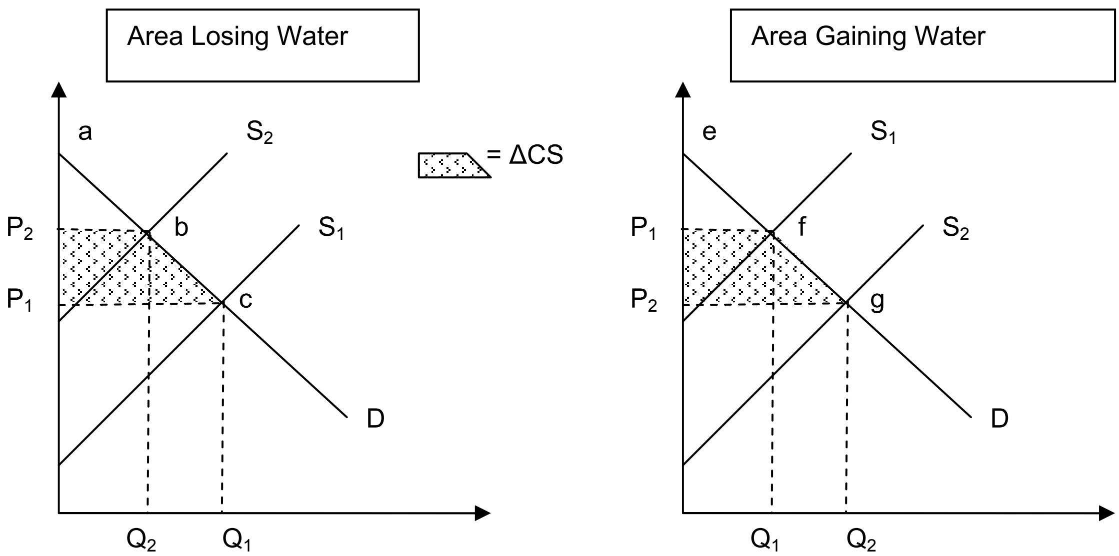
schedules represent the marginal cost and benefits (respectively) from water used to produce outputs in an economic system. Economic surplus is the value producers and consumers derive from the production and consumption of a good, above what they would pay for that production. It is equivalent to the area between the supply and demand schedules over the range of the quantity produced (see Figure 1). Any change to the regulation of water flows will result in the marginal cost curve shifting (from $S_1$ towards $S_2$): outward, in the case of more water being made available for the production of the good in question, or shifting towards the origin in the case of water being restricted from a production process. Any change in the marginal cost curve will change the area of economic surplus. It can be assumed that the marginal cost curve is perfectly elastic (or horizontal at the price level in Figure 1) if only small changes are made to the distribution of water. It is this welfare change that economists prefer to measure (Sinden and Thampapillai, 1995).

What is measured here is the economic impact of changing the way water is controlled in the Musi. Of interest is the cost to agricultural producers along the Krishna River, and the benefit to domestic and industrial users in Hyderabad and agricultural producers downstream of Hyderabad.




CS before redistribution: $acP_1$ | CS before redistribution: $efP_1$
CS after redistribution: $abP_2$ | CS after redistribution: $egP_2$
$\Delta CS$ = area $P_2bcP_1$ (loss) | $\Delta CS$ = area $P_1fgP_2$ (gain)
$Rs/m^3 = \Delta CS/(Q_1-Q_2)$ | $Rs/m^3 = \Delta CS/(Q_2-Q_1)$

*Figure 1. Economic values to be measured*

For more details on the general approach to modelling the whole Krishna basin see Davidson et al. (2006). While the whole basin needs to be modelled from a social perspective, the private costs and benefits of redistributing water around the Musi basin can be assessed initially and separately. In undertaking this task what is modelled is the impact of moving water from one part of the basin to another, from the perspective of those who lose and those who gain from any redistribution.

*The Hydrological component*

Details of the hydrological model are presented in George, et al. (forthcoming). In this model the hydrological effects of changing the distribution of water amongst agriculture, domestic and industrial sectors is assessed. In particular, in the simulation that is undertaken water is redistributed away from the agricultural zone serviced by the left bank canal of the Nagarjuna Sagar and sent to supply the domestic and industrial sectors in Hyderabad, with concomitant flow on effects on the agricultural zone downstream from the city, known as the wastewater irrigated area. It is further that 80% of the water received by the city flows to the wastewater irrigated area. In addition, 20% of the water that leaves the original source is lost before it arrives in Hyderabad. Finally, the year analysed is 2002-03, a very dry year and one in which producers did not receive their full entitlements of water.

*Costs of supplying water in the system*

The costs of supplying water from various supply points to Hyderabad City range from 3 Rs/$m^3$ from reservoirs close to the city to 18 Rs/$m^3$ for water from the Krishna River. It should be noted that as the supply system has grown, the costs of supplying water to Hyderabad have increased. Of interest in this study are the costs of accessing water from the Krishna River. It is assumed that the costs of accessing extra water from this source remain constant at 18 Rs/$m^3$. The implicit assumption in using this figure is that the costs of distributing water under the current regime are non existent.

*Benefits*

The benefits from water are derived by those who use it. In this basin those users can be segregated into domestic and industrial consumers based in Hyderabad City and agricultural producers. Details of the consumption of water throughout the basin and the benefits derived from it are detailed in Table 1. It should be remembered that as water is only one of numerous inputs into a production process it is necessary to only account for the benefits water adds to that process, not the totality of the benefits from that process.

*Table 2. The Quantity of Water Demanded and the Values Derived from its Use 2002-03*

| Item | Water Qty ($m^3$ million) | Consumer surplus (Rs. million) |
|---|---|---|
| Agricultural users | 976 | 1,102,050 |
| Domestic users | 181 | 37,235 |
| Industrial users | 42 | 972 |
| Wastewater Agricultural Users | 179 | 47 |

*Agricultural water use*
The benefits of irrigation water must be estimated, since it is seldom the case that farmers bid for water under competitive market conditions involving other economic sectors. The value of irrigation water is assumed to be the net income received by the farmer per unit of water.

By far the greatest user of water in the Musi basin is agriculture. Individual input demand equations for water can be derived for each major crop, using a spreadsheet model designed by Perry (pers. Comm. IMWI, 2006). The model provides a simple framework for collecting data related to farm incomes, water and labour use and automatically computes indicative returns to land, labour and water. By subtracting the cost of other production factors from the gross production value, the net value added per unit water can be calculated (see Appendix 1).

It is possible to obtain a partial budget of a farm given: the area farmed and the cropping pattern; the quantities of all inputs (labour, surface water supplies, fertilizers and pesticides); the yields of all crops produced and their respective evapotranspiration rates; and the prices of all inputs and outputs. From this base, the average values of all inputs, including that for water, are derived. The input data needed to work each spreadsheet for each zone was derived from the District Handbook of the various regions (Government of Andhra Pradesh 2005).

It is important to note that such returns to water are difficult to compute precisely in the absence of a major modelling exercise, as the precise technical coefficients (yield/ha, water use, etc.) will vary across farms and by year. In addition, production costs are generally difficult to obtain and standard costs of production will not reflect variations among farmers. Besides that, some inputs are difficult to capture accurately because they are not monetised (like family labour), or may be subject to distortions due to taxes or subsidies (market prices often differ from economic prices due to price policies). Finally, the costs of fixed assets are not considered, as it is hard to translate financial costs of production into the economic costs.

The question is how farmers will respond to less water availability. Vinod (pers. comm, IMWI, 2006) argues that during a period of severe water shortage in 2004, farmers in the Nagarjuna Sagar command areas received limited quantities of water from the dam. Farmers reacted by not cultivating their fields. If they did anything, they put in a dry crop. As a consequence, it was decided to allow the area planted to adjust to changes in water distributions in the model.

*Domestic water use*
For domestic consumers water is a necessity of life. As such, the value of water to these consumers is incalculable. The own price elasticity of demand is assumed to be highly inelastic (at -0.1) and that any further provision beyond what is currently supplied would be consumed and valued more greatly than by any other user group. Thus water for domestic consumption is valued using an opportunity cost approach, where the price is assumed to be marginally greater than the next highest users' value of that same quantity of water.

*Industrial water use*
Hyderabad City is a large and growing industrial centre. What is not known are the quantities taken by individual industries (Van Rooijen, et al, 2005). In valuing the economic surplus by the industrial sector an elasticity of demand for water by industries is needed. Kumar (2006) estimates the own price elasticity of demand for water by various industries in India to be -0.902. Using this elasticity and the supply price to the industrial sector (of Rs. 35/m3), the economic surplus is estimated to be Rs.42 million.

## 5.3 Competing claims and water valuation in the Musi catchment of the Krishna Basin

The Musi catchment is a mature water market, as to meet the increasing demand for water from domestic and industrial use in the city of Hyderabad water has to be diverted away from agriculture. What makes this Musi Catchment interesting is that farmers use wastewater from the city, complete with its nutrient pollutants, to irrigate crops. It is hard to think of a solution in the basin in which agriculture is not affected. Supplying more water to Hyderabad increases the amount available in a downstream wastewater irrigation scheme, but also reduces the amount of water available to irrigators elsewhere in the system.

To ascertain the usefulness of our methodology the impacts of implementing what is known as Stage II and III of the Krishna River Project is simulated. Under Stage II of the Project 85 $m^3$ million is diverted from irrigators situated on the left bank of the Nagarjuna Sagar to Hyderabad. This has a flow on effect to farmers in the wastewater area. Under Stage III 159.6 $m^3$ million is redistributed in a similar manner. It should be noted that the cost of undertaking this redistribution is Rs18/$m^3$. This cost only includes the private costs of transferring the water (not the full social costs). Similarly, only the private benefits derived from this transfer are determined. The results of these transfers are presented in Table 3.

It can be concluded that the simulations worked as expected. Producers in the Nagarjuna Sagar Left Bank lose somewhere in the order of Rs.3973 million in Stage II of the project and Rs.6245 million in Stage III, while those in the wastewater area gain approximately Rs.0.04 million and Rs.0.06 million with each increase in water diverted from the Krishna River.

Domestic and industrial consumers in Hyderabad gain Rs.46,048 million and Rs. 108,342 million from Stage II and III, respectively. The benefits of the diversions outweigh the costs from any diversion, to the order of Rs.40,541 million with stage II and Rs.99,225 million with Stage III.

*Table 3. Private Costs and Benefits from Redistributing Water from Nagarjuna Sagar under Stages II and III of the Krishna River project*

| Item | Units | Stage II | Stage III |
|---|---|---|---|
| Water reallocated | $m^3$ million | 85.2 | 159.6 |
| Agricultural users losses | Rs.million | 3973 | 6245 |
| Domestic users gains | Rs.million | 45,482 | 107,160 |
| Industrial users gains | Rs.million | 566 | 1182 |
| Wastewater Agri. Gains | Rs.million | 0.04 | 0.06 |
| Cost of diversion | Rs.million | 1533 | 2872 |
| Net returns | Rs.million | 40,541 | 99,225 |

Given this outcome it could be concluded that it is in the interests of the state to undertake Stages II and III of the Krishna River project, from a purely private perspective. The costs of redistributing water under the existing system are not currently accounted for in the analysis. These need and will be included in future work and would involve an extensive social benefit costs analysis. Despite this deficiency, it can be concluded that the costs of delivering and distributing the water, along with any negative externalities that arise from using the wastewater, would need to be less than the net benefits calculated above, if Stage II and III are judged to be viable from a social perspective. So, although the results would lead one to conclude that such a project is worthwhile, such a conclusion could be considered to be premature. To understand the full ramifications of this project a more complete social Benefit Cost analysis would need to be undertaken. The analysis reported in this chapter could be used as a central component of any more detailed work.

## 5.4 Valuation and reliability of water supply

Special attention will be paid in this section to the relationship between reliability of water availability and productivity of water, as it has implications for the water required to meet specific levels of production and the design and management of the irrigation system.

Water availability can be unreliable in terms of three parameters: rate of supply, duration of supply and periodicity between successive deliveries. While there has been extensive research in the impact on actual yield of variations in water availability, little is known about the impact on farmer behaviour of his *ex ante expectations* of variation in water availability.

It is likely that the farmer will be ready to invest more in a chosen crop if the availability of water is more secure: he will be ready to select high yielding but water sensitive varies, prepare the land carefully, plant intensively, and invest in high quality seeds, fertilisers and pesticides. It is therefore interesting to derive the value of reliability of water delivery. It is likely that returns to water - with a rather reliable supply - are higher than returns to water with a rather unreliable supply.

Insight into differences in the water productivity of water –both in terms of the agricultural yield per unit of water consumed as well as in terms of the net agricultural production value per unit water consumed- among various farming systems will enable us to assess the benefits from more reliable water supply. The gains from reallocation can be immense when there are significant differences in the value per unit of water consumed across farming systems. For example, a farming system that receives an unreliable water supply may generates not more than $0.05 per cubic meter of water, while a farming system that receive a very reliable supply may generate more than twice that value. This means that farmers will be willing to pay for a more reliable supply of water.

To achieve more reliable water supply and improve water allocation, changes in laws and institutions governing water use and allocation are required.

Estimating returns to irrigation water for different farming systems enables us to assess the benefits from more reliable water supply. One representative Perry spreadsheet has to be made for each farming system. The minimum data requirement to make such a spreadsheet for each farming system is:

- Area of each crop farmed
- Yields from each crop
- Output prices for each crop (not the ones received by the farmers, but the shadow prices received in the market, less the implicit tax)
- Prices for each input (once again net of any subsidies received).
- Labour requirements, though the model will work without them.
- Monthly surface water requirements available in each zone.
- Fertilizer application rates
- Surface water supplies
- Reliability of water supply

However, no primary data have been collected so far for the different farming systems in the Krishna Basin, which is required to assess differences in water productivity (returns to water) due to reliability in availability, for the various farming system.

## 5.5 Remarks

The purpose of this chapter was to present a methodology that is capable of assessing the private benefits and costs of distributing water within a catchment. Given that water distribution schemes involve massive public investment, a more ideal model would be based on a social benefit cost methodology. In India the prices of inputs, such as water and fertilizer are subsidised, while outputs tend to be taxed implicitly through a set of low procurement prices (Gulati and Narayanan 2003). In a social benefit cost analysis these effects would need to be accounted for and taken out of the analysis. As in this chapter we only aim to illustrate the methodology only private benefits are assessed. Any cultural and/or environmental impacts have also been ignored, but should be considered ideally. Finally, given that water has both a spatial and a temporal element to it, an ideal model must be capable of assessing the impacts changes may have on diverse regions at different times. In this chapter the first step towards that type of model is made.

# 6 Scope for improvement of agricultural benefits by allocative water management

*Prem S. Bindraban[17], M. Devender Reddy[18], Senthilkumar Kalimuthu[19]*

## 6.1 General outline

Agriculture is by far the largest user of water ranging from over 90% of water withdrawal from natural systems in various developing countries in the semi-arid regions, to some 50% in highly industrialized nations. The use efficiency in agriculture of water is rather low, as a small fraction of both irrigated water and rain water only is actually used as transpiration, i.e. the actual physiological process in crop growth. Largest amounts of water would therefore be saved as a means to resolve water scarcity problems by raising the use efficiency of water in agriculture (Molden et al., 2007).

A range of agronomic practices can be introduce at the field scale to improve the water use efficiency, some of which will be briefly introduced in this section. In Hyderabad in particular, rice is a major crop that uses excessive amounts of water per kilogram of rice produced. Research has shown that water use can be reduced by half without penalty on rice yields at the field scale.

Whether farmers will adopt or adapt the management practices associated with water-saving rice depends very much on an array of factors internal and external to the farm household. Internal factors are under the control of the farmer, while external factors are imposed on his/her farm household activities. The many small-holders in Hyderabad develop their specific systems to deal with their environmental diversity by matching crops, crop mixtures and animal to the variations in the immediate biophysical environment and the reliability of resource supply such as water. In addition, socio-economic, institutional and cultural factors such as educational level, family circumstance, communal use or private land rights, and distance from the household to the market further shape the characteristics of the farming system. Increasingly, income is generated through off-farm employment as revenues from agricultural activities are decreasing due to overall decline of food prices. Therefore, many different forms of farming systems may develop even within short distances. Adoption by farmers of the new management practiced will therefore depend on total package of on- and off-farm activities, farm size, irrigation source, water and labour availability, use of other inputs and knowledge of the new technologies. Comprehensive understanding of factors affecting farm livelihood is hence needed to support the adoption process. It is for this reason that options to

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enhance water productivity should be developed in the view of the entire farming system (e.g. Bindraban, 2006; Langeveld et al., 2005).

Scope for water saving practices should be looked for in the context of enhancing farm livelihood. Options might include incremental adjustments, i.e. single and relatively simple changes to the existing systems, or entirely new approaches that might alter and affect a range of activities at the farm and in the household. Indications of some of these options will be described only briefly, as the research to classify farm households is still on-going.

## 6.2 Backgrounds of low water productivity in the agricultural sector

In his essay "The Tragedy of the Commons" Hardin (1968) claims that farmers are not concern about the "commons", i.e. resources that are shared by a group of people. Every individual is using as much as possible of the commonly available resources to maximize profit. This is especially true for a fluid resource like water that is not strictly allocated to individuals such as land. This strategy may have unfavourable consequences for others and might eventually negatively affect themselves. When the reliance for natural resources is high, as is the case for the resource poor farming community in Hyderabad, resources will be allocated such as to secure livelihood at the short term, which in the long term may turn out to be unsustainable. Incentives to use natural resources more efficiently should therefore not emphasize the resource itself but associated factors such as total income, opportunities to diversity income, risks associated with current and alternative practices etc. Classification of farming systems is a first step in identifying entry points as to how new technologies and approaches can be successfully embedded in farming systems.

Farm households that rely on a limited resource base are facing various challenges at the same time. The small land area does not allow much diversification and any failure to properly manage the production system creates high and unacceptable risks, which may lead to risk aversion, little abilities to engage in loans for investment, and inability to adopt new and unknown practices, no matter how innovative.

The reliance on rainfall for instance is high, but the low and erratic nature of the monsoons in this tropical semi-arid zones leads to moisture deficit for crop production. While farmers do receive irrigation water, they have little control over its availability as irrigation boards are responsible for the supply of water from reservoirs. The reliance on water is further jeopardizes because of the decreasing groundwater level from 5-10 meters below soils surface some two decades ago to almost 60-100 meters to date in some regions (REF?). The deficient and uncontrolled availability of water entails high risk to crop failure which in turn hampers investments. The resulting low productivity and high vulnerability of farmers who have to cope also with decreasing prices of basic food items, such as rice, place them in a difficult situation to escape poverty (Brugere and Lingard, 2002; Ellis, 1988; English, 1990).

One of the means for farmers to minimize risk of crop failure is to over-irrigate their crops, particularly if water for irrigation is available free of charge. The high inefficiency of water use is obvious; over-irrigation of e.g. rice fields upon delivery through the canal for irrigation leads to inefficient water use in the head of the irrigation canal and water deficit to the farmers at the tail end. Barret and Skogerboe (1980) demonstrated that doing so was economically safer, although potentially leading to problems of water theft and conflicts over the use of common resource. It is understandable therefore that under moisture deficit condition the common interest among farmers to utilize the available natural resources more effectively within the community is hard to realize because of experienced risk and uncertainty to the individual.

## 6.3 Farming systems and water reliability

Agricultural holdings in India are generally small and fragmented with tiny plots scattered over the village. The size of the small holding is even further decreasing because of increasing population, inheritance laws and a decline in joint family systems. The total number of small holdings in India increased from 71 million in 1970 to 106 million in 1990 whereas the area remained almost the same, marginally increasing from 162 to 166 million hectares in that same period. A substantial proportion of the small holdings are marginal farm households with less than 1 hectare. Together with the medium farms with 1-4 hectares, they account for almost 60% of the farms. The number of large farms with more than 10 hectares declined from 3 million in 1970 to 1.6 million in 1990 with total area declining from 50 to 29 million hectares.

There is a strong relation between farm size and agricultural activities undertaken. Small farms prioritize food self sufficiency, which allows the growth of cash crop only when subsistence needs are met. Larger farms can therefore devote larger areas to cash crops. The reliance on natural, social and economic resources differ between the farms which result in different responses to changes in internal and external factors. On the one hand, the need for minimizing risk calls for diversification, on the other hand, the cultivation of some crops may be very persistent. The persistence of millet in dry regions should be explained from risk minimization point to view to secure food availability. In other occasions rice cultivation is maintained by farmers that convert their inundated rice cultivation to dry crops like banana and sugarcane, because of the cultural desire to produce your own rice. The activities also depend on socio-economic aspects such as land ownership, literacy rate of farmers to adapt and adopt new technologies, prices of commodities etc.

Farm typologies are a means of categorization, which enables to organize the wide diversity of actual farm households from a perspective relevant to the objectives of the study that is being undertaken. Farm types are then inferred from the sampled farm characteristics, generally by multivariate analysis and clustering techniques (Durvernoy, 2000). So far no adequate method has been developed to quickly identify the farms of a study area and the type to which they belong for assessing the proportion and distribution of each farm type. In different regions in the world farm have been grouped based on varying criteria such as land cover of a farm (Durvernoy, 2000), area of the various crops per farm and the availability of time and equipment (Leenhardt and Lemaire, 2001) and, mode of survival and survival strategies (Daskalopoulou and Petrou, 2002).

The approach that will be pursued in this study is to categories farms holistically by considering the farm variables which have been observed in the explorative survey. A questionnaire has been developed to collect farm data that will allow analyses for addressing pre-determined objectives. The questionnaire is presented in Appendix 2.

Not all the parameters collected through the questionnaire may necessarily have to be included in the analysis for typifying farms. Generally, farmers in a region do follow some similar management practices, such as the level of fertilizer application or use of pesticides because they following recommendation from State agricultural departments. These parameters could show little variation and may be disregarded, however only after a preliminary statistical control. Secondly, high correlation may exist between parameters due to their high interdependence, such as the number of animals in the farm and the application amount organic manure, which justifies exclusion of one variable in the further analysis of the farm typology. Then only the variables with a high variation among the farm households would be considered for farm typology.

The data sets should be analyzed statistically (e.g. using the statistical package Canoco for windows version 4.5) through the Principal Components Analysis (PCA) (Ref to be added). PCA is an exploratory data analysis with the aim to summarize multivariate data in a convenient way. Data are arranged in a two-way table with rows representing farms and columns representing descriptive variables. PCA transforms a number of correlated variables into a smaller number of uncorrelated variables called principal components. By displaying the results in scatter diagrams, a better understanding is reached about the relations between farms and descriptive variables. In short, PCA reduces the dimensionality of the data set and to identify new meaningful underlying variables. Before employing PCA, the descriptive variables have to be standardized by subtracting the mean and dividing by the standard deviation.

Roughly three categories of farm households can be distinguished (e.g. Rufino et al., in prep). A first group is marginal farmers that generate much of their income through off-farm employment activities. These farmers can hardly afford investments and run low-investment with little incentive and opportunities to innovate their farm activities. A most common strategy is to exit from agriculture and to become fully engage outside agriculture. A second group concerns large farmers that may live in near-by villages or cities and do not run the day-to-day operations, but remotely manage their farming activities. These farmers often have other income sources as well which reduces their reliance on agriculture. This allows them to adapt and adopt new options to improve their farm activities and increase their profit margins, making them innovative and entrepreneurial managers. A third group concern farmers in between these two groups. Their reliance on farming is high with low off-farm income as they are fully engaged in farm activities. These are most vulnerable groups because of their strong dependence on the limited and uncertain bio-physical resource, their fluctuating income as a result of market developments and price instability, etc.

## 6.4 Scope for alternative farming systems

Farmers are continuously adjusting their farm practices to comply with changing needs and conditions. The responses will depend on the type of farm household. Poor households with much off-farm income may increasingly seek for employment opportunities outside agriculture to cope with uncertainties in agriculture. Wealthier farmers may bring in investments generated from other (off-farm) activities to innovate and upgrade farm activities. These groups may have the ability to adequately respond, though differently, to sudden and drastic changes imposed on their activities. Medium farmers, fulltime engaged in agriculture, may be less well able to deal with such changes. A more strategic approach for this group may be to advance their farm activities through incremental changes, i.e. little modifications introduced over longer periods of time.

The farming systems in Hyderabad compare very will with the systems in its southern province Tamil Nadu. In this reports some preliminary observations from Tamil Nadu will be reported as well to substantiate the considerations for Hyderabad.

Generally, crops and cropping systems can be selected such as to reduce water requirement. Particularly with regards to cropping sequences, substantial water gains could be obtained. Obviously, farmers should meet other objectives before any introduction or adjustment of crops or cropping systems would be made. On-station experiments and on-farm demonstrations plots show that much water can be saved by reduced irrigation frequency, such as in cotton, turmeric, chilly, maize and groundnut, while crop yields would be even slightly higher (Reddy et al., 2001).

Agronomic measures related to soil management also inherit a number of options to reduce water use, while maintaining or even increasing yields. Mulching and zero-tillage for instance reduce non-productive evaporation to the benefit of increased productive transpiration. By attuning fertilizer application to water availability, the efficiency of the entire system will increase. Yields may go up, water will be used more efficiently, while use efficiency of fertilizers increase as well. While this basis concept is well known, local fine tuning is needed to specific soil conditions, rainfall patterns, and crops. Adjustments of agronomic practices may have implications for the production system and their applicability should be considered from the entire farm household perspective.

Dryland crops such as maize, cotton, sunflower and sugarcane are generally grown in furrow systems. Some crops can be grown closely without yield penalty, such as wheat, because of minimal interference and competition between neighbouring plants. Yield penalty occurs in crops like maize as the cobs grow smaller because of competition from too close neighbours. Research has shown reduction in irrigated water requirement up to 50% if alternate furrow (instead of all furrows) are irrigated because horizontal seepage is sufficient to provide the remote rows with water (Raman, 2001). For crops that can be grown closely together, a reduction of up to 70% irrigation water can be attained under paired row planting and furrow irrigation.

Rice remains a staple food and rice cultivation is predominant in the state, which require higher amount of water than any other crops. Typically, total water input in rice fields varies from 500 to 3000 mm depending on environmental conditions and the length of the growing period (Bouman and Tuong, 2000; Bouman et al., 2003), with a water productivity ranging from 1000-2000 liters water per kilogram rice, but may be as high as 5000-10000 liters. Dry cereals, such as wheat have typical water requirements of 500 to some 1500 liters per kilogram of grain.

Incited by the looming water crises, such as the recurring shortages of water that reduce the rice cultivate area, much effort has been put recently to reduce the use of water for rice production (e.g. Bindraban et al., 2006), including in Hyderabad and Tamil Nadu.

In Andra Pradesh, Reddy and Krishna (1998) tested dry seeding of rice to cope with the unreliable availability of irrigation water and found similar yield levels as with sowing when soils are inundated. Raman (2001) report possible saving of water use in rice up to 40-50% without substantial penalty on yield in Andra Pradesh. Studies on water saving rice cultivation revealed that the rice farmers of Tamil Nadu can save nearly 50% of the water compared to the conventional method of flooding the rice fields. Thiyagarajan et al. (2002) reported that the water productivity in rice can be increased by about 40 and 47% in wet and dry seasons respectively, using an alternative wetting and drying irrigation scheme. Rice soils are kept at soil saturated condition rather than flooding through more frequent irrigation with less water per irrigation.

Preliminary results of farm household research in Tamil Nadu suggest that quick adoption and adaptation of water-saving rice is not likely. The implications to the household are substantial. The labor profile changes, the reliance on reliable water supply increases, practical experience with several of the management practice is lacking, etc. For farmers to adopt all these changes, the yield gains should be substantial in view of all the required changes in management, in order to result in higher profit margins. Water-saving in itself is not a mean driving force to change their practices. Higher income could, but is still bound to the many internal and external factors to the farm. By grouping farm households more in-depth insight in the farmers view might be generated in order to better attune new water saving technologies to their needs.

## 6.5 Preliminary results from survey of farming systems

The entire sub catchment of Krishna river basin from Nagarjuna sagar to Prakasam barrage is the study area. The entire sub catchment covers total 151 mandals in 13 revenue divisions of 7 districts i.e., Mahaboobnagar, Khammam, Nalgonda, Warangal, Ranga Reddy, Prakasam and Guntur. Two to three mandals with maximum total cultivated area from each revenue division are purposively selected. Thus, total 25 mandals are selected from 7 districts. From each selected mandal 5 sample farmers, thus total 125 sample farmers from selected 25 mandals in 13 revenue divisions of 7 districts will be covered under survey for primary data collection on 'Farm typology and choice of farming systems'.

Secondary data have been collected for the basin and still need to be analyzed and summarized. Based on primary data collection so far covered 25 sample farmers in 5 mandals of 2 districts i.e., Khammam and Warangal the following observations can be made.

- Most of the farmers are maintaining on an average 2-3 milch buffaloes for household milk purpose and in general almost all farmers are maintaining on an average 4-5 poultry birds.
- In some urban area few farmers are growing plantation crops like Subabul and Eucalyptus this year.
- The farmers in the two districts are willing to shift to new crops if there is a great demand and high market price provided. However, majority are raising improved varieties only which have demand in the market.
- In Khammam, Wyra division sample farmers are interested to undertake additional leased in land as they have sufficient irrigation source from canal.

These observations reveal the high diversity and farmers need to secure food, while the introduction of activities for the markets is welcomed only under sufficient market demand.

# 7 Scope for improvement of ecological benefits by allocative water management

*Ingrid Gevers[20] en Willem Brandenburg[21]*

## 7.1 General outline

For a triple P (people, planet, profit) development of the Krishna estuary, the coastal resources have to be restored, conserved and sustainably managed. This may conflict with the interests of local communities and other stakeholder groups depending on the coastal resources for their livelihoods. The establishment of integrated multi-trophic aquaculture systems, producing both plants and animals for local income generation may lead to stakeholder support.

## 7.2 Backgrounds of degradation of deltaic ecosystems

The coastal waters of Southeast Asian countries have some of the world's richest ecosystems characterized by extensive coral reefs and dense mangrove forests. These waters are further enriched with nutrients from land which enables them to support a wide diversity of marine life.

The coastal zones are subjected to increasing population and economic pressure pressures manifested by a variety of coastal activities such as fishing, coastal aquaculture, waste disposal, salt-making, tin mining, oil drilling, rural construction and industrialisation. Indiscriminate logging and mining in upland areas impact on low land activities such as fisheries, aquaculture and coastal tourism. Unregulated fishing effort and the use of destructive fishing methods have caused serious destruction of fish habitats and fish stocks. Indiscriminate cutting of mangroves for aquaculture development, fuel wood and timber has brought temporary gains in fish production, fuel wood and timber supply but losses in nursery areas and commercially important fish and shrimp, coastal erosion and land accretion.

The Krishna River basin in India, covering an area of 258,000 km has a combined population of 67 million and is spread across three large southern states—Karnataka, Maharashtra, Andhra Pradesh. It is one of India's largest domestic waterways and supplies water to important food production areas including the "Rice Bowl" region in the Krishna delta. Water extractions for agriculture, industry, and domestic uses from the Krishna continue to grow to support one of the fastest developing regions of peninsular India. Rapid urbanization in the basin also makes demands on water supplies, resulting in

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adverse social, economic and environmental impacts. As the three states share the shrinking water resource, basin closure has resulted in interstate water conflicts.

The Krishna river is a critical component of the delta estuary coastal sea ecosystem. The river run-offs provide energy for a number of vital processes in downstream estuaries, delta and coastal areas, upon which healthy fisheries are dependent. These processes include transport of nutrients, organic matter and nutrient-rich silt, oxygen enrichment, entrainment of nutrients in bottom sediments, dilution and flushing of pollutants, etc.

The storage capacity in the Krishna basin has increased significantly since the independence of India. At that time 3.2 $km^3$ of the total water flow was stored upstream. Nowadays, the increased fresh water need for mainly drinking water, irrigation and industrial purposes in the upstream areas of the river basin has led to an increased total storage capacity of 34.5 $km^3$. This has resulted in a significant decrease of fresh water flow into the Krishna estuary and an increase of saline water intrusion. Bouwer et al (2006) have studied the combination of this increased water use in the upper Krishna river basin in view of the expected climate change. They concluded that the impact of salt water intrusion will increase even more in the next decennia.

Conversion of mangroves in the delta of the Krishna river basin for agriculture, aquaculture and salt pans resulted in saline soils and loss of biodiversity due to environmental degradation. The reduced fresh water has had a large impact on the growth and regeneration of mangroves. Land-use activities such as agriculture cause pollution and drainage of the tidal areas is problematic.

## 7.3 Coastal ecosystems, saline aquaculture and agriculture

Coastal mangrove ecosystems are the natural nursing grounds for hundreds of aquatic species including economically important fish and shellfish. Mangroves play an important role in controlling erosion caused by flooding and storm surges. They also act as a barrier during cyclones and protect the coastline. Thus it is necessary to conserve the existing mangroves and plant mangroves where ever they can be grown near the shrimp ponds. Mangroves will also help in reducing the impact of sea level rise anticipated due to global warming and will protect the adjacent farming lands.

Salinisation in the coastal zones of Andhra Pradesh is increasing. Such is very obvious in the lower Krishna River Basin. Andhra Pradesh is the main state producing aquaculture shrimp for export purposes. Both larger companies and small scale farmers have invested in this business. For the construction of ponds large parts of the natural coastal zone vegetation has been removed.

Nowadays, most of the coastal mangrove vegetation has been converted to aquaculture ponds, salt pans and paddy fields.
Outbreaks of viral diseases are the major constraint to shrimp aquaculture production. White spot disease (WSD), vibriosis and loose shell syndrome are the most common disease problems in India. The most successful strategies for controlling diseases in shrimp ponds are based on a combination of prevention by exclusion, and Better Management Practices that focus on creating a healthy, non-stressful environment for the shrimp.

Outbreaks of diseases, fluctuating in market prices and lack of capacity, expertise and financial means have caused a lot of small scale farmers to look for alternative sources of income in Andhra Pradesh.

Moreover, the traditional scheme of rice cultivation is under threat unless the local farmers are in a position to plant salt tolerant rice varieties. ANGRA University conducts trials at their local research station located in the estuary of the Krishna river basin, to identify which local rice varieties are more salt tolerant. The results of the trials are promising.

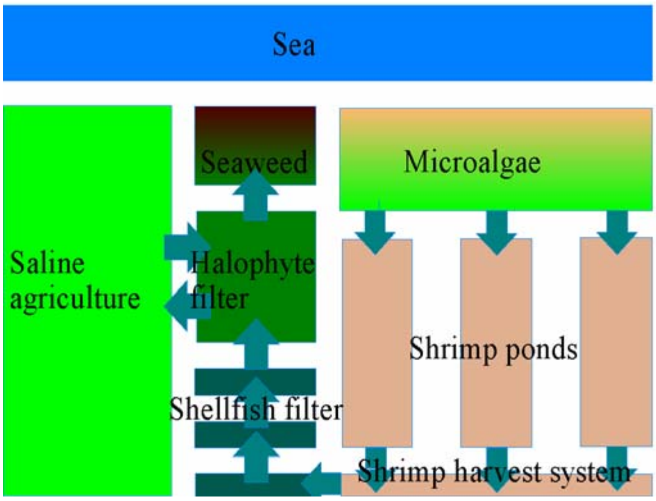
Not only small farmers face difficult times, but also the local fishermen. With the collapse of coastal zone vegetation, the nursery of fish and shellfish has gone.

The development of sustainable aquaculture practices, inclusive of the restoration of mangrove vegetations is essential (Rönnback, 1999). This was also the main conclusion of the stakeholder meeting held at September 21, 2007 in Manchilipatnam, a town located in the delta of the Krishna river basin. The purpose of the workshop was to facilitate a multisectoral dialogue between various stakeholders around the concept of salt water farming, including good aquacultural practices, as an alternative livelihood approach for the coastal zone.

## 7.4 Scope for rehabilitation of coastal areas

Two mangrove restoration programmes are already being implemented in Andhra Pradesh. One is coordinated by the Swaminathan foundation in the East Coast of India, especially Orissa, Andhra Pradesh and Tamil Nadu. Another restoration programme is implemented by OMCAR and DEEPWAVE (Balaji & Gross, 2006). The FAO has acknowledged that restoration of mangrove vegetations throughout Southeast Asia is key for the realisation of sustainable fisheries and aquaculture practices (FAO, 2005).

In order to establish a sustainable biological production system one should follow the principle of integrated multi-trophic aquaculture (IMTA) i.e. with a closed nutrient cycle, with sanitary precautions and a good combination of low input and economic benefit. It is therefore necessary to combine both animal and plant production systems in such a way that the nutrients that come from the animal production systems are taken up by the plant production systems. The integrated system has to be designed in such a way that the dimensions of the different components meet the requirements for the mentioned closed nutrient cycle: saline water IN = saline water OUT. This condition is set by the combination of both a production system and coastal nature conservation, as laid down in the scheme below:




Andhra Pradesh has a coastal zone with a length of 600 km and has a potential ranging from 300,000 – 500,000 ha for integrated multi-trophic aquaculture.

When looking at issues such as food security and competing claims in the field of renewable energy, nature conservation and other societal functions, it is obvious that integration towards multifunctional land use alone can hardly meet all claims at the long run. At the same time the marine and coastal resources are still being used in a very similar way as centuries ago; the main human activities still being collecting, hunting, mining and dumping. Mankind thus threats the marine resources but overlooks the marine potential of triple P sustainable biological production: fish, crustaceans, shellfish, seaweeds and micro algae.

Keeping India's ambitions in the field of economic development, food production, renewable energy production, and at the same time conservation of its biodiversity in mind, mariculture could have great potential in the coastal zone of Andhra Pradesh close to the mouth of the Krishna River. The on-going shrimp production has resulted in the destruction of mangrove ecosystems that now are understood to have an important function in coastal defense as well as breeding, nursing and feeding ground for marine organisms. Starting with mangrove restoration programmes, it is worthwhile looking at the possibility of including the establishment of seaweed farms in the development planning.

Today, seaweeds are recognized as an important natural source to produce a range of products, such as minerals special proteins, carbohydrates, fatty acids and a range of special secondary metabolites. Increasing interest in these products has been expressed by the food and pharmaceutical industry, the personal health care industry and recently the energy sector.

Traditionally, seaweeds were collected in the sea both in temperate and tropical regions. One of the first applications of these sampled seaweeds was as green manure in agriculture. Presently various seaweed production systems are designed: offshore, near shore and even at the landside in pond systems. Many of those systems are, however, not sustainable due to their polluting impact on the marine environment.

Energy Centre the Netherlands (ECN) and Wageningen UR (Wageningen Imares, the marine and coastal resources institute at Yerseke and Plant Research International at Wageningen), in partnership designed a production system for seaweeds which aims to produce in a sustainable productive way and is balanced in its energy costs. The principle behind the production system is to make optimal usage of the photoreceptor systems in seaweed, to apply a precise nutrient feeding technique and to use the marine environment as an energy source for the processing of the harvested product. It is estimated that it should be possible to produce at least 70 tonnes dry matter/ha/year under tropical zone conditions. Such yields are feasible, if adequate plant nutrition is provided.

Seaweed is of increasing importance globally; the global market values about U$ 600 million and is growing annually with 10%. Seaweed is harvested for hydrocolloids: alginates, carrageenan and agar. Seaweed does not contain lignin or lignocelluloses. Consequently, 80% of its dry matter - under Indian conditions 56 metric tonnes - is fermentable. It is therefore an efficient resource for the combined ethanol and electricity production. Based on these figures it can be concluded that seaweeds could provide and important resource in terms of food (binding agency in food processing) and bio energy for India. The Andhra Pradesh district appears to be geomorhologically suitable for the establishment of seaweed plantations with near shore processing of biomass based on seaborne energy sources by nutrient upwellings.

The two figures on the next page show the areas with high potential for seaweed production farms in India and Andhra Pradesh in particular. Following a schematic representation of a seaweed plantation is shown.

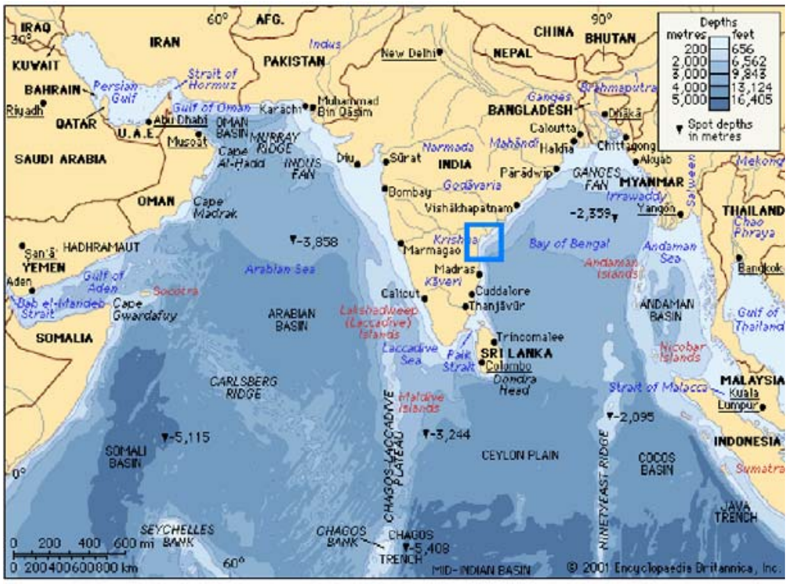



*Figure 2. Bay of Bengal* ■ *potential locations of seaweed plantation*

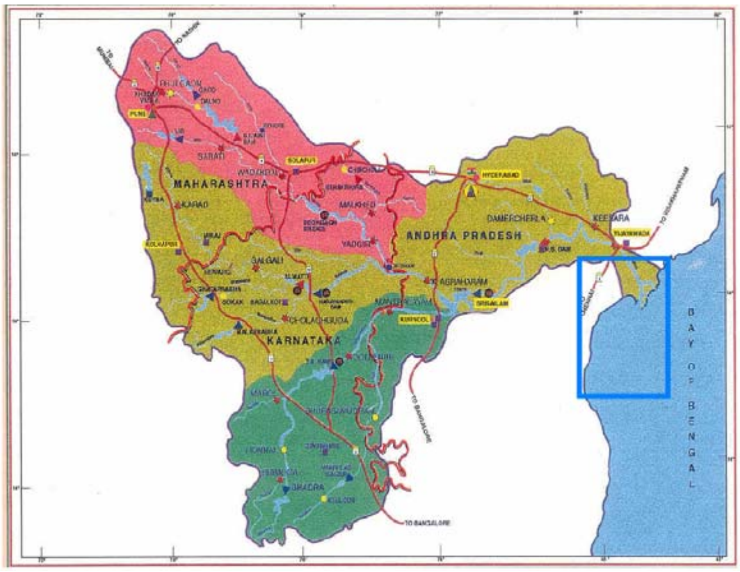



*Figure 3. Krishna river basin* ■ *location of seaweed plantations*

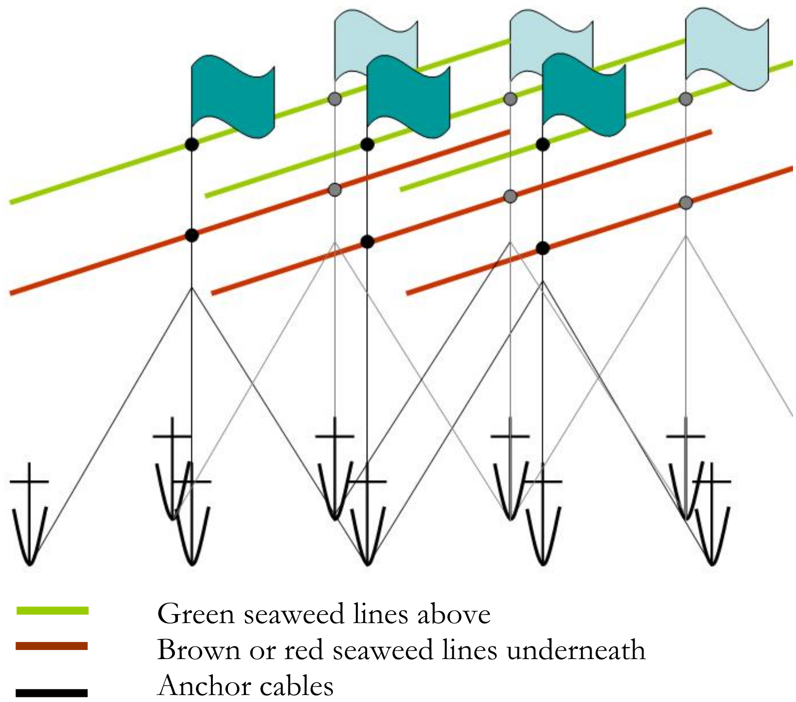



*Figure 4. Schematic presentation of a seaweed plantation:*

Seaweed lines also function as devices for (additional) plant nutrition.

The possibility for the introduction of saltwater agriculture in the Krishna river basin delta still needs to be further explored and developed in partnerships with local, regional and state authorities and relevant science institutes such as Swaminathan Research Foundation, MPEDA-NACA and ANGRA University. A larger consultation workshop in which these different stakeholder groups participate and discuss how these concepts of salt water farming can be realized would be a good approach for follow-up. Concrete action plans can then be formulated and stakeholders can commit themselves to a longer term involvement and investment in such concepts. Once implemented the lessons learned can be taken to other parts of India or could result in the development of an international salt water farming programme for coastal areas in tropical and sub-tropical climates.

# 8 Management information system for allocative water management

*Herco Jansen, Christian Siderius,[22], G. Ravi Babu, A. Mani,[23]*

## 8.1 General outline

Allocative water management requires that the water management entities have adequate information on the available water resources at any time, and at the appropriate level, and on the repercussions of any management intervention (either strategic or operational). Such information requires a decision support system which can assess the land and water resources. Information on the hydrology and available water resources should be obtained through a hydrological system analysis and a monitoring system.

The activities undertaken in this project were aimed at developing a general applicable methodology to obtain a decision support system on land and water resources. In order to be flexible and easily implementable in other areas, a land and water resources model was developed, which requires minimum data collection, which is not location-specific and which does not require (time consuming) primary data.

## 8.2 Land and water resources model

The river basin model concept HydroSplash! was further developed and applied to assess the spatial and temporal availability and requirements of water resources (Smit, 2007).

The model has been integrated in a GIS environment to allow for rapid spatial assessments and planning, using free-of-charge (internet) and other easily obtainable data (minimum data requirements). The model can thus primarily support water managers in the (re)allocation of water and in setting the right priorities in times of water scarcity.

## 8.3 Area selection

Allocative water management can only be effectively implemented if land and water resources are managed at (sub) catchment level. The project envisages to develop generic methodologies and tools that can similarly be applied to other areas, or upscaled. In order to show their applicability these methodologies and tools have

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[23] Acharya N.G. Ranga Agricultural University, Rajendranagar, Hyderabad – 500 030, India

firstly been applied to a selected area. For the selection of the area the following criteria were applied:

1. State: The area should be in Andhra Pradesh.
2. Catchment scale: The area should be entirely within one of the main river catchments.
3. Relevance: In the catchment water management problems should already be experienced, such as water shortages, excess water, problematic spatial or temporal distribution of the water resources and/or (potential) conflicts between water uses.
4. Decision support: The authorities should still be in the process of formulating policy options or planning, so that the outcome of the study may contribute to the decision making.
5. Availability of data: It should be possible to obtain sufficient existing (secondary) data. Collection of field data has to be avoided.
6. Managerial aspects: It should be possible to conduct the assessment within reasonable time. Hence the area should not be too big or too remote.

Based on these criteria the (entire) sub-catchments that discharge into the Krishna River between the Nagarjuna Sagar Project and the Prakasam Barrage of Vijayawada were selected as study area. The area covers approximately 40000 $km^2$ (approximate size of The Netherlands). The length of the section is approximately 160 kilometres and includes the districts of Nalgonda, Mahaboobnagar, Hyderabad and parts of Khamman, Warangal, Guntur and Krishna. Figure 5 presents the location of the study area.

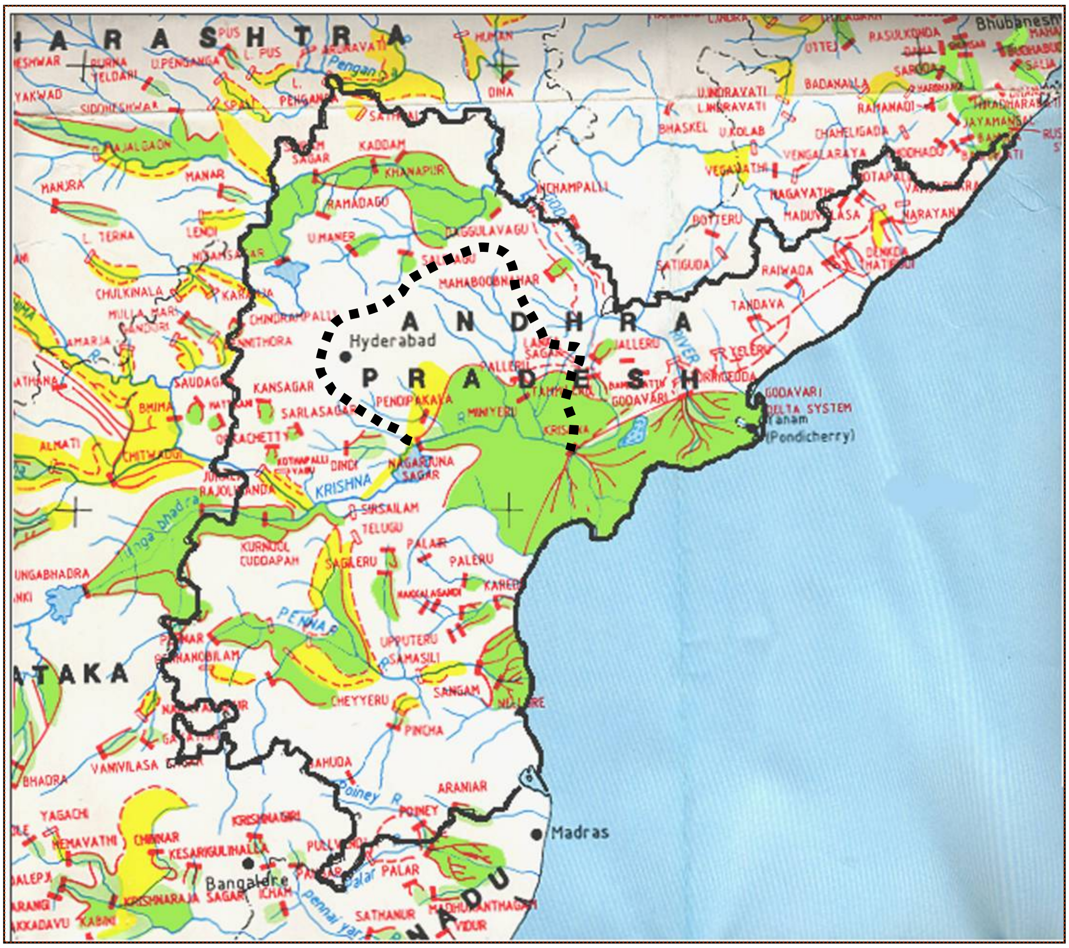


*Figure 5. Study area for holistic integrated water assessment modelling.*

## 8.4 Data collection and analysis

### *Area delineation*

The delineation of the catchment was done with a digital elevation map with a resolution of 90 x 90 metres. This information is available from the internet at no costs. The main sub-catchments between the Nagarjuna Sagar Project and the Prakasam Barrage of Vijayawada are the Musi, Paleru and Munneru catchments (Figure 6). Table 4 present their main characteristics.

*Table 4. Characteristics of subcatchments*

| Subcatchment: | Musi | Paleru | Munneru |
|---|---|---|---|
| Area ($km^2$) | 11212 | 3263 | 10409 |
| Elevation (m.+MSL) | 50-600 | 50-300 | 30-500 |
| Length of run (km) | 267 | 153 | 196 |

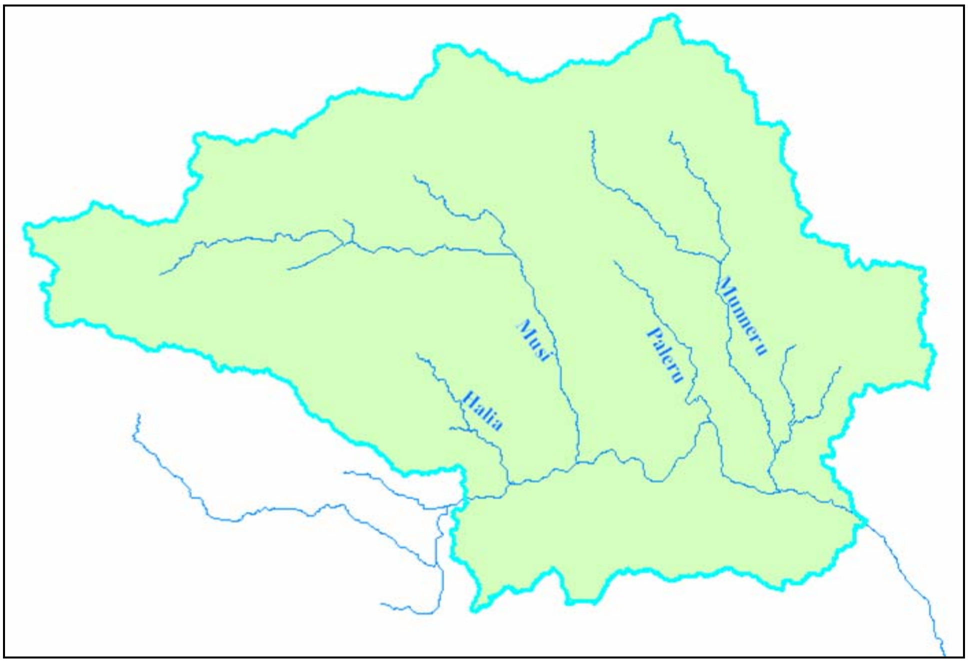


*Figure 6 Area delineation with main subcatchments*

***Spatial resolution***

The data were collected for the entire sub-catchments.

Mandals are the smallest unit for which adequate secondary data are available (*spatial resolution*). The number of mandals in the study area is in the order of two hundred. Figure 7 presents the locations of the mandals. Data that are only available at a larger scale (district or sub-district level) were –where necessary- downscaled (e.g. by interpolation of regional data). High-resolution data were upscaled (by accumulation of data).

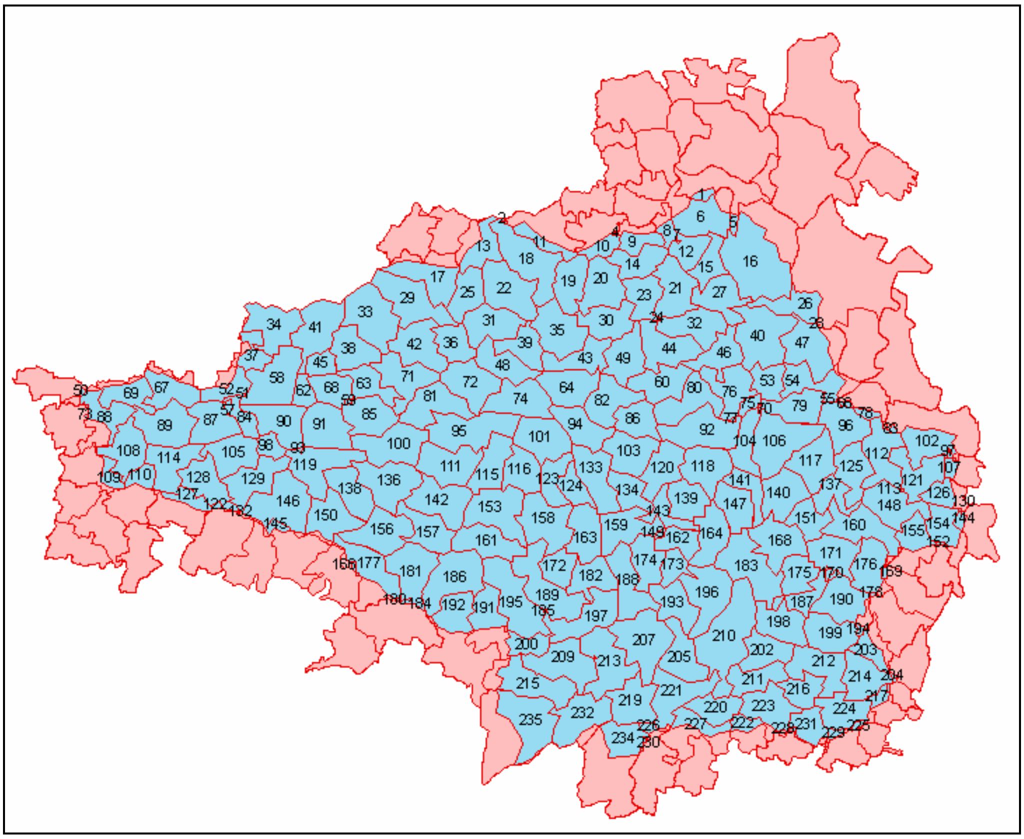

*Figure 7. Mandals in the study area*

### ***Selection of time period***

The calibration of the model was done for a recent *average hydrological year*. The calibration year was selected on the basis of the *annual* and *monsoon* rainfall data. These data were collected for the period 1991-2004 (fifteen years) at all rainfall stations in the study area. The annual and monsoon rainfall data were analysed and compared with the (long-term) mean annual and monsoon rainfall data. Figure 8 shows that the rainfall varies from year to year and also has a distinct spatial trend.

On the basis of the rainfall analysis the year 2001/2002 was selected as *"representative average hydrological year"*. This year was used for the calibration of the model, and also serves as *"reference year"*. Results of scenario calculations can be compared with the reference year.

In addition, a dry year was selected to investigate the implications of low rainfall for the availability, use and management of water resources in the catchment, and to recommend on prioritization. The dry year will also be used to *verify* the model calculations. The year 2002/2003 was selected.

The verification of the model for a wet year was omitted to save time, and because wet years are less relevant for this study.

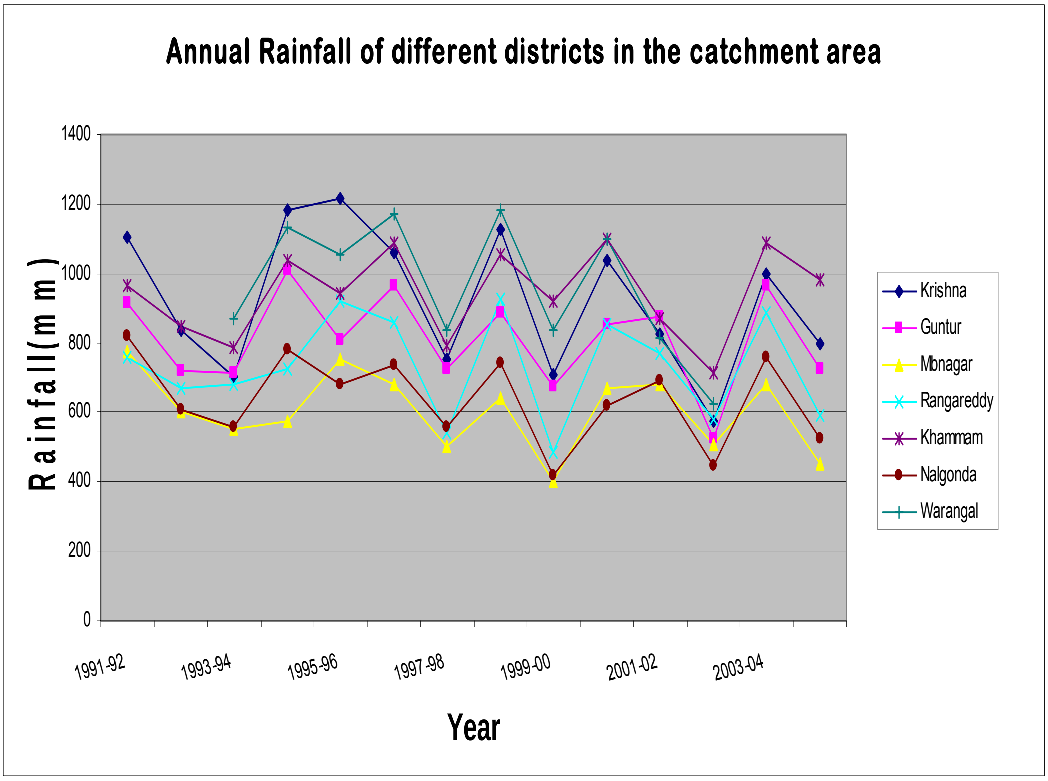


*Figure 8. Annual rainfall in the study area*

### *Data collection and processing*

The model is integrated in a GIS environment. Digital base maps were prepared using the extensive land resources maps by the National Bureau of Soil Survey (NBBS) and Land Use Planning (LUP), composed for each district in 2002. For this purpose for each district the following maps were scanned:

- Administrative divisions
- Hydrogeomorphology
- Land capability
- Land irrigability
- Land use
- Soils
- Soil depth
- Soil slope
- Soil texture
- Water capacity

The scanned maps were georeferenced and mosaiced in order to obtain images in the right projection (co-ordinate system), covering the entire study area. An example of the processing of a (printed) map to a digital GIS image is presented in Figure 9.

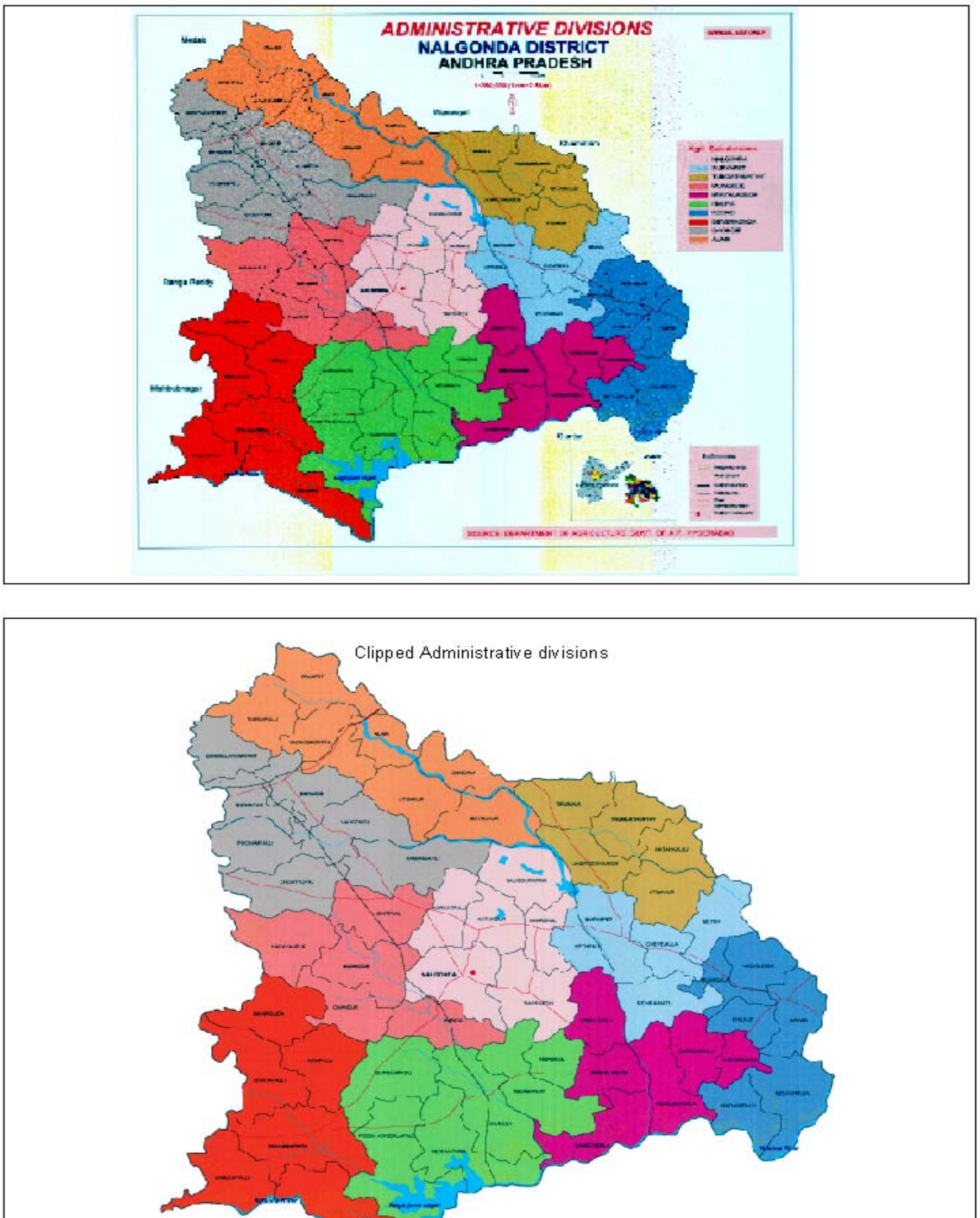


*Figure 9. Example of processing of map*

A GIS procedure was developed to classify the information on the georeferenced images in order to obtain maps with attributes (classified geographical information). After rastering these maps can then be imported in Hydrosplash! Figure 10 shows an example of a classified and rastered soil map.

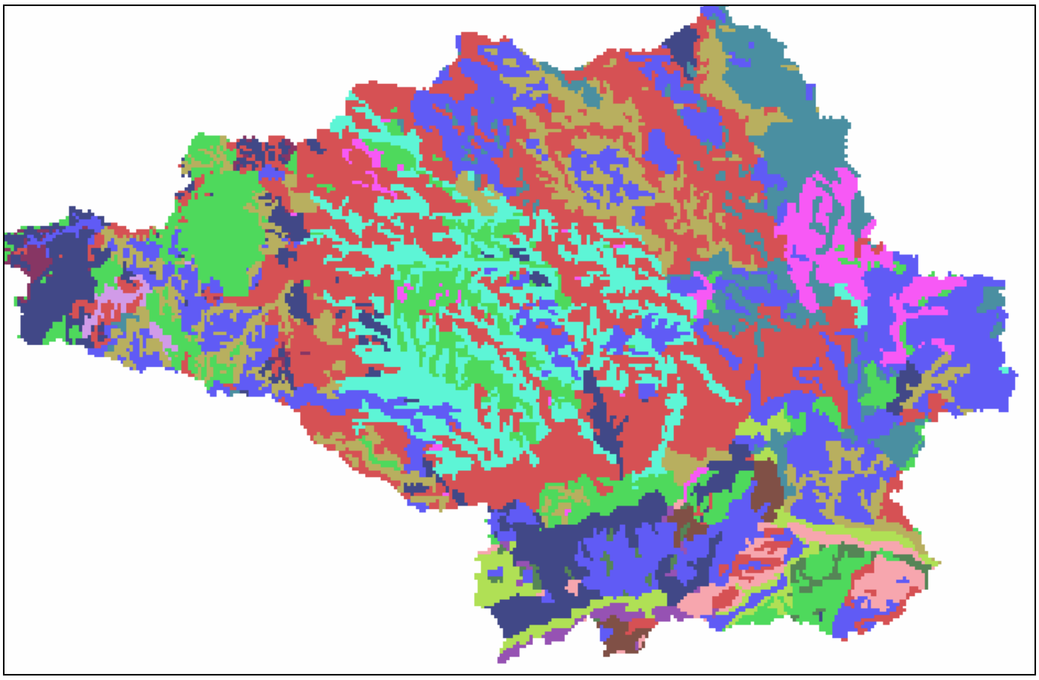

*Figure 10. Example of classified soil map.*

## 8.5 Scope for strategic and operational allocative water management

In 2007 the GIS-based integrated land- and water management & assessment tool Hydrosplash! will be further developed on the basis of the outlines established in 2006 and the feedback from the problem holders.

At the time of issuing this report the model is being calibrated using historical data on climate, river discharges, reservoir levels, soils and land use.

On the basis of acquired hydrological knowledge of the area and understanding of the responses of the catchment to hydrological events and land and water interventions, scenarios for improved water allocation and management will be formulated.

The model will be used to simulate and evaluate possible strategic water management scenarios. An example of strategic allocative watermanagement (the concept) is presented in Figure 11.

The model can also be used to recommend on water prioritization in times of water scarcity (operational allocative water management).

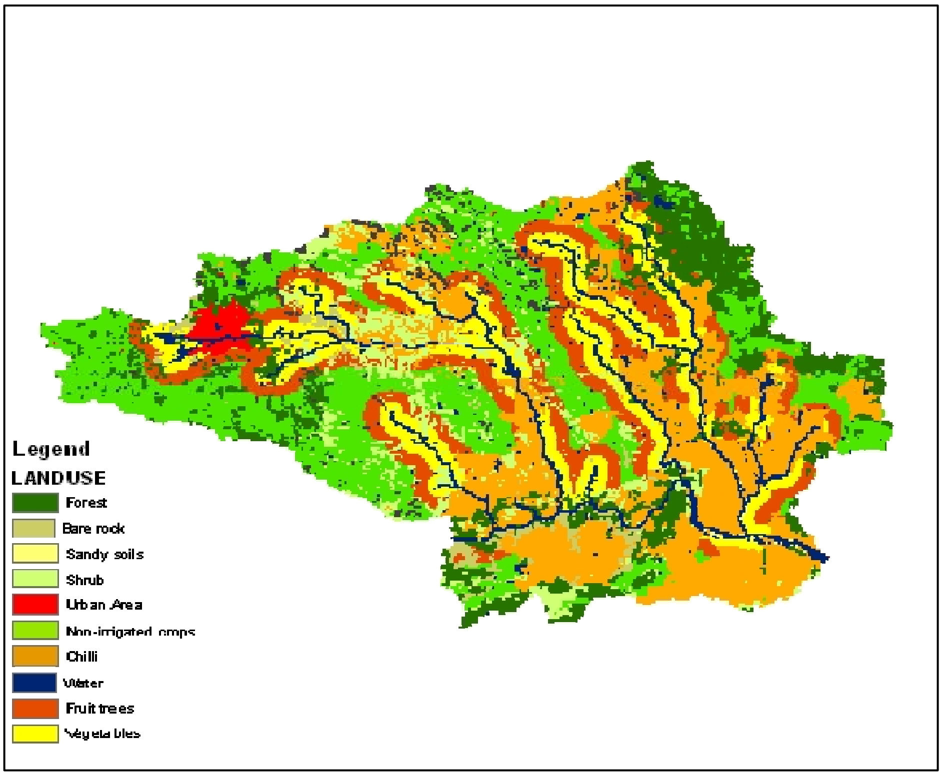


*Figure 11. Concept of strategic water allocation.*

# 9 Water allocation in the Krishna Basin: an institutional perspective

Gerdien Meijerink[24]

## 9.1 Introduction: the importance of institutions in the Krishna Basin

For a long time, water has been regarded as a public good to which no one could be denied access. The growing scarcity and rising cost of water (supply) have led to the realisation that water has to be allocated and used more efficiently. This means that the allocation of use rights to water has become a crucial issue. Related to this is the role of institutions. As Ostrom (1993) has stated almost 15 years ago: “for the next several decades the most important question related to water resources development is that of institutional design rather than engineering design”. Institutions can be seen as the mechanisms or rules that specify how water is allocated, used and exchanged. Institutions exist at several levels (Source: Adapted from Williamson, 2000):

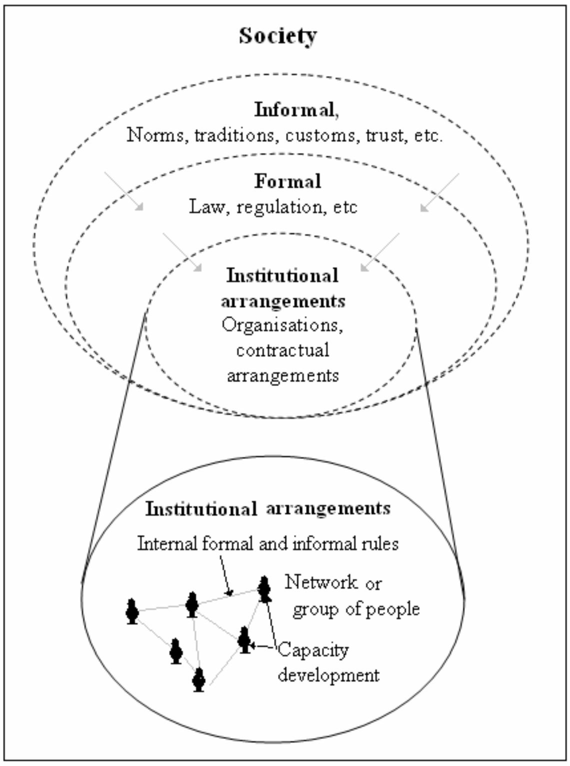


*Figure 12. Levels of institutions*

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The focus of an institutional analysis is often on institutional arrangements or governance structures such as markets, or organisations (such as water user cooperatives). However, these are embedded in the formal rules of a society, specifying the permissible actions (i.e. "rules of the game"). Informal rules are often overlooked, but play an important role. They can be seen as overarching - the extent to which formal rules are obeyed depend to a large extent on the customs, traditions, norms and beliefs within a society. The formal and informal rules within a society are often denoted as the institutional environment, in which institutional arrangements are embedded.

## 9.2 Water institutions in Krishna Basin

### 9.2.1 Institutional environment: informal and formal rules

How informal India's water economy is, was explored in a large national-wide survey[25] carried out in 1998 (NSSO 1999 cited in Shah, 2005). This showed that only 10% of water infrastructural assets use (e.g. for irrigation) by survey households were owned and managed by either a public of community organisation; the rest were mostly privately owned and managed by household (or owned by a public or community organisation but not managed by either). A survey of almost 50.000 farmers throughout India showed that 65% used irrigation and for half of those, the source of irrigation were informal, fragmented pump irrigation markets (see sections below for these markets). Thus India's water economy – both domestic and irrigation use – is highly informal. Based mostly on self-supply and local, informal water institutions, having only little connect with public systems through which water law, policy and administration typically operate (Shah, 2005).

India does not have any explicit legal framework specifying water rights, even though various acts have some basis for defining some form of such rights. All rivers and lakes are the absolute right of the state. While state's absolute rights can affect the development and managerial aspects of water, from the perspective of *water use*, it is the *de facto* control over water by actual users at the micro-level that is more important. Individual rights to both surface water and groundwater are recognized only indirectly through land rights. In the case of canal water, the rights to access are limited to only those having access to land in canal command areas and these rights are only use rights and not ownership rights because irrigation acts do not allow the moving of canal water to non-canal areas. Under conditions of unequal land ownership and income patterns, the practice of linking water indirectly with land and the *de facto* control by better endowed persons emphasised rural inequality and water use inefficiency (Saleth, 2005).

The central government has devolved several responsibilities and legislative powers to the state governments. The central government retains its control over major planning and technical resources and organizations such as the Central Water

[25] 78.990 households in 5110 villages

Commission, the Central Ground Water Board, and the National Water Development Agency--all under the Union Ministry of Water Resources. It also intervenes in inter-state dispute resolution. However, Saleth & Dinar (2000) report that a lack of constitutional power impedes the central government to coordinate institutional issues at the state and inter-state levels. Achieving country-wide consensus on national policies has also proven difficult. Since legislative power, technical capabilities, planning skills, and operational responsibilities are dispersed across government layers, the institutional environment pertaining to water remains "legally weak, functionally disjoint, sectorally biased, and regionally uncoordinated" (p. 28). While physical stress and financial crisis have exposed the legal, policy, and administrative weakness of water sector, myopic political issues and administrative resistance have impeded institutional change. The complex interrelationship between water and politics at several levels in South India was described by (Mollinga, 2001).

At the state level, there have been several recent policy changes, especially in the case of states within the Krishna basin. These changes can be seen both in the organizational spheres (e.g., administrative reorganizations including the creation of basin organizations in states such as Tamil Nadu and Uttar Pradesh) as well as in the policy spheres (e.g., declaration of water policy statements by most states). There are also more substantive changes in a few states. For instance, Andhra Pradesh and Madhya Pradesh have gone for a state-wide programme for the transfer of the management responsibilities of almost all canal irrigation below the outlet and minor levels (Saleth, 2005). In the sections below, we will briefly review several of these institutional arrangements.

### 9.2.2 Institutional arrangements for groundwater use

Around 55-60% of the population in India depends on groundwater (Shah *et al.*, 2003). A major use of groundwater is for irrigation purposes. Groundwater irrigated areas in India increased from around 11.9 million ha in 1979-71 to 33.1 million ha in 1998-99 (i.e. increased with 178%), while the area under canal irrigation rose with 37% (Aditi and Tushaar, 2005). Groundwater is usually pumped up through tubewells, although government and panchayat[26] canals as well as tanks are used.

The control over groundwater at the field level is governed by a de facto system of rights as determined by farm size, the depth and number of wells, pumping capacity, and economic power (Saleth, 2005). In India, following the English law, groundwater rights are attached to the land, such that a landowner can extract as much water as desired without any kind of restriction. However, to be able to do so, an investment in pumping equipment is required, which may impede the use of groundwater to poorer users. Besides this cost, land fragmentation may impede well owners to irrigate all their plots using a single pump.

[26] A Panchayat is an Indian political system which groups five ("panch") villages with each having appointed tasks and responsibilities. A Panchayat also refers to a council of elected members taking decisions on issues key to a village's social, cultural and economic life: thus, a panchayat is also a village's body of elected representatives

The fact that groundwater rights are attached to land means that anyone with land and resources to invest in a pump, can use groundwater. This has led to the emergence of highly dynamic and complex informal groundwater markets (see box 1). Many water markets have sprung up like this throughout South Asia and function unimpeded and unaided by any kind of regulatory authority. An interesting feature is that the government has influence over groundwater pumping through electricity prices. For instance, when the new provincial (state) government of the water-scarce state of Andhra Pradesh announced in 2004 that electricity would be provided free to farmers, it led 'colossal anarchy' in the groundwater economy of South Asia (Aditi and Tushaar, 2005).

*Box 1 Advanced Ground Water Markets in Gujarat India*

*There are a variety groundwater market arrangements in India (Shah, 1993; Saleth, 1998; cited in Dinar et al., 1997). In Gujarat, where water selling is an old tradition, market have become a sophisticated economic institution. The highly advanced water markets in Gujarat differ from elsewhere in South Asia in that (a) farmers invest in modern water extraction mechanisms (e.g., pumps) for selling water which has become a specialized subsidiary occupation, and (b) substantial private investment in underground pipeline networks generate high degree of competition amongst sellers of water. Once one seller establishes a pipeline network, he drives out of business several others who used unlined field canals to convey water to the buyers.*

*Although the evolution of such "irrigation networks" is not uniform in different parts of Gujarat, agriculturally advanced areas have better developed networks. This type of investment in the water market may have a large multiplier effect. In addition to making the water markets more competitive, investments in conveyance and in water extraction increases efficiency in water and power use.*

*Source (Dinar et al., 1997)*

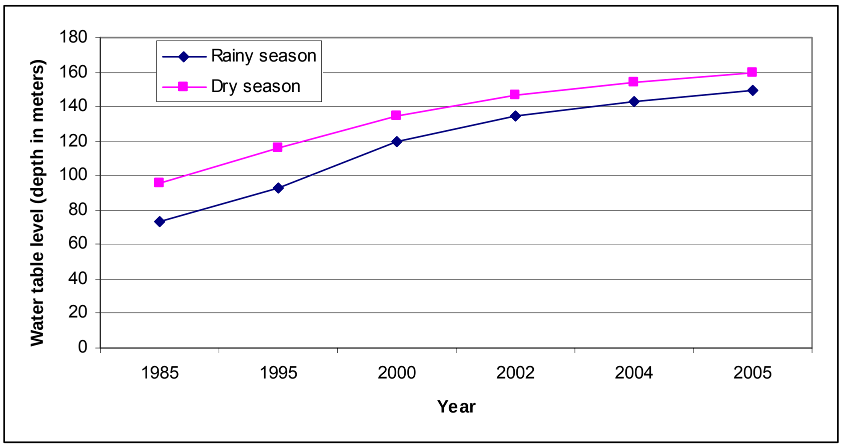
With not much influence of the (state) government over groundwater use, and uncontrolled markets, it is interesting to note that communities have established (in)formal institutional arrangements for groundwater recharge, especially in water-scarce states like Rajasthan and Gujarat (van Steenbergen, 2006). Roy *et al.* (2006) have analysed the institutional arrangements for groundwater use in Gujerat, which is part of the Krishna Basin. They analysed two tubewell cooperatives and six tubewell partnerships. We will make use of their findings in this section to analyse the effectiveness of such institutional arrangements.

Despite the establishment of (in)formal institutional arrangements for groundwater recharge, a mounting problem is the depletion of groundwater reservoirs (see figure 2). The National Water Policy of 2002 (MoWR, 2002) has recognised the need for more government control over groundwater resources:

*"Exploitation of ground water resources should be so regulated as not to exceed the recharging possibilities, as also to ensure social equity. The detrimental environmental consequences of overexploitation of ground water need to be effectively prevented by the Central and State Governments. Ground water recharge projects should be developed and implemented for improving both the quality and availability of ground water resource."*

The tubewell cooperatives and partnerships (hereafter organisations) operate quite independently from the government. Decision on the actual release of water, distribution of water among members (i.e. farmers), pricing of water, and collection of dues were all decided on by the organisation, without any involvement from the (state) government. Other activities such as planning for and actual capital investments, maintenance, monitoring of water use were decided upon by the organisation and individual farmers. What is unclear is how penalties are imposed and enforced. This seems to be a weakness in the design. However, the members of all eight organisations in the study seem very positive about the ability of their organisations to deal with resolution of disputes and dealing with offences. In fact, the members seem to positive about the overall functioning of the organisations and believe that the organisation has led to (amongst others) better maintenance of irrigation structures, equitable distribution of water and empowerment of farmers to manage irrigation systems. The equitable distribution of water is demonstrated by the fact that most members agree that the organisation has led to proper distribution between small and large farmers, and between head, middle and tail farmers.

With respect to the financial sustainability and pricing policy, the success of the organisations seems less clear. Prices are not determined according to the scarcity value of water – thus environmental concerns are not incorporated into the price. Furthermore, although the organisation assesses the quantity of water each season/year, the activities of the organisation is rapidly depleting groundwater resources (see Figure 13). It is unclear on what basis prices are determined – some members seem to think it is on the basis of crops, although others disagree. Members seem to have no clear view on the financial viability of the organisation, although the organisation is able to raise recurrent payments from its members.




Source: (Roy *et al.*, 2006)

*Figure 13: Water table level in Gujarat (depth in meters)*

Although these community organisations seem to function well, especially in achieving equity, there are clearly two main problems. The first consists of the environmental effects (rapidly decreasing water tables) and the second is the financial viability connected to water pricing, which is unclear and not adequate.

### 9.2.3 Institutional arrangements for surface water use

Surface water through the canal system is another major source of water for irrigation, besides groundwater or checkdams. The institutions governing surface water are different than those for groundwater. All surface water in India falls under the jurisdiction and control of the state governments. The medium and major irrigation systems (commanding areas of at least 2000 ha) are governed by a government agency, while the small systems (less that 2000 ha) are usually governed by local agencies such as the village Panchayat. The government agencies deliver water to outlets that serve various farmers. The states set the rates that are charged for water and these vary considerably between states. In some states the water is provided free of charge, while others demand relatively high tariffs (e.g. 2750 Rupees or 47 € per ha in Gujarat). Also within states, tariffs differ. In Gujarat for instance rates vary from 70 to 2750 Rupees per ha (Namboodiri *et al.*, 2006).

Because irrigation through surface water (canals and tanks) has been practiced for centuries in India, the institutional setting is complex. There are various water allocation rules (i.e. systems) that have developed such as the Waribandi system, the Shejpali system, the land class system, the Satta system and the Phad system (Namboodiri *et al.*, 2006). All systems (except the small-scale Phad system) have in common that the (state) government has been the agency in charge.

Many government-run irrigation systems are characterised by various problems that lead to inefficient as well as unfair distribution of water. The problems of the government run irrigation system in Andhra Pradesh are illustrative for other states in India. Most irrigation systems are in disrepair and dilapidated due to inadequate maintenance, leading to reduced command areas. The systems are characterized by low irrigation efficiencies and tail-end deprivation because head-enders appropriate most of the water for themselves. This situation was exacerbated by a lack of coordination among the various Departments of Irrigation, Agriculture, and Revenue. Lack of established operation and maintenance (O&M) procedures, inadequate funds for O&M, and ad hoc expenditures by the Irrigation Department resulted in inadequate maintenance. Most of the agency's O&M funds were being spent on staff salaries; very little was being spent effective maintenance. As a result, major canals are silted and there are drains and damage to their lined sections. Dissatisfied farmers seeking more water, or water deliveries at the appropriate time, have tampered with irrigation structures causing further damage. Such unauthorized irrigation led to a low collection of water charges by the Revenue Department, as the measured water supplied was quite low (Peter, 2001).

In 1997, AP and the World Bank embarked on a program for irrigation sector reform that devolved power from the government to water user associations (WUA) (see

Oblitas and Peter, 1999). This entailed major institutional reform (at a higher governance level as well as at a lower institutional arrangements level).

The WUAs and canal cooperatives (CC) were evaluated by Namboodiri et al. (2006) for the Krishna Basin. Although irrigation users groups such as WUAs or CCs exist in all states, the organisational structure varies between states. The main organisation types are the two or three-tier systems, where three tiered systems have three levels (user level, 55 ha level and system level) and two-tiered systems have two levels (village WUAs and WUAs for distributaries channels). Although the organisational structure differ, the relationship between the WUA's and the government is the same across the country. The transfer of irrigation management responsibilities to WUA's has been done on a hydrological basis. Second, the governments retain the authority over large irrigation schemes. Third, the responsibilities transferred to WUA's concern water distribution, maintenance and the collection of irrigation fees. The rates are set by the government (and vary widely between and within states). Finally the financial resources of the WUA's are composed of part of the irrigation fees, crop area fees, as well as state government support.

Namboodi et al (2006) found that for the members of the WUA's it is sometimes not clear how the responsibilities between the government and the WUA's are divided. For instance, around 30% did not know whether maintenance and repair of the irrigation structures were the responsibility of the UWA or the government. Similar percentages did not know about the responsibilities for monitoring (of use of water) and enforcing rules for misuse or waste of water. It is interesting to note that there is a fair amount of disagreement about whether the institutional set-up of the WUA's is flexible and capable of adapting to change, which is an important aspect of organizations. Some feel that there are clear mechanisms in place for changing the rules of the organization if needed, others strongly disagreed. There was similar disagreement on whether the rules are rigid or flexible, whether there are regular reviews on the rules, and whether the management of a WUA has the authority to adapt the rules.

There is also disagreement on the degree of compliance achieved within a WUA: for instance members disagreed on whether members are aware of and willing to follow rules, and whether the management has sufficient power the enforce rules. On the issue of whether the WUA's have achieved efficiency (in terms of timely and adequate water supply, and better maintenance), most members agreed, although around 30% thought there was no difference between the new form of self-governed WUA and the old government-run system. The majority also agreed that the WUA's have had a positive effect on equity, in terms of equitable distribution of water and empowerment of farmers to manage irrigation systems, although again, over 30% thought there was no difference between the new WUA's and the old government system.

The most negative impact of the WUA's seemed to be on the environment – around 70% of the members were of the opinion that the WUA's are causing flooding and water logging and that the activity of the institution is rapidly depleting ground water in the village.

## 9.3 Economic instruments and institutional change for improved allocation

Economic instruments can be seen as means that can be used by policymakers to alter the rules of the game. Since economic policy instruments are usually applied within existing rules, institutions, and policy processes, the policy and administrative contexts in which they operate become important. Too little attention has been paid to the importance of basic institutions of policy-making -- whether formal or informal. Institutions already in place, for example, may need to be modified or altered to support the use of economic instruments (Anderson, 2001).

Economic instruments (EIs) encompass a rather heterogeneous toolkit of policies whose main defining feature is their reliance on markets and the price mechanism to internalize environmental externalities. The advantage of EIs as policy instruments is normally framed in terms of a contrast with the conventional approach applied in most countries which is a reliance on laws and regulations that dictate in some detail the measures which water users or polluters must adopt under penalty of fines or other sanctions. This approach, which is loosely referred to as 'command-and-control' has been criticized by economists on grounds of both static and dynamic inefficiency (O'Connor, 1999). Economic instruments can be classified into 7 broad categories (Panayotou, 1994):

1. Redefining Property Rights
    - (i) changes in ownership, use and development rights
2. Market Creation
    - (i) tradable permits
3. Liability
    - (i) liability insurance legislation
4. Charge Systems
    - (i) effluent charges
    - (ii) user charges
    - (iii) product charges
    - (iv) administrative charges
    - (v) impact fees
    - (vi) access fees
5. Fiscal Instruments
    - (i) pollution taxes
    - (ii) input taxes
    - (iii) importer tariffs
    - (iv) financial aid in installing new technologies
    - (v) subsidies for environmental research and development expenditure
6. Deposit- Refund Systems and Bonds
    - (i) deposit-refund schemes to encourage recycling

(ii) environmental performance bonds
(iii) land reclamation bonds

7. Financial Instruments
   (i) financial subsidies
   (ii) soft loans and grants
   (iii) sectoral/revolving funds

Whatever mix of economic instruments is chosen, problems of implementation can arise for several reasons (O'Connor, 1999): (i) administrative complexity exceeding public and private sector institutional capacity; (ii) political resistance from those who perceive themselves to be adversely affected; (iii) possible inconsistencies with the existing legal framework; (iv) design flaws involving a mismatch between the type of instrument chosen and the nature of the problem targeted— e.g., when applying, an instrument requires close monitoring of polluters, but the large number, small size, and geographic dispersion of those polluters makes such monitoring unfeasible. We will not discuss all the EIs in this paper, but will concentrate on redefining property rights and market creation, which we will combine to discuss tradable water rights.

This report aims at studying the possibilities to reallocate water to the most productive land uses. We will consider only agricultural land uses for now. Different crops have different water needs per kg of crop yield. One could reason that increasing water productivity is to increase the ratio of crop yield per input of water. However, crops have different values – some crops have a high value per kg while others have a very low value per kg. So when we measure water productivity, it may make more sense to measure it in crop value per input of water. This means that water productivity depends on output prices of crops, and that water should be allocated to the highest value crops.
But water also has an economic value that may differ per region as a function of the costs of water supply (which can reflect scarcity). It follows from this that in fact the ratio value of crop over value of water (cv/vw) should be maximised (which may result in different outcomes from the ratio crop yield weight over water input volume).

### 9.3.1 Water pricing

One way to influence (i.e. maximise) the ratio cv/vw is through pricing of water. Water prices in India (e.g. for irrigation) are still low, and below their economic value[27]. Increasing water prices (to reflect their real scarcity value) can lead to more efficient use. However, water pricing is a contentious and political issue in India, and raising prices to a level where they will have a real effect is a long way off (Saleth, 2005). In a study on the Mula Canal in India (Ray, 2002) argues that water price policy is not the most effective ways to increase irrigation efficiencies and suggests three broad reasons for this conclusion. First, water prices cannot feasibly be raised

[27] Recovered water charges, as a proportion of O&M costs, vary from 4.02 percent in Uttar Pradesh to 73.33 percent in Orissa, whereas the same as a proportion of water productivity vary from 0.28 percent in West Bengal to 5.19 percent in Maharashtra (GOI 1992b cited in Saleth, 2005).

to the point where they can affect water demand and use; second, farm-level inefficiencies are not the most significant inefficiencies, at least on existing canal systems; and third, low water prices are frequently not the reason behind water-intensive and inefficient crop choices.

Water pricing is only feasible when payments can be collected. In the case where farmers pump groundwater from their own land, or from a river that is adjacent to their land (riparian rights), pricing water and collecting payments can be very difficult due to monitoring problems (it will be extremely difficult to measure each farmers' water use). Thobani (1997) makes a similar point and adds that " even if governments could find an inexpensive way to measure and monitor water flow, measuring the opportunity cost of water is difficult because it varies according to location, reliability, season, use, and water quality. (p. 164)". He also points out that the political problems are even more intractable: "It is politically difficult to charge a farmer for water from a river that serves a town (and therefore has a high opportunity cost) a higher price than a farmer using water from a river that is not near a town. Similarly, it is difficult to charge profitable hydropower companies less than poor farmers. Strong farmer lobbies typically pressure politicians to keep water charges well below their opportunity cost".

Finally he discusses the problem that the price of land often already embodies the price of water rights. In areas with low rainfall, irrigated land may sell for ten times the price of un-irrigated land. If water is priced to reflect its opportunity cost, the land will be valued the same as un-irrigated land, resulting in an effective expropriation of farmers' assets. The sheer magnitude of asset expropriation implied, the number of people affected and the socially disruptive aspects of such a policy change make it unlikely that any politician would propose it.

### 9.3.2 Other pricing instruments

Indirectly, the use of water can be influenced, e.g. through taxing water pumps or gasoline that is used by waterpumps. In Kenya, for instance, a registration fee has to be paid when a waterpump is purchased, after which a yearly fee is paid (although this fee is independent from the amount of water pumped because this is difficult to monitor). Using energy prices to regulate water use is not feasible in India, however. This emerges from the fact that the gap between energy cost and the net value of output per unit of power is very high. As long as this gap is substantial and can also be manipulated by crop choice, farmers will not reduce power consumption and hence, their power demand will be insensitive to power tariff changes (Saleth, 2005).

### 9.3.3 Tradable water rights

Tradable water rights (which amount to the creation of a water market) have become popular means to achieve economic efficiency and equity. The reasoning behind is that farmers should be allowed to sell their water shares to higher value uses both within and without the agricultural sector. Such trades would be economically efficient and in the farmer's interest.

In fact, groundwater markets are growing in magnitude and gaining in significance in India. While water selling practices in India are traced to the 1920s, more systematic documentation of this phenomenon started only since the late 1960s. This has occurred without any formal water rights system (Saleth, 2005). Saleth (1998) estimates that 20% of the owners of 14.2 million pumpsets in India are likely to be involved in water trading, providing water for 6 million hectares (15% of total area irrigated by groundwater). For water trading and water markets to arise, first property rights must be allocated ("first allocate then trade"). But because water rights in the Krishna Basin are already (implicitly) assigned – through riparian rights, water trading and water markets have existed for a long time already. Several authors have used some of these as examples of successful markets (see Dinar *et al.*, 1997).

In principal, water trading can be an efficient method for reallocating scarce water supplies. Water markets can also provide the appropriate economic incentives to improve the efficiency of water use and encourage the reallocation of water to higher-valued uses without encountering the traditional opposition of existing water users (Easter *et al.*, 1999). However, Easter et al (1999) and (Mohanty and Gupta, No date) point out that some basic institutional and organizational arrangements must be in place to overcome a number of problems.

In the Indian context, it is important to introduce necessary legal arrangements to facilitate the management of surface water on a river basin basis to overcome the problem of the fragmentation of basins by state boundaries and the lack of cooperation between them. Linked to this, the legal position on individual usufructuary rights for surface water must be clarified because as it is, there is no system to provide secure defensible and enforceable water rights. Riparian rights are the only (implicit) rights that exist. However, tradable (groundwater) water rights or water use rights need to be separated from land rights, which is not the case with many of India's thriving water markets. Institutional arrangements will also be needed to deal with third-party effects that result from changed in return flows and overexploitation of groundwater. This may include establishing limits for withdrawal of groundwater. Informal (ground)water markets such as in India lead to overdraft. Farmers have an incentive to ignore the scarcity and buffer stock value of the groundwater and instead base their decision of the cost of pumping (equalling the market price of water). Ramasamy (cited in Easter *et al.*, 1999) estimates that the overdraft in Coimbatore District is almost 5000 $m^3$ a year and is affecting the tot net returns to farmers. Shah (1993) similarly report overdraft issues for Gujerat. Finally, institutional and organisations changes are required to broaden the market and make it more competitive (including canal infrastructure so that trade can take place over a larger area). And institutional arrangements are required for conflict-resolving institutional arrangements.

Mechanisms to prevent monopoly control over water must also be established. These problems can be dealt with through the design of water rights including how water rights are quantified, allocated, monitored and enforced. However, how to achieve this for groundwater is a difficult issue, because it is usually virtually impossible for a governmental agency to monitor a multitude of (small scale) water traders who pump up groundwater. However, several authors have pointed out that community organisations (such as water user associations) can be successful in monitoring and enforcing overdraft issues (Shah, 1993), (Blomquist, 1995, cited in Easter et al., 1999). The overdrafting problem can also be met by increasing the incentives for efficient water use and making it possible to purchase water from area where water is abundant (Shah, 1993; Easter *et al.*, 1999).

On the monopoly pricing, there is some evidence that informal water markets in India have this problem. The development of water markets have also been shown to be associated with the emergence of 'water-lords' (large farmers who become water sellers) and with contracts for the purchase and sale of water that are biased against the poor (Rawal, 2002).

## 9.4 Conclusion and recommendations on institutions

In general, the institutional environment in India is not conducive to efficient water use. (Saleth, 2005) sums up the problems by explaining the " incentive gap". Pricing of water is very low and rarely revised (i.e. increased), covering hardly 5% of water productivity (i.e., the difference between the average productivity levels of irrigated and rainfed lands) and 8 percent of O&M costs. Since even the low water charges are not fully recovered, the arrears are also accumulating over time in most states. Besides these effects on the financial side, the low and uneconomic water rates also lead to an incentive problem causing widespread water use inefficiency. The incentive gap can be approximated by the gap among water productivity, supply cost, and water rates. The incentive gap indicates not just the poor performance of pricing and cost recovery policies but also the absence of institutional conditions necessary for volumetric allocation such as the water rights including their legal and organizational requirements.

However, institutional reform of the water sector, in order to (re-)allocate water to more water productive economic sectors to more water productive sectors is limited, especially due to the importance of the informal institutional environment and the ineffectiveness of the formal institutional environment. Hence the call for "getting the institutions right". Care must be taken not take a "technocratic" stance, as Vermillion *et al* (2005) pointedly draw attention to:

> *"A lot of institution building goes on informally and incrementally at operational levels (…). In the future, it will become increasingly important (…) to better understand the limitations of comprehensive, technocratic planning for complex irrigation systems and river basins with multiple users and sources of water. The automatic response of technocrats to environmental complexity is to call for more and more sophisticated information and management systems. Perhaps a more realistic response would be to recognize the limitations of comprehensive, integrated planning, and augment these efforts with an equally important process of*

*participatory decision making among diverse groups at multiple hydraulic or administrative levels. So much of water management and use activity occurs at sub-irrigation systems and sub-basin levels, that integrated water management at the system or basin levels may not capture most of the total picture."(p. 502).*

Community associations (such as water users association) seem the right level of decision-making over water and experience has shown that they are able to successfully allocate water among its members. It seems that the less government intervention in these associations is the better: "*In decision making and rules crafting, the authority needs to be devolved to local farmers, rather than imposing on them insensitive and rigid rules*" (Bardhan, 2001). Authority over water allocation should be squarely placed at that level, and this may also entail establishing water rights at this level. Government intervention is required, however, to deal with issues that this encompass the level of the community, such as third-party effects (consisting mainly of environmental effects such as groundwater depletion). Rawal (2002) for instance shows that community associations which can be described as non-market interventions in water-sharing can indeed lead to efficient and equitable development and management if water resources.

On market interventions, the current challenge in India is to establish formal water markets, which will expand the scope of trading and make *inter-sectoral* water transfers possible (Mohanty and Gupta, No date). The legal basis underpinning formal water markets will enable the regulation of ecological sustainability. However, there are many complicated issues to be dealt with for viable formal water markets to emerge. Again, community organisations can play an important role in these.

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## Appendix 1 Framework used to derive returns to water

An existing Excel-based spreadsheet mode has been used. AGWAT(F) is an Excel Spreadsheet with six 'worksheets', developed by Perry. Three of these worksheets contain only data which the user is required to insert. The remaining three worksheets contain only computed results. Locations where data may be entered are Grey cells. The three input data sheets are Prices Data, Farm Data, and Labor and Irrigation, which contain sample data. The data are invented as a basis for explaining the analysis.

### *Data Entry*

The *Prices Data* Worksheet contains the name of the currency (Rs), names of the of the crops (Rice, Maize, Cotton, Wheat), prices for each crop, any byproduct, and seed (Rs3000/ton, Rs100/ton and Rs40/kg in the case of Rice) and the cost of canal irrigation services which may be either per hectare (Rs600 for rice) or per cubic meter. Fertiliser prices are also listed (Rs4000/T for N). The observed minimum and maximum daily rates for hired labour (Rs15 and Rs50) are specified, as are the minimum and maximum charges for well water (Rs50 and Rs100) per thousand cubic meters.

**PRICES**

CURRENCY Rs

| | Crops Rs/Ton | Byprod Rs/Ton | Seeds Rs/kg | Water /ha | Water /000m3 |
|---|---|---|---|---|---|
| Rice | 3,000 | 100 | 40 | 600 | |
| Maize | 2,000 | 200 | 20 | 200 | |
| Cotton | 7,500 | 150 | 150 | 300 | |
| Wheat | 4,000 | 500 | 70 | 400 | |

**Fertilisers-Rs/T**

| | |
|---|---|
| N | 4,000 |
| P | 2,500 |
| K | 3,000 |

**Hired Labor-Rs/day**

| | |
|---|---|
| min | 15 |
| max | 50 |

**Groundwater-Rs/000m3**

| | |
|---|---|
| min | 50 |
| max | 100 |

The *Farm Data* Worksheet includes the farm size, the monthly availability of family labour, and the on-farm irrigation efficiency (2ha and 25 days/month, and 80% respectively). The basic input-output data for the farm are included in a table - the cropping pattern for each of the crops specified in the *Prices Data* table (in terms of percentage of the farm area - this in the example, with 40% of the farm area under Rice, the physical area under Rice would be 2ha x 40%, or 0.8ha). Yields of the crop and any by-product are specified, together with input usage rates for fertilisers and any chemical or other 'per hectare' inputs. The available family labour is also specified (25 days per month in the example). Note that the total percentage area cropped (155%) is in excess of 100%; the first three crops are grown in one season, while the wheat is grown in another season.

| | | |
|---|---|---|
| Farm Size | 2.0 | Ha |
| Family Labor Available-day/month | 25 | |
| Farm Irrigation Efficiency (%) | 80 | |

| | AREA | Output (T/ha) | | - -- - - - Inputs (kg/ha) - - - - - - | | | | - - Rs/ha - - | |
|---|---|---|---|---|---|---|---|---|---|
| | % | crop | byprod | N | P | K | Seed | Chem | Other |
| Rice | 40 | 3.5 | 0.8 | 70 | 20 | 60 | 50 | 500 | |
| Maize | 20 | 2.5 | 0.5 | 20 | | 10 | 30 | | |
| Cotton | 20 | 2 | 0.2 | 120 | 90 | 40 | 40 | 1000 | |
| Wheat | 75 | 2.5 | 0.5 | 80 | 80 | | 40 | 200 | |

The *Labour and Irrigation Data* Worksheet includes the monthly inputs required per hectare of crop. Crop irrigation requirements are specified in terms of millimeters per month, and should be specified by the user to include effective rainfall. Labour requirements are specified in the same format. In the example, Rice requires 50 days labour in June per hectare of crop, and the farm level requirement will be computed based on the farm area under Rice. AGWAT does not compete with programs such as CROPWAT, which should be used for more detailed analysis of crop water balances. Finally, the monthly availability of canal irrigation water to the farm is specified in thousands of cubic meters - here assumed to be constant at 3,000 $m^3$/month from June to October.

**LABOR REQUIREMENTS**

(Days per ha of Crop)

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rice | | | | | | 50 | 30 | 10 | 10 | 10 | 60 | | 170 |
| Maize | | | | | | | 20 | 20 | 20 | 10 | 30 | | 100 |
| Cotton | | | | | 20 | 20 | 20 | 20 | 15 | 20 | 20 | 60 | 195 |
| Wheat | 10 | 10 | 5 | 20 | | | | | | | | | 45 |

**IRRIGATION REQUIREMENTS AND AVAILABILITY**

mm/month

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total ('000 m3) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rice | | | | | | 500 | 300 | 300 | 300 | 600 | | | 20 |
| Maize | | | | | | | 150 | | 150 | 150 | | | 5 |
| Cotton | | | | | 250 | 200 | 150 | | 150 | 150 | 100 | | 10 |
| Wheat | 250 | 150 | 150 | 250 | | | | | | | | | 8 |

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Canal Supply (m3) | | | | | | 3,000 | 3,000 | 3,000 | 3,000 | 3,000 | | | **15,000** |

### *Results*

In the *Labour and Irrigation Demand* Worksheet, the upper table shows the results of multiplying the Farm Size by the percentage area under each crop by the monthly labour demand per hectare. For Cotton in May the relevant figures are 2ha x 20% x 20 days/ha/month, or 8 days. The total demand is calculated as the sum for each month of the demand from each crop. In May, with Cotton the only crop using labour, the total is 8. Since this is less than the available family labour (25, from *Farm Data* worksheet), there is no need to hire labour. In June, however, the total demand is 40 days, so 15 days are hired.

**FARM IRRIGATION DEMAND, SOURCES OF SUPPLY AND COSTS**

(m3 / month)

| Crop | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rice | | | | | | 5,000 | 3,000 | 3,000 | 3,000 | 6,000 | | | **20,000** |
| Maize | | | | | | | 750 | | 750 | 750 | | | **2,250** |
| Cotton | | | | | 1,250 | 1,000 | 750 | | 750 | 750 | 500 | | **5,000** |
| Wheat | 4,688 | 2,813 | 2,813 | 4,688 | | | | | | | | | **15,000** |
| **Demand** | **4,688** | **2,813** | **2,813** | **4,688** | **1,250** | **6,000** | **4,500** | **3,000** | **4,500** | **7,500** | **500** | | **42,250** |
| **Canal Supply** | | | | | | **3,000** | **3,000** | **3,000** | **3,000** | **3,000** | | | |
| Vol Charge (Rs) | | | | | | | | | | | | | |
| Pumped (m3) | 4,688 | 2,813 | 2,813 | 4,688 | 1,250 | 3,000 | 1,500 | | 1,500 | 4,500 | 500 | | **27,250** |
| Rate (/'000 m3) | 100 | 78 | 78 | 100 | 59 | 80 | 62 | | 62 | 98 | 50 | | **765.7** |
| Pump Charge (Rs) | 468.7 | 218.3 | 218.3 | 468.7 | 73.7 | 239.6 | 92.9 | | 92.9 | 439.9 | 25.0 | | **2338.1** |

Note that in the price data we specified the maximum and minimum hired wage rates (50 and 15, respectively). AGWAT computes the total demand for hired labour in each month, then assigns the maximum price to the month of maximum demand (November, where 43 days of hired labour are required) and the minimum to the month with minimum hiring (April, 5 days), and scales between these two extremes depending on demand. In June, with an overall demand of 23 days hired labour, the daily rate is computed at Rs32/day so that the cost of hiring is 21 days at Rs32/day, or Rs726. The associated table - Farm Irrigation Requirements - computes the monthly and total demands by crop in a similar fashion.

**FARM LABOR DEMAND**

(Days)

| Crop | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rice | | | | | | 40 | 24 | 8 | 8 | 8 | 48 | | **136** |
| Maize | | | | | | | 8 | 8 | 8 | 4 | 12 | | **40** |
| Cotton | | | | | 8 | 8 | 8 | 8 | 6 | 8 | 8 | 24 | **78** |
| Wheat | 15 | 15 | 8 | 30 | | | | | | | | | **68** |
| **Demand** | **15** | **15** | **8** | **30** | **8** | **48** | **40** | **24** | **22** | **20** | **68** | **24** | **322** |
| Family Labour | **15** | **15** | **8** | **25** | **8** | **25** | **25** | **24** | **22** | **20** | **25** | **24** | **236** |
| Hired Labour | | | | **5** | | **23** | **15** | | | | **43** | | **86** |
| Wage Rate (Rs/day) | | | | 15 | | 32 | 24 | | | | 50 | | |
| Wage Payments (Rs) | | | | 75 | | 726 | 363 | | | | 2,150 | | **3,314** |

The water requirements are totaled by month, and where canal supplies are inadequate to meet demand (for example, June where demand is 6,000 $m^3$ and canal supplies are 3,000 $m^3$) water is assumed to be pumped to meet the deficit. The cost of pumping is scaled between maximum and minimum demands (Rs100/m$^3$ in January and Rs 50/m$^3$ in November) as in the case of labour, to allow variation of supply with demand. Note that if maximum and minimum prices are set equal, then the cost of water will not vary with demand. Also, if canal supplies are set to zero, then all water will be pumped. If the required supply of pumped water is greater than known availability, it is up to the analyst to either (a) reduce the cropped area, or (b) reduce crop yields to reflect water shortage.

The *Crop Budgets* table computes returns by crop on a per hectare basis. Value of production is simply yield multiplied by price (3.5 t/ha x 3,000Rs/t = Rs10,500/ha for Rice, plus 0.8t/ha x 100Rs/t = Rs80/ha for the by-product). The costs of NPK and other per hectare inputs are similarly calculated. The cost of hired labour is more complex, because the costs of hiring must be allocated on a crop-by-crop basis. This is done by computing the proportion of total demand that each crop accounts for in each month, and distributing the total cost of hired labour for the month on this basis.

**CROP BUDGETS PER ha**

| Crops | VALUE OF PRODUCTION Crop | VALUE OF PRODUCTION by-product | GROSS RETURN | COST of INPUTS and WATER NPK | Other | Labor | /ha | /'000m3 | Pumped | TOTAL COSTS | NET RETURNS Average | NET RETURNS Marginal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rs/ha | | | | | | | | | | | |
| Rice | 10,500 | 80 | 10,580 | 510 | 2,500 | 2,926 | 600 | | 844 | 7,380 | 3,200 | (32) |
| Maize | 5,000 | 100 | 5,100 | 110 | 600 | 1,130 | 200 | | 187 | 2,228 | 2,872 | 1,790 |
| Cotton | 15,000 | 30 | 15,030 | 825 | 7,000 | 1,117 | 300 | | 534 | 9,776 | 5,254 | 3,927 |
| Wheat | 10,000 | 250 | 10,250 | 520 | 3,000 | 50 | 400 | | 916 | 4,886 | 5,364 | 5,114 |

The cost of Pumped Water is similarly distributed among crops on the basis of the cost of pumped water in any month and the proportion of irrigation demand for each crop. With Gross Returns and Total Costs computed on a per hectare basis, the Average Return to each crop is calculated as the Gross Return less all costs.

The Marginal Return is an additional indicator of the attractiveness and returns to each crop. Here the costs are based on the situation if an additional hectare of the crop is grown. Where labour is already hired in a particular month (or where water is purchased from a well) then all additional labour (or water) is purchased at the full cost - hence leading to higher costs than in the 'average' case where costs are a mixture of 'free' family and hired labour, and 'cheap' canal water plus pumped water.

Farmers will generally be interested to increase production of the crops where the marginal return is highest - and it is interesting to observe that in the example, the marginal return Rice is sharply lower than the Average Return - because of the high incidence of hired labour in the cost structure, while Maize remains relatively attractive. Based on Average returns, we would expect farmers to be more interested in increasing rice than wheat.

The Farm Budget provides a picture of the overall farm business, based on the actual area under each crop (note that the Crop Budgets are per hectare of crop, the farm budget is for the whole farm). As well as showing the gross and Net Returns - which are indicators of the returns to land, the table also indicates the return to family Labour and to Water.

**FARM BUDGET**

| Crop | Income per ha Rs | Area (ha) | Farm Income Rs | COSTS Inputs | Labour | Water | Net Income Rs | Family Labor Use (days) | Return Rs/day | Water Use 000 m3 | Return Rs/m3 Gross | Net |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | - - - - - - - - Rs | - - - - - - - - - | | | | | | | |
| Rice | 10,580 | 0.80 | 8,464 | 2,408 | 2,341 | 1,155 | **2,560** | 77 | 33 | 20.0 | 0.4 | 0.1 |
| Maize | 5,100 | 0.40 | 2,040 | 284 | 452 | 155 | **1,149** | 29 | 39 | 2.3 | 0.9 | 0.5 |
| Cotton | 15,030 | 0.40 | 6,012 | 3,130 | 447 | 334 | **2,102** | 66 | 32 | 5.0 | 1.2 | 0.4 |
| Wheat | 10,250 | 1.50 | 15,375 | 5,280 | 75 | 1,974 | **8,046** | 62 | 129 | 15.0 | 1.0 | 0.5 |
| Total/Ave | 10,287 | 3.1 | 31,891 | 11,102 | 3,314 | 3,618 | **13,856** | 235 | 59 | 42.3 | | |

Cropping Intensity = 155%
Utilization of Available Family Labor = 78%
Proportion of Family Labor in Total Used = 73%

### *Interpreting the results*

The first point to consider in interpreting the results is whether they survive a 'sanity check' - Do specific crops show huge positive or negative returns? Is the demand for water much higher or lower than observed availability? Is the calculated need for hired labour consistent with observed scarcity or excess of available labour? This review will often point to flaws in the data, and errors in data entry, and is always a useful and rewarding exercise. From the farmer's viewpoint, his primary goal is to maximise Net Farm Income. Are there obvious opportunities to do this? The Crop Budgets show that Cotton has a considerably higher Average Return (Rs5,254/ha) than Maize (Rs2,872/ha). We can quickly test the impact on farm income of switching 1% of the area from Maize to Cotton, so that the Cropping Pattern in the Farm Data table now reads Rice 40%; Maize 19%; Cotton 21%; Wheat 75%. The resulting Farm Budget is shown below. Comparing this with the base scenario, we see that income has fallen by shifting to the apparently more profitable crop.

Why? In the base case, Maize income at the farm level was Rs1,149, Cotton income was Rs2,102 (total Rs3,251). Corresponding data for the new scenario, above are Rs1,084 and Rs 2,183 (total Rs3,267 - a gain of Rs16). But the higher labour demand of Cotton, competing with Rice in high-demand months induced a fall in Rice income from Rs2, 560 to Rs2, 480 five times the gain from the increase in Cotton!

# Appendix 2 Characteristics of existing farming systems

**Farm Typology on Freedom of Cropping pattern decisions**

*Questionnaire on Land, Water, Ecosystems management in the Krishna River basin*

**ANGRAU – Hyderabad, October 2006**

**1) Farmer Details**

| | |
|---|---|
| Name of the farmer | |
| Village | |
| Mandal | |
| District | |
| Education | Illiterate / Primary / secondary / UG / PG |
| Occupation | Agriculture / Employment (self, Govt, Private) |
| Source of income | Annual income / any |

**2) Family size**

| **Family members** | **No.** | **Occupation** | **Availability for farm work** | **Days of work** |
|---|---|---|---|---|
| Male | | | | |
| Female | | | | |
| Children | | | | |

**3) Assets (Inventory)**

| **Assets** | **Units / No.** | **Year of purchase** | **Present value** |
|---|---|---|---|
| **1) Land**<br>a) Wet<br>b) Dry<br>c) Irrigated dry | | | |
| **2) Irrigation**<br>a) Systems without irrigation<br>b) Systems with surface irrigation (without tanks)<br>c) Systems with surface irrigation (With tanks)<br>d) Systems with ground water irrigation<br>e) Systems with conjunctive use | | | |
| **3) Farm buildings/ Cattle sheds** | | | |
| **4) Live stock**<br>a) Bullock | | | |

| | | | |
|---|---|---|---|
| b) Cows<br>c) Buffaloes<br>d) Poultry<br>e) Sheep<br>f) Goat<br>g) Pig | | | |
| **5) Farm machinery & Implements**<br>a) Tractor<br>b) Power tiller<br>c) Others | | | |
| **6) Crop produce** | | | |

**4) Land holding particulars**

| | **Acres** | | **Guntas** | | **Others** |
|---|---|---|---|---|---|

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Total land | | Wet | | Dry | | Irrigated dry | |

Leased in land:

Leased out land:

Is Availability of land ease?

**5) Cropping pattern –Production- Returns:**

| Season/Crop | Area covered | Cost of cultivation | Yield realized | Market price/ q | Gross returns | Net returns |
|---|---|---|---|---|---|---|
| **1) Kharif**<br>a)<br>b)<br>c) | | | | | | |
| **2)Rabi**<br>a)<br>b)<br>c) | | | | | | |
| **3) Summer**<br>a)<br>b)<br>c) | | | | | | |

**7) Live stock units – Production – Returns:**

| Name of live stock | No. of units | Production | |
|---|---|---|---|
| | | Q.ty | Bulk |
| | | | |

**8) Input supply :**

| Labour | No. | Wages (Annual/Season) | |
|---|---|---|---|
| | | Kind | Cash |
| Permanent labour | | | |
| Availability of casual labour | | | |

**Availability of other inputs:**

| Inputs | Q.ty | Price/ unit | Total value |
|---|---|---|---|
| **1) Seed** | | | |
| **2) Fertilizer**<br>a) N<br>b) P<br>c) K | | | |
| 3) Agricultural chemicals<br>a) Pesticides<br>b) Fungicides<br>c) Herbicides | | | |
| **4) Irrigation Water** | | | |
| **5) Electricity** | | | |
| **6) Others** | | | |

**8) Market:**

| Component | Description |
|---|---|
| Distance to market (Km) | |
| Mode of transport<br>(Bullock/Tractor/Lorry & its charges) | |
| Method of sale<br>(Market/Local/Middlemen) | |

**9) Availability of water:**

| Component | Description |
|---|---|
| Open well | |
| Bore well | |
| Canal | |

Monsoon – Rainfall pattern (3-5 years):

☐ Good ☐ Average ☐ Poor

**10) Sketch of the Farm (include plot size)**

**11) Farmer aim/goal with his farming activity:**

| | | | |
|---|---|---|---|
| | Maximize profit | | Minimize risk |
| | Seasonal income | | Daily income |
| | Resource conservation | | Income stabilization |
| | Secure self-sufficiency | | Subsidiary income (Crop activity along with other non-farm activity) |
| | Profit & resource Conservation | | **???** |
| | Satisfaction of family needs | | **???** |

**12) Farmers opinion on farming**

| | |
|---|---|
| | Good -Happy with the farming |
| | Normal - Satisfied with the farming |
| | Poor - Struggling with farming |

**13) Future perspectives**

| | |
|---|---|
| | Will continue with farming as it is |
| | Will diversify his/her farming activities |
| | Will expand land area in future |
| | Will seek additional income outside farming |
| | Will retire and no successor |
| | Will leave agriculture to work in other activities |
| | Others |

**14) Other Remarks or Specific Information (Farmer side):**

**15) Remarks of the Investigator:**

| | |
|---|---|
| Impression of farmer | Progressive farmer: Implements Opportunities to improve his farming<br>Ordinary farmer: Can't use Opportunities for improve farming<br>Conservative farmer: Can't see Opportunities to improve |
| Other | |
| Other | |
| | |