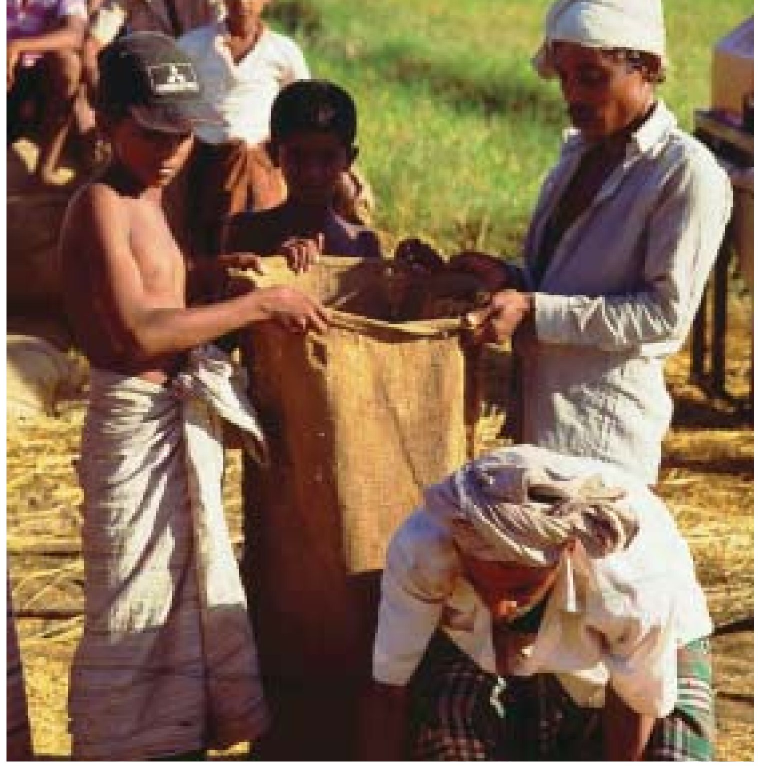
issues

OF WATER MANAGEMENT IN AGRICULTURE: COMPILATION OF ESSAYS



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Comprehensive Assessment of Water Management in Agriculture

The Comprehensive Assessment of Water Management in Agriculture (CA) is an international research, capacity-building and knowledge-sharing program focused on providing water-agriculture solutions that will reduce poverty, increase food security and protect natural ecosystems in developing countries.

The CA evaluates the costs and benefits of the past 50 years of water development for agriculture and the water management challenges people are facing today. The goal is to help governments and farming communities craft better water futures. To accomplish this work, the CA mobilizes the expertise of the Future Harvest Centers of the Consultative Group on International Agricultural Research, the United Nations Food and Agriculture Organization and numerous international and national agricultural research centers worldwide.

The result will be a unique foundation of knowledge and information that will allow better quality decisions on water investments and management, and better targeting of development funding to meet food and environmental security targets over the next 25 years.

Contents

Preface

We have been able to manage land and water resources to produce enough food for rapidly growing populations. World food prices are lower than ever, but at the same time 800 million people remain malnourished. By its nature, food production needs large volumes of water, whether directly from rainfall, or indirectly through irrigation. But there are major problems in this process of using water for food. First is the inability to effectively use water to fight malnutrition and poverty in many areas of the world. Second is the environmental damage caused by agricultural water use, including polluted water ways, degraded ecosystems and drying up of river systems.

We believe that the answer to many problems of malnourishment, poverty, and pollution lies in how water is managed for agriculture. We, therefore, recommend an increase in research and action focused on issues of development and management of water for food production, distribution and equity or access impacts, and impacts of agricultural water use on ecosystems and the environment.

The Consultative Group on International Agricultural Research (CGIAR) centers have teamed up with key partners throughout the world to identify, understand, and take action on key water problems in the use of water for agriculture and food production through two major initiatives—the Comprehensive Assessment of Water Management in Agriculture (CA), and the CGIAR Challenge Program on Water and Food (CP Water and Food). The CA takes stock of the global situation in managing water for agriculture, provides key additional information in this field, and scopes out future research and action needs. The CP Water and Food will follow up on the recommendations of the CA to provide critical knowledge in the public domain, and turn this knowledge into action towards solving the world's water problems.

This book contains essays from lead scientists from partner organizations in these initiatives. Topics include, water and poverty; water rights; agriculture and environment; improving water productivity; water savings in agriculture; rainwater and food production; fisheries; and sustainable groundwater use. We contend that increasing the productivity of water in agriculture—obtaining more value for each drop used in forests, fisheries, livestock and crops—is necessary to bring about change. This is required in both rainfed and irrigated areas. However, increasing water productivity alone is not sufficient to solve the world water crisis. It must be done in a way that maintains important ecosystems and the services they provide. It requires a river basin focus to understand how water use in agriculture affects other users. It needs a focus on poverty, health and nutrition, and a special focus is necessary on groundwater because of the opportunities it provides in food production and poverty alleviation—as well as severe threats from overuse and pollution. Finally, water rights are key to both water productivity and distribution of benefits gained from using water.

The essays analyze problems, as well as provide suggestions for the way forward. As the authors were asked to express their opinions frankly, their suggestions may be thought-provoking or even controversial. If so, I hope that the reader will find them a useful contribution to the debate. I am confident that you will at least find them highly relevant and informative.

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Pathways to Improving the Productivity of Water

David Molden

A remarkable achievement of humankind has been the ability to expand food production fast enough to keep pace with population growth. But the cost of this achievement has been a water crisis—a situation marked by water scarcity and competition, pollution and loss of species, and persisting malnutrition that could in part be solved through better use of water. Improving water productivity is an important necessary step to solve this crisis. Obtaining "more crop per drop" is necessary to relieve problems of scarcity, and relieve pressures that degrade the natural resource basins. But how do we go about the task of improving water productivity?

In its broadest sense, improving water productivity means obtaining more value from the use of water resources for agriculture, domestic, industrial and environmental uses. Within agriculture it means gaining more value from livestock, crops and trees produced per unit of water. We don't think about it often, but eating food requires huge quantities of water. Each person is responsible for converting between 2,000 to 5,000 liters of liquid water to vapor each day just because we have to eat. This is because of the biophysical process of evapotranspiration, necessary for the growth of food and feed producing plants on rainfed and irrigated lands. Bathing with 20 liters, or drinking 2 to 5 liters seems insignificant when compared to this quantity of water. Crop based agriculture is a huge consumer of water resources, responsible for approximately 20 percent of evaporation from the earth's surface. How much more water is necessary for agriculture will depend on, amongst other factors, the productivity of water.

There are three basic approaches in which water can be used for more food production.

1. Supply Side: Develop more infrastructure and more rainfed and irrigated land to supply more water for more agriculture.
2. Conservation: Reduce wastage and loss of water by agriculture.
3. Unit Productivity of Water: Increase the productivity of water for each drop consumed by agriculture.

The first supply side approach is aimed at improving overall food production by supplying more water for more land. This can be done by large projects, such as dams, diversions, and canals, but also by small scale works like pumps and water harvesting structures. While the major dam building era may be past, expansion of irrigated land continues, much of which is fueled by pump irrigation. Providing access to water to poor people remains a major challenge, especially in areas of economic scarcity—where financial and human capital limit development in spite of water being sufficient in nature.

There is no doubt that the benefits, in terms of food security and economic development of this supply side approach have been substantial. But there is also no doubt that the cost in terms of inequitable distribution of benefits, degraded natural resources, and loss of biodiversity and ecosystems is in many cases unacceptable. Clearly improving the process of developing more supplies to minimize social and environmental costs is important. When benefits outweigh costs, this supply side approach can be considered to increase the productivity of basin-wide water resources.

The conservation approach focuses on eliminating waste—water down the drain. Every effort should be placed on eliminating waste and pollution of water supplies by agriculture. Converting wasted water to productive use is a means of improving the productivity of water supplies to agriculture.

While wastage is a problem in some areas, there is a different, but related set of problems that is less recognized. A popular notion has been that irrigation wastes a lot of water, because the bulk of farmers who are only 50 percent efficient waste 50 percent of our water resources. But in fact when we observe the combined actions of a group of farmers, we find that in irrigated areas of Pakistan, Northwest India, Egypt, the North China Plains, and Northeast Colorado, and probably many more areas, farmers within the area are responsible for converting more than 80 percent of supplies to productive evapotranspiration—a practice that could be considered highly "efficient." To adapt to scarcity, farmers invest in technologies and management practices to recapture "waste" flows by reusing return flows to rivers, available water in drains, in groundwater and in small reservoirs. The real problem in these areas are threats to agricultural sustainability and ecosystem degradation caused by burning up too much water by growing crops driven by economic necessity. When ill managed, this situation leads to exploitation of non-renewable groundwater resources, mining water from important ecosystems, or pollution or salinity buildup. It is alarming how many overstressed agricultural systems are being observed.

The third "unit productivity" approach requires an increase in the amount of output or value per unit of water consumed by agricultural practices. Producing more food with the same amount of water is an alternative to the supply side approach. In highly stressed areas, producing more food with less water may be the only option to ensure food security, and to restore systems so they can sustain long-term agricultural practices. For farmers with a limited supply of water, improving water productivity is a chance to improve incomes and livelihoods.

How much scope is there for improving water productivity? In many areas, potential productivity is not realized and this is in part due to poor irrigation management. Considering the productivity of water in more than 40 irrigation systems worldwide, a 10-fold difference in the gross value of output per unit of water consumed by evapotranspiration was demonstrated.[1] Some of this difference is due to environment, or the price of grain versus high valued crops. Certainly not all agriculture can be devoted to high valued crops. But even among grain producing areas, the differences are large. Improving performance of poorly managed irrigated agricultural systems is a high priority action.

Rain-fed agriculture contributes to about 60 percent of cereal production on 70 percent of the global cereal area, and is the primary means of food production in most countries, and the only means of production for many farmers. Consequently, a one-percent increase in rain-fed cereal production would have one and half times more effect than a similar productivity increase in irrigated cereal production. It has been convincingly argued that water management strategies on rainfed lands, including water harvesting and supplemental irrigation deserve considerable attention.[2] This is an attractive proposition especially in that most farmers who benefit from such an increase would be the rural poor and those with marginal sized farms.

To illustrate the food, water, and productivity link, consider water needs for India in 2025.[3] In 1995, average grain yields were 2.7 tons per hectare. About 600 cubic kilometers of water were diverted to irrigation uses. Considering the growth in population and improvements in diet, diversion requirements in 2025 were calculated for different settings. If there is no increase in grain yield, India will have to double diversions to irrigation with the risk of environmental damage. On the other hand, if grain yields increase by 70 percent, no more increases in water diverted to irrigation will be required. While attractive, this water productivity strategy has food security risks, especially in times of drought. While people in India will have to strike a balance between the two approaches, providing means of improving the productivity of water provides more options to choose from to strike the balance between food and environmental security.

What actions are needed? There are a variety of interconnected paths that can improve the productivity of water.

Crop breeding: The greatest gains in water productivity can be attributed to crop breeding efforts. Crop varieties that yield more with the same amount of water, or shorter duration varieties that consume less water, increase productivity of water. Drought resistant varieties help to stabilize yields, and reduce risks in drought prone rainfed areas.

Agronomic and field practices: Good soil tillage, fertilizer practices, water application, and soil-water management can raise productivity of water. On-farm water harvesting practices such as mulching or bunding in water short areas that effectively convert non-productive evaporation to productive transpiration, thereby increasing biomass yield per unit of evpaotranspiration. As everyone knows, it is important to deliver the right amount of water to the crop at the right time. But it has only been in the past two decades or so that we have begun to see just how important it is to do this precisely—*exactly* in the right amount and at the right time. The various forms of precision irrigation—mainly sprinkler, drip irrigation systems and dead-level basins—increase yields over good but ordinary irrigation systems by 20 to 70 percent, depending on the crop and other conditions, and they do so with much less water diverted to the crop.

Low-cost supplemental irrigation technologies for rain-fed areas: There is considerable scope for increasing the productivity of rain-fed agriculture by the application of supplemental irrigation at critical stages in the crop cycle. Such interventions will rely on the use of precision irrigation technologies combined with water harvesting or groundwater use. Providing a limited supply of water at the right time can save harvests and dramatically increases yields. Low-cost versions of precision technologies, based on those used in commercial large-scale agriculture, provide an opportunity for fighting poverty and increasing productivity. In South Asia and Africa, very low-cost bucket and drip sets are becoming increasingly popular with farmers. In areas where shallow groundwater is plentiful, thousands of poor farmers in Bangladesh have used low-cost treadle pumps to supply water for crops for their own food security and additional income.[4] But we do not yet understand the potential, or the mechanisms, for large-scale uptake of these technologies.

Improved irrigation management practices: One basic principle in irrigation is to deliver a reliable supply of water. If farmers do not have a reliable supply, they do not know when the next irrigation is coming, they do not know how much water will come, and they do not know if there will be enough water for their crops. In this uncertain environment, farmers will not invest in seeds, fertilizers and land preparation, and consequently yields and water productivity will suffer. A second basic principle has to do with timing. At various times in a crop's growth cycle, water stress can be particularly damaging. Tubewell irrigation systems in India typically produce yields that are twice as much as produced by canal irrigation systems. Tubewell water is reliably available virtually on the farmer's demand, while in most Indian canal systems farmers must wait for their turn which may not match crop needs. Similarly, the Chinese "melons-on-the-vine system" of canals feeding small tanks, places water closer to farmers fields and lets them store water and apply it when it is needed.

Integrating recycling and reuse into basin and irrigation management: Increasing attention is being paid to reuse as an integral part of water management. For example, farmers in Egypt and other countries place small pumps in drainage ditches to recycle water and the irrigation agency blends drainage water with freshwater to increase useable supplies. Millions of shallow tube wells that recycle water have been developed in the Indo-Gangetic plains, effectively capturing and using water before it flows out of the basin, and giving the ability to reliably and precisely apply the water to crops, thereby

enhancing yields. Many farmers in peri-urban settings rely on wastewater from cities for their crops. Irrigating with low quality water is often the only option for many farmers. Inherent in reuse strategies are pollution and health risks. The problem is that these are often individual or community initiatives often times ignored by water management bodies, leading to sub-optimal situations in terms of water quality degradation and water productivity.

Integrated natural resource management within basins: Within farms, irrigation systems, and river basins, livestock, fish, and forests all have important water needs and implications. Integrating aquaculture into irrigation or examining the tradeoffs between crop water use and water for fisheries is a means of providing more food and nutrition per unit of water. Water for livestock, essential for the healthy lives of rural poor, is a primary water concern of many poor countries. In Ethiopia, for example, livestock watering has much higher priority than crop agriculture. Trees and livestock play an important role in land and water interactions. Denuded landscapes can hasten runoff and sedimentation, detrimental to both upstream and downstream uses. Integrating these production systems within a basin management framework can greatly improve the nutrition and value derived from water resource use, while lessening adverse side-effects.

Policies, institutions and incentives: For any of these practices to work the right set of incentives is required for all the actors involved—a function of policies and institutions. One difficulty faced is that, as competition for water becomes more intense, how water is used in one part of a basin impinges on how it is used elsewhere in the basin. This requires that a set of laws, regulations and organizations be coordinated to match basin-wide water resources. A third area is that subsidies and pricing are often not conducive to increasing water productivity. Grain prices have fallen dramatically since the dam building era of the 1970s removing incentives for farmers to invest in improved practices. This is a topic of immense importance and complexity, but let it be said that we do not have ready-made solutions to change institutions for managing water in more productive ways. The search for such solutions should take precedence.

Increases in water productivity are necessary to solve many of the problems of the water crisis, but they are not sufficient. It is imperative that these be accompanied with a poverty focus to help the poor reap the gains of increases in water productivity. Attention needs to be given on establishing and maintaining access to water, affordable water productivity enhancing technologies and a voice in water decisions.

Whose responsibility is it? Increasing water productivity requires a coordinated set of actions from a range of people: resource managers; farmers, fishermen, and water managers; researchers from agronomy, water resources, irrigation, and natural resource management; and in fact all of us who care about influencing policies about how water is used.

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Rainwater Management: Strategies for Improving Water Availability and Productivity in Semi-arid and Arid Areas

N. Hatibu

Semi-arid and arid areas are home to one sixth of the world's population.[1] Most of these are poor agro-pastoralists who depend totally on the renewable natural resources for their livelihoods. The inhabitants of this region are among the poorest people in the world. This poverty is partly caused by inadequate availability of water for crop, livestock and other enterprises. However, the shortage of water is not caused by low rainfall as normally perceived but, rather by a lack of capacity for sustainable management and use of the available rainwater.[2] The most critical management challenge is how to deal with the poor distribution of rainwater leading to short periods of too much water and flooding, and long periods of too little water. The question is, "can better management of the available rainwater help to reduce the occurrence and mitigate the impact of droughts during period or in places with low rainfall?"

This paper reviews options available for improved utilization and management of rainwater resources available in semi-arid and arid areas. Subsequently the paper identifies outstanding challenges for widespread adoption of these options.

The Problem and Potential

Even in the "so called" dry regions, rainwater is often available in abundance during the rainy season. For example, the total renewable water resources in sub-Saharan Africa (SSA) are estimated to be about 4,000 km^3 per year. This is a lot of water, but most of it is not accessed and put into beneficial use before it evaporates or flows into saline sinks. The main reason is the practical difficulty posed by the nature of rainfall. The rain is very poorly distributed in both spatial and temporal terms. Often there is too much water during a few days of the year, while water supply is insufficient during most of the year. It is estimated that in most Semi Arid Tropics (SAT), the time when it is actually raining is in total about 100 hours per year, out of the 8,760 hours of the year.[3]

Climate variability is perhaps becoming worse due to climate change phenomena. Floods and droughts are among the major constraints to development. A study of 100 years of disaster records in Tanzania reveal that 38 percent of the disasters were caused by floods while 33 percent were related to drought.[4] The seriousness of the problem of alternating floods and droughts has recently been seen in Southern Africa, a region that suffered massive damages due to floods in 2000 and this year (2002) famine is looming due to drought. This is perhaps a result of the current approach to food security, which depends on self-sufficiency at the household level. Given this approach and due to water limitations, subsistence producers often give priority to minimizing risks and not increased productivity and profit. This is a strategic survival mechanism but it denies the people in these areas the capacity to build capital resources required to:

- invest in new technologies
- participate in the market economy
- protect oneself against extremes of climatic and economic downturns

The technologies, skills and capital resources required to overcome the poor and extreme distribution of water resources through storage and transfer, although well known, are not available and widely used. As a consequence there is critically low access to water for agriculture, drinking and sanitation, and the environment. Poor access to water is therefore among the leading factors hindering sustainable development in semi-arid and arid regions. Approaches to overcoming this problem include technologies for enhancing the productivity of water in rain-fed production, rainwater harvesting and precision irrigation.

Available Options

a) Enhance Rain-fed Production

Rain fed agriculture produces by far the highest proportion (over 60 percent) of food crops in the world. When animal grazing is counted the contribution of rain-fed agriculture to food and commodity production is very high indeed. In sub-Saharan Africa it is estimated that over 90 percent of agricultural production is rain fed. Yet, water resources planning for agriculture has largely neglected rain-fed agriculture. Yes, irrigation in sub-Saharan Africa has been tried, but only a limited amount of effort has been directed to up-grading rain fed agriculture through improved water use effectiveness.

Research has shown that in the SAT often only a small fraction of rainwater reach and remains in the root zone, long enough to be useful to the crops. It is estimated that in many farming systems, more than 70 percent of the direct rain falling on a crop-field is *lost* as non-productive evaporation or flows into sinks before it is used by plants. It is only In extreme cases that only 4-9 percent of rainwater is used for crop transpiration.[5] Therefore, in rain fed agriculture wastage of rainwater is a more common cause of low yields or complete crop failure than absolute shortage of cumulative seasonal rainfall. This fact is well known as demonstrated by experience in the USA. Adoption of improved water conservation technologies in the central Great Plains are said to have made the largest single contribution (45%) to increase in average wheat yields. This was significantly ahead of improved varieties (30%) and fertilizer practices (5%). [6] Furthermore, unreliable availability of water for plant growth is perhaps one of the reasons that the green revolution did not happen in sub-Saharan Africa.

The necessary technologies for overcoming loss of water in rain fed agriculture are the well known soil and water conservation (SWC) techniques. [7] The principle requirement is the improvement of infiltration, water holding capacity and water uptake by plants. For example, it has been shown that sub-soiling coupled with manure can lead to fourfold increase in yields of maize per unit of land in dry areas of Tanzania.[8] There are therefore win-win benefits of converting erosion-causing runoff into plant available soil-water, and non-productive evaporation to productive transpiration. The production of dry plant matter is often linearly correlated to seasonal transpiration, while the amount of available water taken up by plants is dependent on the extent to which roots are in contact with water. [9] However, in some areas, even capturing all the rainwater where it falls may not be enough. This may then call for rainwater harvesting.

b) Rainwater Harvesting

Rainwater harvesting is the process of collecting, concentrating and improving the productive use of rainwater and reducing unproductive depletion. This often involves collecting rainwater from a catchment area and channeling the runoff and using it to increase the water available in a relatively smaller growing area. In microcatchment systems, water is collected from land adjacent to the growing area, while with macro-catchment systems large flows are diverted and used directly or stored for supplementary irrigation.

Experience in Tanzania, for example, shows that farmers are aware that both crop and livestock production can be improved substantially through concentration of scarce rainwater as well as provision of supplementary water during critical times. This facilitates production/growing of high-water demanding crops. This strategy is manifested in the concept of *Mashamba ya Mbugani* (fields located at the bottom of landscape). Farmers grow high water demanding crops such as vegetables, rice and maize in the lower part of landscape. The aim is to exploit the natural concentration of rainwater and nutrients flowing into the valley bottoms from the surrounding high grounds in the landscape. [10] Furthermore, a survey of farmers' innovations in semi-arid areas of Tanzania, Kenya and Uganda, found that rain water harvesting innovations constituted 30 percent of the total, soil-nutrient management innovations (20%), and forestry innovations (4%). In total, water management innovations constituted 50 percent of the total. [11]

In the semi arid areas of Tanzania, the *mashamba ya mbugani* concept has been improved to facilitate the cultivation of paddy rice in the SAT. The technology involves the construction of water storage reservoirs to facilitate concentration of high volumes of water and storing it for a longer period. It is designed to capture and store rainwater where it falls with provisions for supply of extra water from external catchments. The cultivated reservoirs are constructed in relatively flat to medium slope terrain by building a bund of 0.3–0.7 m high, around the field perimeter. The environment that is created is only conducive for the growth of paddy rice. For this reason, farmers have changed from the cultivation of sorghum and millet, to rice.

This system is now widely used in nearly all the semi-arid areas of central Tanzania. The system accounts for over 70 percent of the area cultivated with rice and over 35 percent of the rice produced in Tanzania. It has enabled farmers to grow a marketable crop in dry areas, providing opportunity for poverty reduction.[12] Research has shown that Gross Margins obtained by a farmer improves significantly by adopting this technology. Paddy rice is now a SAT crop in Tanzania, as a result of improved management of rainwater.

There is a huge potential of wide adoption of the water concentration approach to many other SAT areas because in most of these areas long-term erosion and deposition has created very fertile areas at the bottom of the topo-sequences. These areas have great potential that is yet to be utilized. These include areas of Vertisols, which are estimated to cover some 55 million hectares in the semi arid areas of mainly Chad, the Sudan, Ethiopia, Kenya, Tanzania and 11 other countries in SSA.[13] Most Vertisols are inherently fertile due to their occurrence at the lower parts of the landscape where flood water and nutrients accumulate each season. They, however, remain largely un-utilized because they are difficult to manage. Therefore, sustainable utilization of Vertisols presents one of the leading technological challenges in the development of the SAT region. This requires improved control and management of the available water.

c) Precision Irrigation

The rainwater approaches described in the previous section are dominated by the classical approach of flooding the land to saturate of the entire field at particular intervals. This approach often leads to high losses of water to evaporation from the soil and water surface, leading to low productivity of water. Water productivity can be improved by introducing precision irrigation. [14] This involves the application of the required quantity of water, when it is required and in the root zone where it is required. This will include for example application of a small amount of water to overcome a stressful dry spell within the growing period. Technologies for achieving the necessary high levels of control are already available. One example, are micro-drip techniques for high frequency, low volume, partial-areas application of water and nutrients to crop fields. [15]

Precision irrigation overcomes the problems of unproductive depletion of water from the soil. By applying the water directly to the root zone, transpiration by plants is increased due to improved contact between water and roots while soil evaporation and deep percolation are reduced. This increases the productivity of water. Furthermore, improved control of the timing of application of water, makes it easy to implement supplementary irrigation strategically to overcome seasonal dry spells. Work by Oweis et al. [16] showed that water productivity in rain fed wheat production in Jordan can be increased from 0.33 kgm^{-3} to 3 kgm^{-3} by strategic supplementary irrigation.

Outstanding Challenge

One of the outstanding development challenges in the SAT region is wide adoption of the well known rainwater management practices, which have been briefly described in the previous section. Sustainable income and profitability is among the most important incentives for investing in any technology. Therefore, to improve effectiveness and profitable use of rainwater and other resources found in SAT areas, these two aspects should be emphasized. Furthermore, efforts should be directed at reducing risks and shocks in SAT areas. Improvement of the management of rainwater has a vital role in the reduction of livelihood and enterprise risks caused by climate variability.

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Sustaining Asia's Groundwater Boom: An Overview of Issues and Evidence

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(This paper was prepared with assistance from Aditi Deb Roy, Asad Qureshi and Jinxia Wang)

"*Groundwater will be an enduring gauge of this generation's intelligence in water and land management*".[1] Nowhere will this generation's intelligence be put to a harder test than in Asia, which uses some 500 m^3 of the total 750 m^3 of groundwater the world uses for agriculture. Although Africa's groundwater reserves are modest, it uses only a small fraction of its groundwater resources. The US, Australia and Europe use groundwater considerably, though largely for municipal and industrial uses. So, though they too face the challenge of balancing demand and availability, their challenge is very different from that faced by Asia.

Between 1970 and 1995, the rapid growth of groundwater irrigation in South Asia and the North China plains was at the heart of an agrarian boom. This placed Asia's groundwater socio-ecology under siege. Groundwater depletion, pollution and water quality deterioration now cause concerns that are fueled by worries about their environmental consequences. However, equally important concerns are raised by the fact that agrarian economies and millions of rural livelihoods now depend upon groundwater irrigation.

India, Pakistan, Bangladesh and China account for the bulk of the world's groundwater use in agriculture. This is because, whilst much public investment was devoted to surface irrigation, the bulk of Asia's agrarian growth between 1970 and 1995 was energized by a rapid rise in the use of small pumps and wells to access groundwater. These were, mainly, financed by the farmers themselves (see box 1). A new analysis of Indian agriculture suggests that, in recent decades, the contribution groundwater irrigation makes to the productivity of a 'representative' (typical) net sown hectare, has grown to nearly twice the contribution of surface irrigation (see box 2). In many areas, groundwater development and use reflect people's needs and demands (i.e. population density) rather than the presence of large groundwater resources (box 3). Moreover, groundwater has proved more amenable to poverty-targeting than large surface irrigation systems; governments can't build large canal systems exclusively for the poorer sections of society, but they can design pump subsidies or build public tubewells. Thus, on the plus side, groundwater development has done more to alleviate water-deprivation than public irrigation projects have. But, on the downside, it has created chronic problems in terms of resource depletion and quality deterioration. With the economic value of groundwater use estimated at some US$10 billion annually, the groundwater economy of South Asia and China is the backbone of these regions' increasingly productive agricultural and rural livelihood systems.

Box 1. Why does groundwater account for 60 percent of India's irrigation?

It is important to realize that groundwater development has had an 'equalizing' influence, which is one reason governments in low-income countries now aggressively support it. While access to canal irrigation is limited to those individuals located in command areas, access to groundwater irrigation is more egalitarian. A 1995 Government of India census showed that ownership of manual lift irrigation devices, followed by diesel pumps and electric pumps, is far less biased than the ownership of farmland. Moreover, as the chart below suggests, unlike large irrigation projects, groundwater infrastructure is predominantly farmer-financed.

Source: Tushaar Shah and Aditi Debroy. 2002. *Major Insights from India's Second Minor Census*, Anand: IWMI-Tata Water Policy Research Program (forthcoming).

The Challenge of the Balance

Throughout Asia, the number of regions that have a sustainable groundwater balance is shrinking by the day. Three problems dominate groundwater use: (1) *depletion* due to overdraft; (2) waterlogging and *salinization* due, mostly, to inadequate drainage and insufficient conjunctive use, and (3) *pollution* due to agricultural, industrial and other human activities.

Groundwater depletion, therefore, has both major environmental consequences and important economic consequences. Declining water tables raise the energy and capital costs of accessing groundwater to prohibitive levels.

Box 2. Groundwater irrigation is big business in India, Pakistan and China.

The market value of groundwater used in India, Pakistan Punjab and north China is estimated to be around US$10 billion per year, allowing agricultural outputs with a value of US$40-60 billion per year. In such poor agrarian economies, this makes groundwater irrigation big business.

However, groundwater irrigation in many parts of Asia is unsustainable. This suggests that Asia is in deep trouble in terms of its groundwater use. But attempts to arrest or reverse this trend, by regulating groundwater use, would be greatly resisted by farmers. So, protecting and managing groundwater brings Asia face-to-face with the most difficult trade off, the one between livelihoods and sustainability.

Source: Debroy, Aditi and Tushaar Shah. 2002. *Socio-ecology of Groundwater Irrigation in India*, Anand, India: IWMI-Tata Water Policy Program.

Box 3. Population pressure, not resource availability determines intensive groundwater use in agriculture.

It has long been commonly believed that tubewell development is (1) concentrated where surface water is plentiful, i.e. in canal commands, and (2) a response to the failure of canal systems to provide farmers with an on-demand irrigation service. It is also thought that, by promoting the use of surface and groundwater in conjunction, private tubewell development improves overall efficiency of large irrigation systems.

However, recent IWMI research suggests that tubewell density actually reflects population density and pressure on land. Tubewell density in the Pakistan Punjab, for example, is highest in the most densely populated districts. Similarly, tubewell density is high throughout the Ganga basin in India, which has high groundwater availability and a very high population density. However, it is also high in many other parts of India (such as Tamilnadu) where groundwater is limited and population densities are high. Elsewhere, in sparsely populated areas of central India, tubewell density is low despite of resource availability. China also exhibits a similar pattern. So, unlike large public irrigation projects, which are driven by hydrologic opportunity, groundwater development is democratic, providing irrigation wherever people are.

Source:

1. Shah, Tushaar, Aditi Debroy, Asad Qureshi and Jinxia Wang. 2001. *Sustaining Asia's Groundwater Boom: Overview of Issues and Evidence*, IWMI Contribution to Bonn conference on Freshwater, December 2001.
2. Shah Tushaar and Aditi Debroy. 2002. Major *Insights from India's 2nd Minor Irrigation Census*, Anand, India: IWMI-Tata Water Policy Program.

In some regions, such as North Gujarat or Baluchistan, entire agrarian economies face extinction because of the decline of their groundwater socio-ecologies. Water quality and health problems—such as very high fluoride and arsenic contents—have similarly negative social impacts in South Asia and China. In region after region, the pathology of the decline in groundwater socio-ecology reflects a four-stage pattern. This pattern underpins the typical progression of a socio-ecology, from the stage at which use of a previously unutilized groundwater resource unleashes an agrarian boom to the stage at which, unable to apply brakes in time, users overexploit the groundwater. But does it always have to be this way? If used early, could adaptive policies and management responses generate a steady-state equilibrium, sustaining the groundwater-induced agrarian boom without degrading the resource itself? More pertinently, what might be done to sustain groundwater socio-ecologies under threat and keep them from collapsing?

A variety of techno-institutional approaches have been tried in order to improve the balance between groundwater use and safe yield. Some have worked, but mostly in the industrialized world where the costs of regulating groundwater extraction, in terms of the livelihoods of large groups of poor people, are insignificant. Attempts to apply such lessons uncritically to the Asian context are destined to fail because, for the next few decades, the major concerns of policy makers in these countries will be to enhance livelihoods in poor households dependent on agriculture.

Evolving Practical Approaches

In countries like the US and Australia, the presence of a small number of large users and a low population density create uniquely favorable conditions in which some institutional approaches can work; but these break down in Asia, with its high population density and multitude of tiny users. For instance, a stringent groundwater law is enforced in Australia, but this would come unstuck in Asia because of prohibitive enforcement costs. Europe has a high population density; but it is much more comfortable than Asia in terms of its overall water balance. Moreover, Europe's high level of economic evolution means it can apply huge technological and financial muscle power when managing its natural resources. South Asia and north China cannot do this. What the Netherlands spends per capita on managing its groundwater is five times the total per capita income of rural North Gujarat. So, while direct resource management is ideal, in Asia, strategies of indirect management (such as economic incentives and disincentives for groundwater use) might work best. Many observers believe that South Asia uses a lot more groundwater than it should because of the presence of perverse incentives. But others also believe that, where groundwater tables are steadily declining, the soaring energy costs of pumping will catch up with and counter the incentives for groundwater use. Management of economic incentives may well offer a powerful approach for influencing the behaviour of millions of individual groundwater users.

Where overuse of groundwater has become a life-threatening problem, there are signs that people and local institutions are shaking off their generally passive attitude of dependency, and are taking charge of the resource. The western Indian states of Rajasthan and Gujarat, which depend on the over-exploitation of groundwater to sustain their agriculture, offer examples of this trend. However, even they place little accent on rule-making and demand management. Instead, great mobilization has occurred in terms of rainwater harvesting and groundwater recharge in a decentralized format.

Scholars have suggested that the first step to resource management under stress is to establish secure property rights over groundwater. As Andrei Shleifer recently showed, this entails attacking two problems: inefficient structures of control rights over the resource (open access in the case of groundwater), and poor contract enforcement. This is easier said than done anywhere in the world, but is particularly difficult in developing Asia.

All in all, we need a more refined understanding of the peculiarities of Asia's groundwater socio-ecology and a suitable resource management approach. In much of Asia, modern groundwater development has been chaotic and unregulated, being shaped by millions of tiny private users. Now, in many parts of Asia where groundwater is under the worst threat of depletion (such as Western India, Baluchistan and North China) there is an equally chaotic and unregulated growing groundswell of popular action that uses rainwater harvesting and local groundwater recharge. At the frontline of this movement are regions like Rajasthan and Gujarat in India, where untold havoc and misery are certain outcomes if the groundwater bubble were to burst. Here, rather than waiting for governments and high science to come to their rescue, ordinary people, communities, NGOs and religious movements have made groundwater recharge everybody's business. Many scientists and technocrats feel lukewarm, even skeptical, about these activities; but the chances are that herein lie the seeds of new institutions for the decentralized local management of a natural resource. People in Asia have long treated water like manna from Heaven, and have seen no need to manage it. Now that they have begun to 'produce' water, we find the first inklings of community efforts to manage it.

Photo: IRRI

Managing Water for Fisheries and Aquaculture

Patrick Dugan

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For the people of Africa, Asia and Latin America the fisheries of inland lakes, rivers and other freshwater ecosystems provide an important source of food and income, and for many these are the principal source of animal protein. In sub-Saharan Africa the larger floodplains of the inner delta of the Niger, the Sudd of the Nile, and the lake Chad basin, each yield up to 100,000 tons per year and provide income of some US$20-25 million in each area.[1] In South-East Asia the annual catch in the lower Mekong is conservatively estimated at 1.6-1.8 million tons with a retail value of US$1.4 billion.[2]

Official statistics indicate that the combined harvest from these extensive wetland systems as well as many smaller systems, currently exceeds 8 million tons annually[3], while informed estimates suggest that the true figure could be closer to 16 million tons. In Asia the value of inland capture fisheries is exceeded by production from freshwater aquaculture, although this is not the case in Africa and Latin America. Globally some 18 million tons is produced from freshwater aquaculture annually.[4]

This brief analysis highlights the considerable contribution of aquaculture and fisheries to the food produced from the world's freshwaters. Yet for much of the past 50 years neither the overall value of these resources, nor the key role that they play in providing income and nutrition to resource poor households has been well recognised, and in many areas continues to be ignored today. As a result the dominant approach to improving water productivity in agriculture has judged the value of fisheries and other non-crop benefits to be marginal compared to the benefits to be obtained from irrigated agriculture.

Today however as the constraints to irrigated agriculture have become more widely recognised, and understanding of the value of natural ecosystems has increased, much greater attention is being given to freshwater fisheries and ways through which its contribution to poverty alleviation and food security can be enhanced. In support of this more holistic approach to water management in agriculture, future policies and management approaches will need to be supported by improved understanding in four major areas: resource valuation; water requirements; policies, institutions and governance; and water productivity. The present paper highlights some of the priority requirements in each of these areas. A fuller discussion is provided in Dugan et al.[5] from which the present review is drawn.

The Value of the Resource

Growing concern for improved management of freshwater fisheries has been driven by the increased recognition of their role in supporting rural and urban livelihoods, and in providing an affordable source of high quality protein.[6] However, for this concern to lead to the development and effective application of improved policies and management practices further, and more site specific, information needs to be provided. In particular the use of fisheries by different communities, their contribution to sustaining and enhancing livelihoods, reducing poverty and improving food security, and the potential cost to society of the impacts that result from the degradation of freshwater ecosystems, all need to be documented for priority river systems. In turn, this information needs to be made available to all stakeholders as a means of fostering informed debate about management of these resources and of the water resources that sustain them. Greater capacity to effect such analyses needs to be developed wherever such information will assist in improving governance and the quality of decision-making about water use and its impact on fisheries.

Water Requirements

The productivity and value of freshwater fisheries is highly dependent upon the quantity and quality of the water supply. River fisheries are particularly vulnerable to changes in flooding regime, as indeed are many estuarine and inshore fisheries which are dependent on inflow of freshwater and nutrients from rivers. For most tropical river systems fish harvest, and benefits to people are generally lower in years of low river flow and when flow is altered by dams or water abstraction for irrigated agriculture. [7]

The World Water Vision, the Dialogue on Water, Food, and Environment and the World Commission on Dams (WCD), have all recognised the importance of providing water to meet these and other in-stream requirements. However, if the awareness and policy frameworks generated by these and other international initiatives is to yield sustained benefits for poor communities dependent on aquatic ecosystems they must be supported by information of high quality. Of particular importance is the need for accurate information on the flow regimes required to sustain tropical fisheries. Practical tools that can generate such information in a timely and useful manner need to be developed.

Policies, Institutions and Governance

Efforts to improve understanding of the value of inland fisheries and their water requirements will lead to little long term improvement in the lives of rural and urban poor unless they are derived from and designed to support improved policies, institutions and governance arrangements for the management of these resources and the water upon which they depend. A sustained investment in improving policies, institutions and governance is therefore a prerequisite for improving the contribution of freshwater fisheries to improving livelihoods and food security.

Efforts to address this need can build upon the wider efforts being made in many countries to develop more efficient policies and governance regimes for natural resources, most noticeably of fisheries, forests and wildlife. This is particularly so in light of the processes of decentralisation that are currently being pursued in many countries. [8] However, there is a wide gulf between recognition of the need for change and identification of the specific actions that need to be taken. In many developing countries, policy-making and implementation systems for aquatic ecosystems and their resources are not clearly understood. There is, therefore, an urgent need to better understand these policy making processes as a basis for improved governance of these resources.

Improving Water Productivity

Water productivity can be increased by integrating fish and other living aquatic resources into existing farming systems at several organisational scales. At the scale of individual farms some examples of recent developments include: (i) the raised-bed farming of vegetables and fruits between a pattern of trenches used for irrigation and cultivation of fish and freshwater prawns in lowland areas of Thailand and southern Vietnam; (ii) the intensive reuse of off-farm and on-farm manures for vegetable and fish production in northern Vietnam (VAC system); and (iii) the intensified use of wetland areas (dambos) around seasonal or perennial streams for crops and increasingly for fish production in Malawi, the latter also providing for food security through the possibility of vegetable cultivation in empty ponds in drought situations, utilizing residual moisture. In places where natural aquatic ecosystems have been degraded this integration is especially important, providing protein and other benefits that were once provided by natural systems. By becoming water managers and growers of fish and other living aquatic resources on their farms, farmers can move from being part-time fish hunters to being part-time fish farmers.

Opportunities for shared water use at a larger scale include irrigation schemes and seasonal floodplains. For most irrigation schemes the primary purpose for their design and establishment has been the production of agricultural crops. However opportunities exist for fish production within the controlled waters of such schemes. These are in the water reservoir itself (usually not managed for optimal fish production), the supply canals, ponds located within the scheme area, and small trenches and pits within rice fields for combined fish-in-rice culture. In canals with constant water flow (i.e. not pulse-operated) opportunities exist for fish production in canal segments or fenced-off partitions or in net cages.

A different situation exists in which flood prone ecosystems can be used for additional fish production, thereby making use of this unutilized and free water resource. In these ecosystems where seasonal floods cover lands used for crop cultivation in the dry season, the opportunity exists to fence-in large areas (up to several hectares) by creating enclosed water bodies and stocking these with fish. In this case the communities who usually access and utilize these lands and waters can form community management groups that jointly decide on management and share of benefits, based on agreed rules. Recent work in Bangladesh and Vietnam has shown that besides the natural fish production of 200 kg/ha per 6 month flood period, an additional production of up to 1000 kg/ha per 6 months of stocked fish can be achieved. The arrangements involved landholders and landless, who received shares of the returns based on their contributions to management and upkeep. The landless, who were seasonal fishers in the area, had income gains from their labor and additionally were able to conduct fishing for indigenous non-stocked fish and thereby meet their family nutritional and income requirements during this period.

These examples highlight the benefits that can be obtained by integrating fish production into crop farming systems. However, the approaches developed have been carefully tailored to the specific biological, hydrological, social, economic, and institutional conditions prevailing at each location. Thus, while there is great scope to replicate this success in a wide range of situations elsewhere, attempts to do so will need to be based upon a similarly rigorous understanding of the conditions prevailing at each site and pursuit of an adaptive learning approach to integrating fish production into each farming system.

Conclusion

As the demand for water increases the full economic and social value of freshwater fisheries and the potential of aquaculture need to be recognised and managed as an integral part of efforts to enhance water productivity, improve food security, and sustain rural livelihoods. More effective engagement of stakeholders in river, floodplain, lake and reservoir fisheries through decentralized management institutions will be required to achieve this, while investments to foster aquaculture as a component of water efficient farming systems will need to be rooted in a sound understanding of the specific biological, hydrological, social, economic and institutional constraints and opportunities provided by each location.

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Challenges and Prospects: Agricultural Water Management from a River Basin Perspective

F. N. Gichuki

Because of the diverse socio-economic and biophysical factors that affect water supply and demand, a river basin perspective is necessary for the effective management of water in agriculture. Relevant challenges and prospects are considered below, following a brief description of the issues facing river basins, and of their main characteristics.

Basin Characteristics and Implications for Agricultural Water Management

Main Characteristics

Nine major characteristics of river basins are relevant to this discussion. By considering each in turn, it is possible to gain a better understanding of the implications each has for agricultural water management.

High spatial variability of land resources: In most basins, the amount of land suited to rainfed agriculture is limited and, in some cases, is covered with natural and plantation forests or by urban developments. Generally, there is a mismatch between land suitability and land use and between good quality land and water availability. Meticulous land and water use planning are required to balance the multiple objectives of equity, employment creation, sustainability, cost minimization, maximization of returns and high productivity per unit area and per unit of water.

High spatial and temporal variability of water resources: Rainfall can be highly variable and unpredictable. Consequently, water availability in river basins can vary, creating areas and periods of extreme shortage and excess and, therefore, a need for water storage and/or conveyance works to match supply with demand.

Multiple uses of water resources: Water is used in both homes and industry. It is used for crop, livestock and fish production, for navigation and recreation, and for sustaining ecosystem processes. Such uses require that different quantities and qualities of water be available at different locations and times. As demand increases—and supply is reduced by drought, over-use or pollution—competition for water increases. Competition can lead to conflicts, which cause adverse environmental, social and economic impacts. Agriculture accounts for most water use (60-80% of surface and groundwater withdrawal) and, as scarcity increases, will be expected to use less. So, water productivity in agriculture needs to be increased, by reducing storage, transmission and application losses and by increasing yield per unit of water transpired (more crop per drop).

Many managers and institutions: At a river basin scale, water is managed by many managers operating at different scales, in different locations and at different times. These managers have diverse goals, competencies and capacities. Similarly, water management issues are tackled by different government and non-governmental organizations, and by formal and informal organizations that have different mandates and capabilities. This can cause conflicts of interests. Cooperation is a pre-requisite for attaining win-win outcomes. Upstream irrigators should cooperate with downstream water users to ensure fair allocation and to meet minimum streamflow and water quality requirements.

High diversity of stakeholders: Water stakeholders in a river basin are many and diverse, in terms of gender, wealth, culture, ethnicity and power. Asymmetric power-relations may be caused by economic, political and/or hydrological factors, and may result in inequitable water allocation and/or restricted access, thereby leading to water conflicts.

Technically complex: The many components, processes and interrelationships of river basins make it difficult to foresee the effect of specific measures. This fact is complicated by a multitude of water resource development options and by the un-coordinated efforts of various actors. The same combination of interventions may have different outcomes in different ecological settings. Hence the need for an improved understanding of these processes, interrelationships and impacts in different settings, and for site-specific water management interventions.

Phases of basin development: Typically, river basin development involves three phases, each with different implications for agricultural water management. In the development phase, increases in demand are met by the development of abstraction, storage and delivery infrastructures. During the utilization phase, no significant new water resource development is feasible; the goal is to make the most of available water resources through water savings. The allocation phase begins when water depletion approaches available water limits; managing demand is critical; efforts are made to increase the productivity, or value, of every drop of water. Competition for water increases, and water is reallocated from "lower value" uses (agriculture) to "higher value" domestic and industrial uses. Hence, there is a need to manage agricultural water more efficiently.

River basins as sources and sinks of salts: River salinity increases, from source to outlet, as salts, derived from weathering, the dissolution of salts in rocks and/or soils, irrigation water and fertilizers, are transported by water into the surface or groundwater systems. For example, the Nile's salinity varies from 50 mg l^{-1} at Lake Victoria, to 350 mg l^{-1} at the apex of the Nile Delta to 1000 mg l^{-1} at its outflow into the Mediterranean Sea.[1] Where irrigation water percolates below the root zone, leading to saline groundwater rising into the root zone, land salinization occurs. Waterlogging and salinization lower the productivity of both land and water resources, as extra water has to be used to leach the salts; crop yields fall almost linearly with increasing salinity.

Links with coastal areas: Coasts and river basins are linked through hydrological and socio-economic processes. The quantity and quality of water flowing into the oceans is determined mainly by land and water management activities in the river basin. Coastal ecologies and human activities can be influenced positively by favorable flow regimes and by the provision of food and energy, and negatively by the degradation of the ecosystem and its economic base. Since agriculture is the main water user and polluter, agricultural water management has a major influence on such outcomes.

Implications for agricultural water management

Rainwater, in its journey to the terminal water body from which it will evaporate, flows through different landscapes and territories, and crosses political, social and economic boundaries. As it flows, it picks up or deposits pollutants and changes in volume (through abstraction or inflow), all of which may cause problems along the water's path.

Competition and conflicts result from different people having different water requirements (in terms of both quantity and quality), and occur between upstream and downstream users and uses. They are most easily solved at a river basin level, as analyzing agricultural water management at a farm or irrigation project level may fail to identify the impacts agricultural water use has on other water uses and on ecosystems in the basin. Furthermore, it may fail to identify the impacts that other water uses and ecosystem processes have on agricultural water and its use. Analyzing agricultural water management within a river basin perspective, therefore facilitates:

1. The integration of different water sources (rainfall, surface water, groundwater and wastewater) and uses (rural and urban domestic use; use in industry, power generation, and crop and fisheries production; use by livestock and wildlife, and use for sustaining ecological processes)
2. The integrated planning of land and water use with that of agricultural sub-sectors (crop, livestock, fish and tree production), taking into consideration ecological, hydrological, demographic, sociological and economic aspects
3. The integration of upstream and downstream activities and their effect on the quantity and quality of water resources and trans-boundary uses

4. The integration of ideas, from different disciplines and of different resource managers, through the establishment of river basin forums that bring stakeholders together to jointly discuss problems, set goals and define solutions for the river basin. These forums assure a high level of stakeholder involvement and better cooperation between the actors in designing and implementing goals for the river basin

Challenges in Agricultural Water Management

As agricultural activities increase in a river basin, both the effects that agricultural water use has on other water uses, and the effects that other water uses have on agricultural water use, become more evident. In fact, the challenges associated with agricultural water management can be divided into four main areas.

1. Protecting water catchments: Past efforts to increase food production (through land use intensification and the conversion of forest, wetlands and marginal grazing lands into cropland) have threatened the environmental security of the areas in which they were applied. Concrete examples of such environmental damage include the environmental degradation of the Ethiopian Highlands, the salinization of irrigated lands in Egypt and the desertification of extensive semi-arid areas as a result of over-grazing. So, the challenge is to discover how our water catchment areas could be managed to minimize such negative impacts.
2. Enhancing food security with less water: Between 1961 and 2000, the percentage of Africa's population that mainly depend on agriculture decreased, from 78 to 56 percent.[2] However, the number of people without a secure food supply continues to rise. In developing countries, incidences of chronic under-nutrition decreased from 941 million, in 1969, to 637 million, in 1988. However, in Sub-Saharan Africa, it rose from 94 million to 175 million during the same period and is projected to rise to 296 million.[3] Environmentalists are challenging the notion that future increases in agricultural production should come from increased agricultural water use. Therefore, our challenge is to discover how agricultural water resources could be managed in order to achieve both environmental and food security.
3. Sustaining and/or enhancing minimum stream flows (low and flood flows) and water quality for downstream users and uses: Basin water resources are recharged by rainfall. However, if river water abstraction exceeds the recharge rate, river flows decline and the duration of low flows increases. For example, the dry season flows of

the Ewaso Ngiro North River at Archer's Post, Kenya, have significantly decreased over the last 40 years. The mean 10 year flow for the driest month, February, dropped from 9 $m^3 s^{-1}$ in the 1960s, to 4.59 $m^3 s^{-1}$ in the 1970s, to 1.29 $m^3 s^{-1}$ in the 1980s, to 0.99 $m^3 s^{-1}$ in the 1990s.[4] The number of days with a mean flow of less than 1 $m^3 s^{-1}$ illustrates the trend. Low flows have adverse environmental, social and economic impacts. Such adverse environmental impacts include modification of riparian and aquatic habitats, depletion of fish stocks and species diversity, reduced groundwater recharge and, in some cases, saltwater intrusion. Socioeconomic impacts include financial losses, reduced employment opportunities and increased incidences of conflicts between uses and users. Since agriculture is the main user and polluter of water, our challenge is to find ways to reduce such negative impacts of agricultural water use.

4. Managing water use conflicts: As demand water increases, competition increases and, in some places, escalates into violent confrontation. Water conflicts in the Nile basin center around securing water that is needed to irrigate the arid lands of Egypt and Sudan, and the semi-arid areas of the upstream riparian states. Such conflicts will continue unless ways can be found to reduce water use in agriculture and to resolve water use conflicts. A prerequisite for conflict management is cooperation. Yet, co-operation among parties competing for the same resource is not easy to achieve. Fortunately, normal weather cycles create opportunities for cooperation, when negative impacts on the affected parties are minimal. And, in some cases, water conflict can trigger initiatives that aim to manage water better and enhance cooperation and partnership. Our challenge is to develop methods of better agricultural water management that reduce conflict.

Prospects for Agricultural Water Management

Most trends in agricultural water management are unsustainable. The future calls for the integrated management of the following major aspects of water: water availability (use of rainfall, runoff and groundwater), water quality, water infrastructure (i.e. diversion canals, reservoirs, wells, treatment plants) and regulations pertaining to water, such as water rights, priority uses and quality standards. Economic considerations, such as supply costs, environmental costs and economic values, should also be included in this approach, as should the demand for water (for domestic and industrial uses, for irrigation, hydropower, navigation, recreation, inter-basin transfer and ecosystems).

The aim of integrated river basin management is to ensure that the multiple functions and uses of the basin can be sustained, human needs can be met and essential ecological and physical processes can be protected. This calls for three things:

1. Effective institutions that provide a policy, legal and organizational framework for the fair sharing of resources, for property rights (including water rights), and effective participation, partnerships and cooperation of stakeholders, as well as conflict avoidance and management. The organizations should also prepare realistic basin-wide plans, based on the best available knowledge and with sufficient political support and financial means for their implementation. Implementation should be supported by effective monitoring and evaluation of the performance of the development projects and of the environment. Since the management of water is intended to prevent disputes between users, it is a political responsibility that requires full consultation and participation.
2. Enhanced socio-economic status of the basin inhabitants, through complementary programmes that contribute to poverty alleviation, better health, reduced conflict and people's capacity to make better use of production resources.
3. Effective technical interventions to enhance resource use efficiency and conservation.

Achieving the above requires a strong and credible knowledge base, and appropriate technologies and management tools. Also essential are suitable governance mechanisms, effective stakeholder participation, transparency, adequate administrative capacity, effective policies and political will.

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Agriculture: Re-adaptation to the Environment

Annette Huber-Lee and Eric Kemp-Benedict

Agricultural Impact on Natural Ecosystems

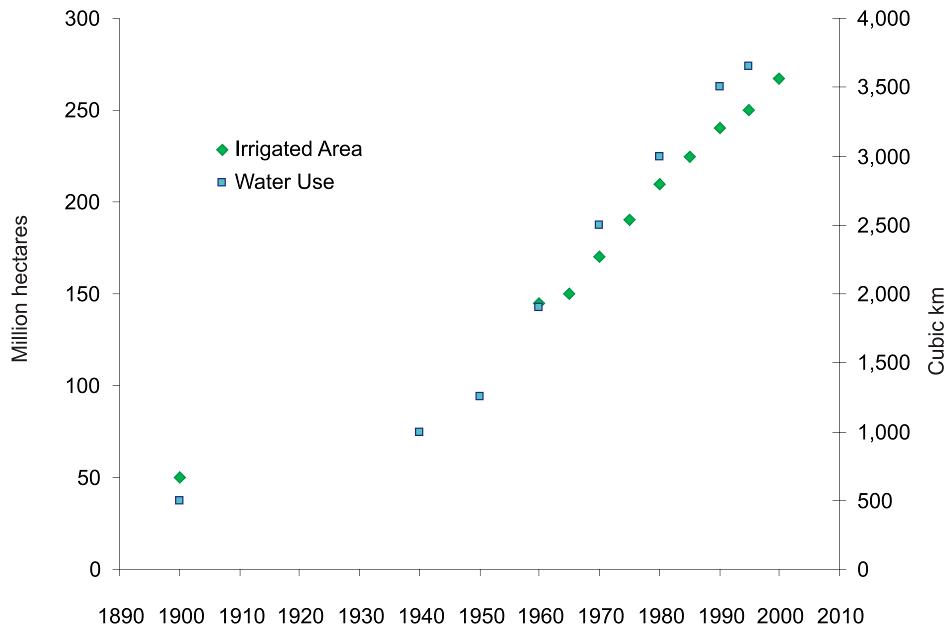
Agriculture—since its beginnings approximately 10,000 years ago—has significantly modified natural ecosystems in order to yield adequate and permanent staple food supplies for human populations. In creating artificial ecosystems, agriculture inherently interacts closely with pre-existing environmental conditions. Hydrology, soils, climate, topography and biology all have a major influence over the productivity and profitability of agriculture. Traditional agriculture has worked with these inter-relationships with the environment by adapting in ways that coordinate with local ecology. As early as 200 BC, Roman farmers were aware of methods to manage soil fertility. For example, Cato the Censor advised that land should be allowed to lie fallow for a year, as well as planting various legumes "not so much for the immediate return as with a view to the year later".[1] The Romans were not alone in the observation of lost soil fertility. In the same period, Chinese were using "green manure," a legume crop plowed into the ground before the next planting.[2]

While the recognition of the relationship between agriculture and the environment is longstanding, concern continues to heighten over increasing agricultural pressures on the environment. This is particularly true for aquatic and riparian habitats, as well as wetland ecosystems. Irrigated agriculture underwent exponential growth over the past half century—from 50 million hectares globally in 1900 to 267 million hectares in 2000.[3] As seen in figure 1, water use—dominated by irrigation—saw a parallel rate of growth. The marked increase in irrigated area from the 1960's through the 1980's can be largely attributed to the massive efforts of the Green Revolution, which rested on the modernist assumption that technological innovation alone could solve the problem of adequate food supply. By breeding better varieties of staple cereals, combined with improved access to fertilizers, pesticides and irrigation, annual increases in food production more than kept pace with increases in population.[4] For example, the average annual growth in rice production for Asia increased from 2.1 percent per annum during the period 1955-65 to 2.9 percent per annum during 1965-1980, surpassing the annual population growth rate of 2.3 percent.[5] As a consequence, hunger as a percentage of the population fell dramatically, from 35 percent of the developing world in 1970 to 20 percent in 1991, despite an almost 60 percent increase in population. [6] The increases also allowed many countries to become self-sufficient in production of food staples. Nevertheless, self-sufficiency as measured by trade only reflects the needs of those with the wherewithal to buy food. Hunger is still widespread, with over 800 million people suffering from chronic undernutrition today. [7]

Impressive as the Green Revolution gains in agricultural productivity were, they nevertheless came with a high environmental price in the form of increased pollution and depletion of water resources, primarily due to the effects of the package of inputs required by the green revolution plants: pesticide and synthetic fertilizers, as well as consistent watering, achieved in nearly all cases through large irrigation projects.[8] The resulting cascade of impacts includes compromised human health, declines in wildlife populations and biodiversity, dislocation of human populations, inundation of cultural sites, and loss of productive land. [9] Many of these impacts were not immediately evident, but have developed as widespread "slow-motion" crises.

Intensive agriculture has often been enabled by major public support for the overexploitation of water resources, and its consequences have been severe. In the United States, the State of California constructed the largest irrigation project in the western hemisphere. While giving the state one of the richest agricultural areas in the world, California's aquatic ecosystems and wildlife populations have been decimated,[10] and flows that had supported a rich estuarine delta system in the state of Baja California in Mexico only reach the system now in infrequent flood events.

Figure 1. Global irrigated area and annual water use.

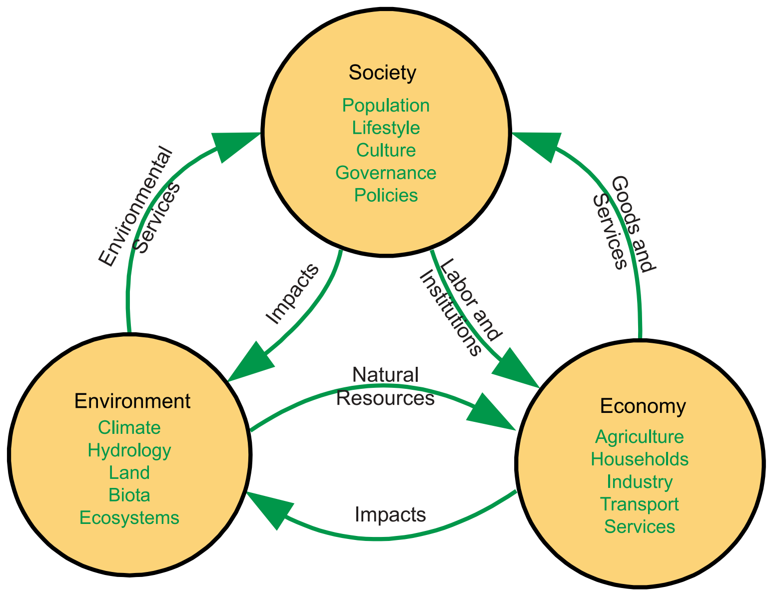


As a result, over 90 percent of the delta has disappeared.[11] Between 1980 and 1995, Saudi Arabia consumed 75 percent of the proven reserves of fossil groundwater in its major aquifers to irrigate wheat crops,[12] which will take hundreds if not thousands of years to restore. Groundwater overdraft in India, encouraged by energy subsidies for pumping water, now threatens the ability of India to be self-sufficient in food.[13] Perhaps most dramatically, irrigated cotton production in Central Asia has diverted so much water from the Amu Darya and Syr Darya rivers that they no longer reach the Aral Sea. With the sinking of the sea and extinction of endemic species of fish, a 44,000 ton fishing industry that supported 60,000 jobs in the 1950's has completely ceased.[14] Entire fishing villages have been abandoned due to contamination by salt and pesticide residues of the dry, windswept bed of the former Aral Sea, and as their source of livelihood vanished. The consequences of these vast projects are likely irreversible—certainly the extinction of species cannot be reversed and the public health damages cannot be undone. The link between human lack of awareness of natural systems, political short-sightedness and adverse environmental, social and economic impacts could not be more apparent.

How might these kinds of large scale errors and failures have been avoided? Although the history of the Green Revolution was well known by the time Gordon Conway documented it in 1997, Conway, now President of the Ford Foundation, chose to do so "…as a reminder of the power and limitations of innovative technology, and the crucial importance to its success of the economic, social and institutional environment within which it has to operate." To the economic, social and institutional environments, Conway also adds the natural environment in his book *The Doubly Green Revolution* (1997).

We believe all of these elements are required if we are to realize sustainable agriculture, with special emphasis on the importance on the underlying natural resource base and ecological systems. These elements of sustainable development – social, economic, and ecological—are depicted in figure 2. [15] Sustainable societies rest on the strength of these three pillars, each dependent on the others. Neglect of these interdependencies leads to development failures, including continued hunger, lost livelihoods and ecosystem destruction.

Figure 2. Elements of sustainability (adapted from Gallopín and Raskin 2002).



Re-adaptation

Since the early 1990's, agriculturalists and development specialists increasingly recognize the importance of a tripartite, integrated approach to agricultural development, with important efforts to design new policies and programs with long-term sustainability in mind. The 1980's saw increasing recognition of the interrelated nature of a number of different issues in both industrialized and developing countries. These were given a coherent voice in the report of the Brundtland commission, *Our Common Future*,[16] the report that introduced to the policy world the notion of *sustainable development*. In 1992, the international understanding was codified in Agenda 21 (1992). That same year, responding to increasingly obvious problems with water—for both ecosystems and people—the Dublin Principles were set forth by the Dublin International Conference on Water and the Environment (1992). Consistent with these changes, agricultural policy and research institutions began to change. In one notable shift, at the turn of the 1990s, the CGIAR changed its mission statement to include "sustainable improvements in the productivity of agriculture, forestry and fisheries," in order to "enhance nutrition and well-being, especially of low-income people." Organizations such as the FAO, the EU, the United States Department of Agriculture and the World Bank now promote sustainable agriculture in their publications. The idea of learning to re-adapt to better accommodate ecosystems is in the air, and methodologies are being developed on the ground. A key statement of the new approach is found in Conway's *The Doubly Green Revolution*. The "doubly green" revolution is "green" in two senses, the original sense of the Green Revolution as the green of plants in the field, and the word "green" as interpreted to mean having an environmentally-sensitive focus.

It would be easy to despair of a policy of re-adaptation, given the current degraded state of many agricultural and natural lands. However, we have learned that some ecosystems are resilient and may be restored if sufficient resources and knowledge are applied. For example, the new sustainable management regimes for agriculture, forests and wildlife on arid or semi-arid lands are resulting in rapid recovery of these systems in Africa. Globally, coastal resource systems also respond to management for sustainability, involving cooperation among tourism, fishing and community interests.

A recent trend in North America and elsewhere is to decommission dams that caused serious ecological damage in the past. In North America, nearly 500 dams have been removed to restore natural river flows.[17] Fish population recovery on some of these rivers has been dramatic. For example, within a few months of removing a dam in the state of Maine in the US, salmon, striped bass, alewives and other affected fish returned to waters above the old dam site in a matter of months—water they had been absent from for 162 years.[18] In Europe, the International Commission for the Protection of the Rhine (ICPR) adopted a 40-year action plan in 2000 that includes measures on flood management and habitat protection and restoration in the alluvial zone around the river's banks. The flood management goal is to restore as far as possible the natural course of the river. The emphasis is on planning around the water system itself, rather than trying to control the water. This is a major shift, particularly for the Dutch, who have been building dikes for the past 1000 years.

We are also learning that as open space is lost to urban development, agriculture can be an essential habitat for displaced wildlife. For example, a recent literature review revealed that while irrigation or activities associated with irrigation *can* cause adverse impacts to wetland ecological resources—ranging from localized and subtle, to large-scale and severe—they can also result in the creation or enhancement of important wetland ecological resources. Further, depending on the irrigation activity and scale, irrigated agriculture and ecological resources can coexist in a potentially sustainable fashion.[19]

One example of re-adaptation to a degraded environment is the change taking place in a series of villages located in the Indian state of Mahrashtra, which experiences recurrent droughts. An NGO established in 1993, Watershed Organization Trust (WOTR) brought about significant improvements in the quality of life and the ecosystems in 20 villages, over an area of 20,000 hectares. Their work is based on a simple premise: "the nature and incidence of poverty in a rural agrarian economy is closely linked to the robustness of the local ecology and environment…as well as the socio-economic relationship…".[20] WOTR works closely with villagers, building their capacity to restore and manage their natural resources, both land and water.

In Mahrashtra, the impact on water resources relates directly to the increase in biomass vegetative cover, which enhances the ability of soils to absorb and hold water. This is particularly important in a country like India, which receives 80 percent of its rainfall in three to four months, most of that coming in the form of intense monsoon storms. The soil's ability to absorb water in these events can make the difference between devastating floods and droughts and a stable year-round supply. With WOTR's work, combining institutional capacity building and technical training, the villagers made landscape modifications. These included the use of gully plugs and bunds combined with afforestation to improve soil moisture, reduce erosion and control drainage. As a result, groundwater tables have actually *risen* in parallel with a rise in biomass. The increased biomass translated into increased incomes for the villagers. This in turn brought sufficient security for farmers to send more of their children to school, from a pre-intervention rate of 50 percent to nearly 100 percent. Problems of migration in the villages WOTR operated in for the last 5 years were virtually eliminated. All three elements of sustainability—social, economic and ecological—are being addressed successfully. Water and agriculture are linked in this project as a joint positive force across each dimension of sustainability.

Future Directions—Sustainability

Ultimately, agricultural professionals, governments and farmers must approach the creation of socially and environmentally sustainable agricultural systems with a long-term perspective. With regard to water resources, one definition of sustainability is, "the use of water that supports the ability of human society to endure and flourish into the indefinite future without undermining the integrity of the hydrological cycle or the ecological systems that depend on it."[21] Other definitions, such as those of American Society of Civil Engineers and the Global Water Partnership, are similar. What prevents us from achieving sustainability? This is a question that people have been attempting to answer with increasing urgency since the publication of the Brundtland report.[22] In the case of agricultural water use, the broad and practical outlines of an answer have been emerging from literature since the early 1990s.

The central issue is illustrated in figure 2, namely, that agricultural water use is determined by and affected by a combination of social, economic and environmental factors. Although these can sometimes be ignored in the short term, they will all play a role in the long run. Moreover, they interact with one another. When farmers have secure access to land, or hold secure tenure to the land they work, they take a more environmentally sustainable approach to land management.[23] Thus the application of policy and law to promote sustainable management can be critically important.

Pricing incentives and disincentives can also be major management instruments. A rise in the price of a land-intensive export crop can lead to rapid expansion of production for short-term gain. Alternatively, the removal of subsidies and the provision of other alternative incentives can help restore degraded agricultural and ecological systems. In this case, the economic environment (pricing) affects both the natural environment and social structures.

In the case of agriculture, the difficulties of integrating the three elements of sustainability are acute. The aggregate figures for total national crop production that are reported in national yearbooks are the result of thousands of micro-level decisions, made under uncertain and risky conditions. Adoption of new techniques requires not only knowledge of the technique, but also a reasonable certainty of a substantial short-term payoff, to make the investment of time worthwhile.[24] To reduce the risk, governments may choose to take some of the burden when the weather is poor or commodity prices fall. They may also try to encourage production of highly-valued cash crops. But these strategies can lead to distorted outcomes. In the case of water, this may take the form of subsidies for water or agricultural energy consumption, or high levels of production of water-intensive crops, such as cotton or rice.

Ensuring *real* sustainability, beyond rhetoric, requires that existing economic, political and institutional frameworks be restructured using approaches that cause minimal disruption to human well-being and natural systems. National decisions have global implications. The inability to take steps toward true sustainability is still painfully obvious, even in highly developed countries. For example, the United States' recent decision to offer large export subsidies to domestic farmers is contrary to long-term, wise management of resources. Even under an administration that is strongly aligned with a free-market stance, subsidies were adopted that are both potentially environmentally damaging within in the U.S., and economically devastating to farmers in low-income countries. [25]

The work being undertaken to examine agricultural production decisions to sustain both agriculture and the environment—from the field level, to watersheds, to river basins—must be continued and given increasing priority. In other words, agricultural management on all scales must be linked directly to economic, social and ecosystem function, with integrated attention to each of these pillars. Critical institutional barriers to planning exist at each of these levels. To overcome them, we must work together to achieve real sustainability, real coordination between agriculture and the environment, and real security for those people living in poverty.

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Growing Rice with Less Water

B.A.M. Bouman and T.P. Tuong

Food security in Asia is challenged by increasing food demand and threatened by declining water availability. Rice is the most important staple in Asia where it provides 35-80 percent of total calorie uptake.[1] More than 75 percent of the annual rice supply comes from 79 million ha of irrigated paddy land. Thus, the present and future food security of Asia depends largely on the irrigated rice production system. However, because of its typical wetland growth conditions, the water-use efficiency of irrigated rice is low, and to grow rice requires large amounts of water. It takes 3,000-5,000 liters to grow 1 kilogram of rice, which is roughly equivalent to 2-3 Olympic-sized swimming pool per ton of rice. In Asia, irrigated agriculture accounts for 90 percent of total diverted fresh water, and more than 50 percent of this is used by rice.[2] Until recently, this amount of water has been taken for granted, but now the "water crisis" threatens the sustainability of the irrigated rice ecosystem. Ways must be sought to grow rice using less water. Also, actively reducing the amount of water used in rice can have positive societal or economic impact if the water saved is used elsewhere, such as in industry, cities or natural reserves (wetlands, for example). However, rice is very sensitive to water stress and attempts to reduce water input may result in yield reduction and thus threaten food security. The challenge is to develop economically viable and environmentally sustainable novel rice-based systems that allow rice production to be maintained or increased in the face of declining water availability.

Water Scarcity in Rice-growing Areas

In Asia, rice is mostly grown under supplementary irrigation in the wet season, and under full irrigation in the dry season. Irrigated wet-season rice mostly grows in the sub-tropical regions of north and central China, Pakistan and northwest India. Dry-season irrigated rice is concentrated in south China, south and east India and the whole of southeast Asia. Tuong and Bouman[3] estimated that a total of 2 million ha of the dry-season rice and 13 million ha of the wet-season rice will experience "physical water scarcity" by 2025 . Most of the approximately 22 million ha dry-season rice in South and Southeast Asia falls in the "economic water scarcity" zone. In principle, water is always scarce in the dry season when the lack of rainfall makes cropping impossible without irrigation.

Rice and Water Use

Water use in irrigated rice is high because the crop is grown under "lowland" conditions. At the start of the growing season, the land is prepared by so-called puddling (wet land preparation). A layer of water is imponded on the surface, and a muddy topsoil is created by repeated plowing and harrowing. A few days after puddling, rice seedlings are transplanted into the muddy topsoil. Initially, a shallow water layer of 2-3 cm is maintained, but with the growing of the crop, the water depth is increased to about 10 cm. The fields are surrounded by bunds to keep the water in. Because of the continuous presence of ponded water, there are large losses of water by evaporation from the water surface and by vertical percolation to below the rootzone. These water flows do not contribute to crop growth and are therefore called "unproductive". Moreover, the wet land preparation of rice fields requires an extra amount of water compared with the dry land preparation for crops such as maize or wheat. In typical lowland environments, the total, seasonal water input to a rice field is a water layer of about 1.5 m, but this can increase up to 3-4 m when soil and hydrological conditions are unfavorable.

Large reductions in water use can potentially be realized by reducing the unproductive evaporation and percolation flows. A first thing to start with is proper field preparation and maintenance.[4] Before the start of land preparation, fields may come out of a dry period that has caused cracking of the soil surface. If these cracks are wide and deep, they rapidly transmit imponded water to deeper soil layers. In such cases, water can be saved by shallow plowing of the soil to close the cracks before imponding any water. A level field ensures a good distribution of water and eases careful water control. Moreover, it promotes uniform crop growth and therefore contributes to a high water-use efficiency. Thorough puddling creates a compact layer below the muddy topsoil that reduces the percolation rate. Beside vertical percolation, water also leaks horizontally out of a rice field through the bunds. Holes and cracks in bunds may be caused by drying and shrinking and by burrowing animals such as rats. Good bund maintenance by repeated plastering with fresh mud and closing any rat holes helps to keeps water in the field.

Water-saving Technologies

Large amounts of water can be saved by so-called water-saving irrigation technologies that reduce evaporation and percolation.[5] Instead of keeping the rice field continuously flooded with 5-10 cm of water, the floodwater depth can be maintained just around saturation. Soil saturation is mostly achieved by irrigating to about 1 cm water depth a day or so after disappearance of ponded water. Implementing soil saturation requires good water control at the field level, and frequent, shallow irrigations that are labor intensive. Water savings in saturated soil culture can be as high as 30% whereas yield reductions are kept at a minimum of 5-10 %. Saving more water can be accomplished by alternate wetting and drying where irrigation water is applied after a number of days (from 2 to 7) have passed since disappearance of ponded water. Some researchers reported yield increase,[6] but our recent work indicates that these are the exception rather than the rule.[7] In most cases, alternate wetting and drying decrease yield. The level of yield decrease depends mostly on the groundwater table depth, the soil type and the drying period in between irrigation events. Mostly, however, relative reductions in water input are larger than relative losses in yield, and water productivities increase.

A fundamental approach to reduce water inputs in rice is to grow the crop like an upland crop such as wheat or maize. Upland crops are grown in non-puddled, aerobic soil without standing water. Irrigation is applied to bring the soil water content in the root zone up to field capacity after it has reached a certain lower threshold. The potential water savings when rice can be grown as an upland crop are large, especially on soils with high percolation rates. However, new varieties must be developed if the concept of growing rice like an irrigated upland crop is to be successful. Upland rice varieties exist, but have been developed to give stable though low yields in adverse environments where rainfall is low, irrigation is absent, soils are poor or toxic and farmers are too poor to supply high inputs. Recently, the term "aerobic rice" was coined to refer to high-yielding rice grown in non-puddled, aerobic soil.[8] Aerobic rice has to combine characteristics of both the upland and the high yielding lowland varieties. Evidence for its feasibility comes from northern China where aerobic rice cultivars have been developed that yield up to 6-7.5 t ha^{-1} under supplementary irrigation.[9] In a recent study, it was found that yields of 4-6.6 t ha^{-1} were obtained with as little as 476-612 mm of total water input, compared with 1300 mm in flooded lowland rice.[10] It is estimated that these aerobic rice varieties are now being pioneered on some 190,000 ha in the north China plains.

Conclusions

Water-saving technologies that combine a good yield with a low water requirement are suitable for water-scarce environments. If water scarcity is relatively mild, saturated soil culture and alternate wetting and drying are promising options. When water is scarcer, however, aerobic rice is a good alternative. Suitable policies, institutional organization and legislation are needed to promote the adoption of water-saving technologies. The adoption of water-saving technologies at the farm level will have consequences for the hydrology and water use at larger spatial scale levels. Water saved at the farm level does not always mean that water is saved in the whole irrigation system. Water lost from individual fields enters the surface and subsurface flow system and can be reused further downstream. If such is the case, field-level water savings upstream do not lead to water savings at the system level.

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NIKE

Water Development for Poverty Eradication

Barbara van Koppen

Poverty in developing countries, especially in Sub-Saharan Africa, can be eradicated—not just alleviated but eradicated—by enhancing the productivity of smallholder agriculture. In such a case, agricultural growth serves as an engine for overall economic growth. This win-win scenario of poverty eradication through agricultural and overall growth has been successful throughout history, and continues to be valid today. It provides a strong justification for investing in further water development for small-scale agriculture, in order to increase and stabilize the supply of agricultural outputs throughout the year. Improved water control increases yields and cropping intensities, reduces the risk of crop failure and prevents soil erosion. It also facilitates the adoption of high-yielding varieties of food crops, diversification into cash crops, fertilizer application, pest management and intensification of farm practices.

This path of poverty eradication, through initial agricultural growth, is gradually being better appreciated in the circles of national and international policy debate and action. However, prevailing misconceptions still prevent clear insight being achieved with regard to the potential merits of this scenario and, especially, in terms of its implications for action. Three misconceptions about the nature of economic growth, poverty, and water scarcity are discussed in this essay.

Agriculture: Engine of Economic Growth

The first misconception holds that engines of economic growth lie outside agriculture. It is assumed that off-farm enterprises, industries, trade, and services are the 'more important' sectors. Current thinking is that poor people should be absorbed by these sectors as soon as possible. The fact that the growth of GDP is typically accompanied by a decline in the contribution made by agriculture, a decline in the share of the labor force employed in agriculture, and by a rapid increase in urbanization, would seem to support this argument. Following this line of reasoning, then, stimulating a sector as backward because it is agricultural would simply "block the poor in a poverty trap."

Human history proves that this assumption is wrong. Causes and effects have been confused with each other. Past economic growth in high-income countries, and recent growth in the Asian Tigers (such as Thailand, Malaysia, Indonesia, Vietnam, or parts of China) were typically preceded by, and based upon, agricultural growth. Therefore, as economists have pointed out for a number of decades, agriculture is the actual engine of growth.[1] Higher farm productivity enhances producers' own incomes, in cash and in kind, and creates a demand for agricultural labor. Growth is multiplied in three ways: first, through backward linkages with an agricultural input supply sector; second, through forward linkages with agro-processing industries, transportation and trade and, third, through consumer linkages when enhanced rural prosperity leads to new demands for goods and services from rural and urban providers. Moreover, production of export crops brings in foreign exchange while, last but not least, the availability of food at relatively low prices enables a growing labor force (employed in expanding secondary and tertiary sectors) to feed itself at modest wage rates. Agriculture is a dynamic engine of growth and an important contributor to welfare in later stages of economic development. Growing rural, and urban, off-farm employment *reflects* agricultural growth. Secondary or tertiary production is not an *alternative* growth pole, but depends heavily upon agriculture. The few exceptions to this remarkably uniform pattern of economic growth are the oil- or mineral-based economies, in which agriculture may lag behind.[2]

Many Western and Asian governments were well aware of the importance of agricultural growth and fostered it, often at high public cost , for example, by building irrigation schemes. Many middle- and high-income countries, including the USA and those within the European Union, continue to support agricultural production, both directly, through market protection and support such as research, subsidies, or risk sharing, and indirectly, in the form of income grants for farmers or the introduction of high quality standards for imported food. Significantly, market protection in agriculture went hand in hand with dramatic increases in land and labor productivity. Apparently, the belief that protection necessarily leads to inefficiencies is not true for the agricultural sector, in which millions of family enterprises compete. Agriculture differs from monopolistic industry. In sum, policy measures and public investments in agriculture pay off.

The harsh reality of poverty-stricken areas constitutes the other side of the same coin; this is especially evident for most countries in sub-Saharan Africa. Such countries suffer from rising numbers of people living below the poverty line, rising proportions of poor people in the total population, and a decline of per capita agricultural productivity (food production has been growing by less than two percent in the past two decades, while population growth before the HIV epidemic was about three percent).[3] Furthermore, they suffer from agricultural stagnation and overall economic malaise, having only marginal secondary and tertiary sectors. Smallholder agriculture in sub-Saharan Africa has been taxed rather than subsidized. Restricted public support given during the first three quarters of the last century was biased toward large-scale, mechanized, white settler agriculture and capital-intensive, notoriously inefficient state-managed estates. Extractive marketing boards appropriated a substantial proportion of the value of export produce and kept food prices artificially low in order to favor an urban minority. International development policies implemented since the 1980s, including structural adjustment programs, further restricted public investments in agriculture.

Agricultural stagnation in sub-Saharan Africa has led to growing national food deficits. The World Bank estimates that Africa could suffer a food shortage of 250 million tons by 2020, more than 20 times the current food shortfall, if present trends continue. With declining shares of African exports in world trade and with foreign debts rising astronomically, there will be insufficient foreign exchange to pay for this food.[4] The demand for food is currently being met by imports, either on a commercial basis or in the form of food aid. Currently, about half of the aggregate food shortage is met by food aid whilst, by contrast, only 15 percent of cereal imports were provided by aid in 1970. Thus, smallholders in sub-Saharan Africa are poorer and less productive than farmers elsewhere in the world. Moreover, they receive less public support, and face more competition from the cheap foreign products that flood their markets. Without protection, African producers and ultimately the economy as a whole, will lose out because of these massive imports.[5]

For sub-Saharan Africa, enhancing the productivity of smallholder agriculture is the only way out of this poverty trap. On the supply side, there exists the well-known need for technological change, including water development, rural financing facilities, training and human resource development and health care. On the demand side, there exists the need to improve roads and railways, transport facilities and storage; smallholders need to be organized and empowered, in order to allow the bulk purchase of inputs and the profitable sale of produce, to which end price information is warranted. However, food imports, drawn from ever-cheaper world markets, jeopardize the implementation of prices that are sufficiently high to reward the farmers' efforts, which is the most critical driver of intensification. This new and unique problem in the world market can only be solved by the introduction, or reinforcement, of import duties by poor African countries.[6] For development purposes, such special, differential treatment seems at least as legitimate as the continuation of agricultural market protection in high-income countries.

The Rural Poor: Key to Growth

The second misconception considered here regards the nature of poverty. It is recognized that most poor people in Africa and Asia are small farmers who depend upon ever-decreasing areas of land, or who are laborers without land who therefore tend to migrate to urban areas, thus compounding urban poverty. However, a patronizing myth exists which states that being poor means being dependent upon a transfer of resources from the wealthier sections of society, in order to make life somewhat less unbearable. A related myth also exists which states that that small farm size necessarily inhibits intensification and higher productivity.

There is ample evidence that smaller farmers play a greater part than larger farmers in engendering both pro-poor agricultural and overall economic growth both in Asia and Africa.[7] There are three reasons why this should be so. First, smaller farmers tend to produce more per unit of land than larger farmers, because of a higher-value crop mix, more double cropping, more intercropping, and less fallowing. Yields are often also higher, especially in Asia. Second, labor input by family members and wage laborers, per unit of land, is higher among smaller farmers. This demand for labor has especial importance for the poorest people, who have extremely small, infertile land holdings, or who have no land at all. Third, prosperity among small farmers leads to a demand for goods and services that are locally produced, while better-off farmers tend to spend their newly acquired incomes on non-local products and services. Thus, instead of being 'surplus' to the requirements of society and bottomless drains for other people's wealth, as is commonly assumed to be the case, small farmers and agricultural wageworkers are actually key actors in the above-mentioned pathway of economic growth.

Water Scarcity: Equitable Expansion

A third, recently formulated, myth states that water is so scarce that current water use needs categorical regulation and that further development of water resources has become impossible. However, two basic issues are overlooked: First, water scarcity is often the result of a lack of financial and human resources that could make physical water resources available for human use ('economic water scarcity'). In Africa, for example, FAO[8] estimated, based on land suitability, water availability and irrigation requirement, that only one eighth of the country's irrigation potential is currently being used. The answer to economic scarcity does not entail cutting down on water use, but expanding water use by developing and disseminating, on a very large scale, appropriate and affordable technologies. These technologies would include methods of water harvesting and storage on small plots or in homesteads, tillage practices, vegetative measures and contour bunds for soil and water conservation, methods of roof water harvesting, treadle pumps or small mechanized pumps, low-pressure drip irrigation, collective pump and gravity irrigation schemes and small village dams or larger dams.

Second, under conditions of absolute water scarcity, when all available water resources have been developed and competition over water resources is becoming fierce, any regulation of further use should take inequities in water use into account. Water scarcity is not a uniform phenomenon; it exists for some people, but not for others. Inequities in water distribution may be huge, as in the Mhlatuze Basin in South Africa, where 90 percent of the people have access to less than 3 percent of the water.[9] When water was still seen as an open-access resource, a few individuals, typically the better-off, who had more powerful equipment, larger tracts of land, and often more state subsidies for construction of the necessary infrastructure, started tapping disproportionately large shares of water. The rationale for distributive water reforms is exactly the same as for distributive land reforms: enhanced productivity and equity for poverty eradication through agricultural growth. Expansion of smallholders' water use is justified, even under conditions of absolute water scarcity.

Conclusion

Water resource development targeted at poor smallholders is linked to poverty eradication through agricultural growth. Some complexities in these links have been discussed, but gaps in knowledge still remain. Further dialogue will confirm the existence of common ground between poverty and water perspectives, and will reveal new grounds for discussion and collaboration. This will result in, and guide, better decision-making and action, from both perspectives.

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Water Rights Issues in Agriculture

Ruth Meinzen-Dick

This paper draws upon Bruns and Meinzen-Dick (2000) and Meinzen-Dick and Pradhan (2002)

In the water sector we are seeing more attention to water rights in response to greater competition for the resource and greater expectations of farmers' roles in managing water. The scarcity and competition come not only from greater demand for irrigation, but also from greater demand from other water uses, especially cities and industries that are often drawing water away from agriculture. Clear water rights can reduce conflicts over the resource in such contexts. Expectations of farmers' roles in water management have increased through irrigation management transfer programs in which the government transfers responsibility for operating and maintaining irrigation systems to farmers' associations. Without clear rights over water, farmers often lack the incentive and authority to invest the necessary time and resources for such management responsibilities.

It is therefore appropriate that we should give more attention to water rights in many countries. The question is what types of water rights are appropriate for each context, and what can be done to support such rights. Policymakers and advisors that recognize a need for secure water rights often think that it is a matter of passing the "right" law—often borrowed from another country. This approach suffers from two major problems. First, state law does not by itself define water rights. Customary, religious and other types of law are also very important. Second, what may work well in one country or context will not necessarily apply in another, where physical and socioeconomic conditions are different, including different backgrounds on water rights. What is needed is a more flexible approach, adaptable to local conditions.

This paper describes key factors for understanding water rights. This includes recognizing the multiple sources of water rights (legal pluralism) and the bundles of rights that different stakeholders can have. It concludes with implications for water rights policy or reform processes.

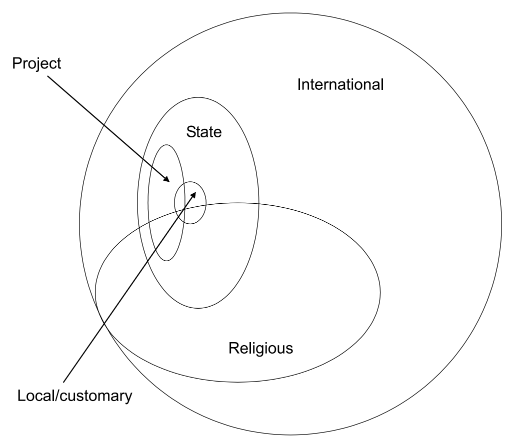
Sources of Water Rights

While state law is one source of water rights, it is not the only one. In many contexts, state law may have little bearing on water rights "on the ground." Instead of taking a top-down view of water rights that begins with state law, it is more useful to begin with people's own experience with access to and control over water, in which individuals draw upon a range of strategies for claiming and obtaining resources.

In addition to state (government) law, people may claim water rights based on customary law, religious law, international law, project regulations and local norms. The coexistence of different types of law is referred to as *legal pluralism*. Claims from each type of law are only as strong as the institution that stands behind it. Customary law is often strong where there are farmer-managed irrigation systems, especially if the farmers themselves have built the systems and the farmers' organizations are strong. Religious law regarding water often applies to basic human needs and especially drinking water, but may also be applied to purity and pollution of water. International human rights law is appealed to for basic human needs, while international conventions like the Ramsar Convention may be invoked to preserve water for nature. Most water projects produce their own regulations that also affect water rights of different potential users. Local norms often produce their own claims on the resource, as well as influencing the local interpretation of other types of law. Depending on the system, water rights may be acquired by state allocation, purchase, or inheritance, but also by investing in the water control system, membership in a community, or even use over time.

These types of law do not exist in isolation, but overlap, interact, and influence each other (figure 1). Changes in state law will therefore not automatically change water rights on the ground. Their effect will be shaped by other types of pertinent "water law" and by the extent to which the state or other institutions back up and enforce the new laws. At the same time, customary and other types of law are not unchanging, but may be affected by changing conditions or new state laws, especially if the latter are widely applied. Thus, water rights should be viewed as dynamic, changing over time and place like the resource itself.

Figure 1. Overlapping types of law related to water rights.



Derived from Pradhan and Meinzen-Dick 2002.

Bundles of Rights

For water resources, we may hear either that "there are no water rights" or "the state owns all water." This comes from thinking of "ownership" of water, like ownership of land. But this is not the most useful way of thinking about water rights. It is more useful to think of different *bundles of rights* that different stakeholders may have. While there are many variations, the most common types of bundles relate to:

Use rights, for instream uses or withdrawing water

Control rights, to make decisions about who can use the water or how it is managed, or to change its flow

Transfer (alienation) rights, to sell, lease, or otherwise reallocate water to others

Ownership is usually considered the combination of all these bundles of rights, but in practice we rarely find that any one stakeholder has of these rights. Instead, we might find a combination such as fishers with rights to instream use of water; community members with rights to draw water for domestic use; farmers with land in a defined area holding rights to draw water for irrigation while others might hold a right to the drainage water from higher land; a water users' association with control rights over how the water is delivered; and the state claiming rights to reallocate water to others if it deems them of higher priority.

Overlapping uses and claimants do require considerable coordination, and increase the transaction costs compared to a single user. However, given the vital nature of water resources, overlapping uses are often necessary to accommodate many stakeholders, and can greatly increase the productivity, equity, and sustainability of water systems.

Rights may be held by individuals (such as fishers or farmers), groups (such as water users' associations), communities, or by the state. Individuals are most likely to have only use rights, with the state claiming higher-order (control and transfer) rights for itself. Governments that have adopted irrigation management transfer programs may have provided some control rights to user groups, either explicitly through changes in laws or project rules, or implicitly. Although most government management transfer programs have focused on transferring responsibilities, a balance between rights and responsibilities is needed. Without control rights, water users' associations will not have the necessary authority to manage the systems. Rights to water (not just to the infrastructure that conveys it) are also important to provide incentives to users for taking on an expanded role in water management.

Transfer rights are the type of bundle least likely to be held by individuals or even user groups. Transferable water rights are now receiving greater attention from researchers and policymakers, especially in "closed" basins where new water uses cannot be accommodated without reallocating from other users. Under non-transferrable water rights, a user may only have the right to use water for a specified purpose in one place. Such a system provides little incentive for users to conserve and make more available for others, because the right-holders derive no benefit from the water they do not use. Other water demands are then met by the government reallocating water, often with little or no compensation to the original use right-holders. If users held transferable water rights, the possibility to sell or lease unused water to others can provide an incentive to reduce consumption, and instead of state expropriation of farmers' water to meet growing municipal water demands, the farmers and rural communities can be assured of payment. However, poorer farmers or those with less education may have difficulty in benefiting from transfers, or those holding other bundles of rights may be negatively affected by the transfers. For example, if a farmer sells water, domestic users drawing water from a source, or other farmers depending on drainage or groundwater recharge, may lose out when water. Careful provision therefore needs to be included for protecting the interests of third parties.

Implications for Policy

While water rights are increasingly important, rushing to "establish" or reform water rights without first understanding what already exists may create more problems than it solves. While secure water rights can reduce conflicts and improve users' incentives to manage the resource, tenure security does not necessarily come from state-issued "ownership" of the resource. Other types of law may provide stronger bases for claiming water rights if there are effective local institutions backing them. Furthermore, we need to look beyond ownership, to consider how different bundles of rights are distributed among various water users and the state.

If water rights are to be changed by a government or a project, passing legislation or regulations is not enough. Legal literacy campaigns will be needed to inform both water users and those implementing the new rules about the changes. Careful provision should be made to ensure that the poor and other marginal groups with customary use rights are not excluded. Local enforcement is likely to be necessary for any rules to be effective. Even then, the outcome will vary from one place to another, depending on local circumstances and preexisting water rights. Complete registries of water rights may be neither feasible nor desirable. At best they rigidify, and at worst distort the allocation of water rights. Because of the fluid nature of water resources, dynamic water rights are often more appropriate. Rather than attempting to codify all water rights, it is better to focus on ensuring processes for negotiation and conflict resolution that all stakeholders, especially the poor, can access.

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