Investing in Water for Food, Ecosystems and Livelihoods

BLUE PAPER
Stockholm 2004

Discussion Draft
by
David Molden and
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COMPREHENSIVE Assessment of water management in agriculture

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Comprehensive Assessment of Water Management in Agriculture

The Comprehensive Assessment of Water Management in Agriculture takes stock of the costs, benefits, and impacts of the past 50 years of water development for agriculture, the water management challenges communities are facing today, and teh solutions people have developed. The results of the Assessment will enable farming communities, governments and donors to make better-quality investment and management decisions in the near future and over the next 25 years.

Through a process of research synthesis, review, and dialogue, the Assessment is bringing together scientists from over 90 institutes worldwide with policymakers, development professionals, and water users. The results of this process will enable farming communities, governments and donors to make better-quality water decisions in the near future and over the next 25 years.

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The paper has not been accepted or appoved by the Comprehensive Assessment process. It is intended to present issues dealt with by the Comprehensive Assessment to open up discussion around these. Please send your comments to the email address given below.

Partners:
The Comprehensive Assessment is an initiative of the Consultative Group on International Agricultural Research (CGIAR), convened by the International Water Management Institute (IWMI). It is made possible through support from the governments of Netherlands, Switzerland, Sweden, Taiwan, Japan and Austria; FAO, the OPEC fund, the Rockefeller Foundation.

New partners are welcome. More information about how you and your organization can participate in the Assessment process is available on our website or you can contact us at the address given below.

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Investing in Water for Food, Ecosystems and Livelihoods

Sustainably meeting the food and livelihood needs of a growing population will require some very difficult choices about how water is developed and managed in the next 25 years. More food will be necessary, and more food translates into more water for agriculture. More water for agriculture will in many cases mean less for the environment. So how do you manage water for food and the environment? And how do you do so in a way that also reduces poverty?

In the following pages we review several policy and water investment options—along with their livelihood and environmental implications. This paper presents issues being addressed by the Comprehensive Assessment of Water Management in Agriculture, an international research program that brings together scientists, development professionals and stakeholders from around the world. This is the first time science has been focused at this level and intensity on answering questions related to water, agriculture, poverty and environmental conservation.

The Assessment is at the mid-way mark and won't be complete until 2006, but already we have evidence to suggest which approaches are the most promising. Our intention in sharing these preliminary findings is to raise awareness that water in agriculture is a pressing issue, that business as usual is not an option, and that there are potential solutions, but they are not necessarily the ones that have received the most attention.

How much water do we need to feed people?

By 2025, there will be an estimated 2 billion more people to feed. Growing more food means using more water. To produce one kilogram of grain, plants must transform between 500 and 4000 liters of water—depending on the type of crop, the climate, and water and land management practices—into vapor through the process of evapotranspiration (ET) (see table 1).

Table 1. The amount of water used to grow food (in liters evapotranspired per kilogram).

	USA	France	China	India	Japan	World
Wheat [a]	1,390	660	1,280	2,560	1,350	1,790
Rice [a]	1,920	1,270	1,370	3,700	1,350	2,380
Maize [a]	670	610	1,190	4,350		1,390
Beef [b]	10,060	7,740	12,600	14,379	9,540	9,680
Pork [b]	3,370	1,940	2,520	7,560	4,080	3,680
Onions [c]	140					
Tomatoes [c]	130					

[a]from Fraiture et al (2004) [b]Chapagain and Hoekstra (2003) [c]Renault and Wallender (2000); data for California

Depending on their diet and where their food is grown, each person is responsible for the conversion of 2000 to 5000 liters of liquid water to vapor each day. The daily amount of water we drink (2 to 5 liters) and use for washing, sanitation, and other household tasks (50 to 200 liters per person) seems insignificant when compared to the amount of water we eat.

In preparation for the second World Water Forum, groups of researchers forecast how much more water would be needed in the year 2025. The amount of additional water withdrawn from rivers for irrigation ranged from 24% to values less than zero. The difference in forecasted values reflect different ideas about how water should or could be used in the future (box 1). Considering both rainfed and irrigated agriculture, Rockström et al (1999) estimated that the amount of water consumed by agricultural ET would have to increase from 6,100 km^3 to 9,700 km^3, given current trends in population growth, improvements in living standards and water use patterns. This is an enormous quantity of water that has to be converted to evaporation for food production unless we change the way business is done.

How much more water, where it comes from, and the environmental consequences of its use, depend very much on choices made in the next few years. To a large extent, how much additional water will need to be withdrawn from rivers depends on how much more food it is possible to grow on existing rain-fed and irrigated lands. The Comprehensive Assessment will be able to provide a good estimate of rain-fed and irrigated potential and tools to explore different scenarios. But in making decisions about where to focus resources, it is important to consider not just production potential, but also poverty reduction potential.

Box 1. How much irrigation do we need? Current best guesses.

Projected increases in water withdrawals for irrigation (in km^3).

Source	Total irrigation withdrawals		
	1995	2025	Increase 1995-2025
Shiklomanov	2,488	3,097	24%
IWMI	2,469	2,915	18%
FAO**	2,128	2,420	14%
IFPRI			4%*

*IFPRI number represents projected increase in irrigation depletion, not in irrigation withdrawals.
**FAO uses 2030 as projection year.

Researchers from several leading organizations have explored what they consider to be business as usual or base scenarios of future water supply and demand. Looking at the table below you can see that under all four scenarios, irrigation withdrawals increase by 2025—but with significant differences in by how much.

Shiklomanov's projection (2000) considers present trends and extrapolates them into the future. The IWMI base case (Seckler et al 2000) projects increases in efficiency and productivity in irrigation, but is pessimistic about the amount of gains from purely rain-fed agriculture (without any supplemental irrigation). It also assumes that most countries will opt for food self-sufficiency rather than rely on trade. The FAO scenario (2002) is slightly more optimistic about gains in rain-fed areas, and thus predicts less need for irrigation. The IFPRI scenario (Rosegrant et al, 2002) is very optimistic about gains in rain-fed areas, particularly in developed countries, and assumes that global food trade will form a significant part of the solution.

The water and poverty connection

The majority of people living in developing countries still depend on agriculture for their livelihoods. Approximately 70 percent of the world's poor live in rural areas with limited livelihood opportunities outside of agriculture (World Bank 2004b). Providing these people with a reliable source of water—whether it's from small-scale water harvesting or large-scale irrigation—makes it possible for them to move beyond subsistence farming. It prevents yield losses due to short-term drought, which in sub-Saharan Africa may claim one out of every five harvests. It gives farmers the "water security" they need to risk investing in other productivity-enhancing inputs, such as fertilizers and high-yielding varieties. And it enables them to grow higher-value crops, such as vegetables, which are more sensitive to water stress and which have higher input costs. While water resource development has been significant in reducing poverty (Rijsberman, 2003), investments have declined.

Although irrigation development has negatively impacted the environment, it has positively impacted poverty. It has provided employment and income and lowered food prices—benefiting both urban and rural poor (Lipton 2003). In India, Shah and Singh (2003) found that more irrigation means fewer people below the poverty line. Hussain and Hanjra (2003) in a review of 120 studies found higher wage rates in irrigated than in rain-fed areas. From a broader national perspective, Bhattarai et al (2002) estimate a multiplier of 3.15 for irrigation in India, meaning that for every $1 generated by irrigated crop production that directly benefits farmers, another $2.15 indirectly benefits economic development. Poor communities, women in particular, also benefit from irrigation as a source of water for domestic uses, small-scale industry, and fishing (Meinzen-Dick and van der Hoek, 2001; Bakker et al., 1999) (See box 2).

Box 2. Women, poverty and water.

Rural women are responsible for half of the world's food production and produce between 60 and 80 percent of the food in most developing countries (FAO 2004). It is likely that their contribution to food security is growing due to a process known as 'feminization of agriculture' where men go to the city in search of paid jobs leaving the women to do the farming and provide food for the family (Song 1999, FAO 1998).

But, overlooked and undervalued, women's contribution to food security is not reflected in ownership and access to services. Fewer than 10 percent of women farmers in India, Nepal and Thailand own land; women farmers in five African countries received less than 10 percent of credit provided to their male counterparts; and only 15 percent of the world's agricultural extension agents are women (FAO 2004). Traditionally, irrigation agencies have tended to exclude women from access to water—often implicitly, for example, by requiring land titles to obtain access to irrigation water (Koppen 2002). Explicitly targeting women farmers in water development schemes and giving them a voice in water management is an essential ingredient for the success of poverty alleviation programs.

Women also use irrigation water for domestic purposes, home gardens and cottage industries. Recognizing these multiple uses in water development and management would greatly benefit women.

Of course, irrigation does not have to be large-scale to have an impact on poverty. The introduction of small-scale water harvesting and groundwater pumps for supplemental irrigation in rain-fed areas is having a dramatic effect on incomes and food security in some of the world's poorest communities. According to Paul Polak of International Development Enterprises, an NGO with 25 years of experience introducing small-scale technologies, "The design and mass dissemination of a whole new generation of affordable small plot irrigation technology will have a more dramatic positive impact on the lives of the rural poor than the introduction of personal computers created in the west." Affordable small-plot irrigation technology, combined with a move to diversified, high-value marketable crops, can add up to an estimated $500US to the annual incomes of people currently living on less than $1 per day (Polak 2004). The market for treadle pumps in India and Nepal alone is estimated at 9-10 million. Given that treadle pumps help farmers earn an average of $100US more per pump per year, this would translate into $1 billion in the hands of some of Asia's poorest people (Shah et al 2000).

How much water for the environment?

Irrigation development has often come with a high environmental price tag. These costs range from aquatic ecosystem degradation, fragmentation and desiccation of rivers, and drying up of wetlands. A few widely quoted studies from Barbier and Thompson (1998) and Acreman (2000) show that in some cases the values generated by irrigation proved to be less than the values generated by the ecosystems they replaced. Lemly et al (2000) in a global study of wetlands sums it up by stating, "The conflict between irrigated agriculture and wildlife conservation has reached a critical point at a global scale." It seems likely that the main competition for water over the next century will be between agriculture and the environment (Rijsberman and Molden, 2002).

Figure 1. Water stress in major basins taking into account environmental water requirements.

Basins are shown as having a high degree of water stress if the amount of water withdrawn for human use is a large proportion of the amount available after environmental requirements are met. In most of the basins identified as water-stressed (with a Water Stress Indicator of 0.7 or higher), aquatic ecosystems are already suffering some degree of degradation, and there is little or no scope to increase water withdrawals without causing irreversible damage.

According to a recent global study of environmental water requirements conducted as a part of the Comprehensive Assessment, over 1.4 billion people already live in river basins where high water-use levels threaten freshwater ecosystems (Smakhtin et al. 2004). This first view of environmental water scarcity shows that many countries are already having to make serious environmental tradeoffs to grow food, and that many more will be facing the same dilemma in the next 25 years (figure 1).

Alcamo et al (2000), estimating irrigation withdrawals in 2025 based purely on environmental considerations, found that in order to sustain ecosystems, irrigation withdrawals need to be reduced by 7 percent from 1995 levels. Clearly some tradeoffs between environmental considerations and food production will be unavoidable, but there are various options that have been put forward for minimizing them.

Box 3. Co-managing water for irrigation and ecosystems.

Water use in agriculture affects ecosystems and the services they provide (Gordon and Folke, 2000) not just by reducing the amounts of water available, but also by polluting water, altering river flow patterns, and reducing habitat connectivity by drying up parts of rivers and streams. Co-managing water for agriculture and the environment can minimize these impacts.

Steps in co-management include:

- Assessing the value of fisheries and other ecosystem services and their role in livelihood strategies.
- Assessing environmental flow requirements—the flow amounts *and* patterns needed to sustain desired ecosystem characteristics and services.
- Creating forums for dialogue and negotiation between parties with different interests—for example farmers and fishers—based on knowledge of tradeoffs and potential impacts of water management decisions.
- Allocating water to sustain ecosystems taking into account all of the above.

Reorienting irrigation planners and managers to appreciate the needs of multiple water users, not just farmers, can both lessen environmental impacts and improve the productivity of irrigation systems. For example, with appropriate water management, irrigation systems can also sustain fisheries, substantially boosting food production from the system and contributing to livelihoods and nutrition (Nguyen-Khoa et al forthcoming).

In many cases, there are simple but effective ways to lessen irrigation’s impact on biodiversity in aquatic and terrestrial ecosystems—for example, providing “corridors” for movement of animals and fish, maintaining a diversified landscape instead of promoting huge mono-cropped tracts, and reducing off-site drainage to reduce the flow of water polluted with agro-chemicals into rivers and wetlands.

How can we meet the water needs of both people and the environment?

So more water to feed people, more water to reduce poverty, and more water to sustain natural ecosystems. And because of increasing water demand for cities and industries, less water to go around.

The options that have been put forward for solving this dilemma can be divided into six basic pathways:

- Influencing diets towards less water-consuming foods
- Increasing food trade from water-abundant countries to water-short ones ("virtual water")
- Using alternative sources of water such as wastewater or saline water
- Improving irrigation efficiency
- Increasing water productivity ("more crop per drop") on both rain-fed and irrigated lands
- Upgrading rain-fed systems through the introduction of supplemental irrigation and better land and water management practices.

While any lasting solution will most likely involve multiple pathways, of these six we consider a combination of the last two—increasing water productivity and upgrading rain-fed systems—to have the most potential to improve food security and reduce poverty at the lowest environmental cost. Any solution will require supportive policies and institutions to make it a reality.

Influencing diets

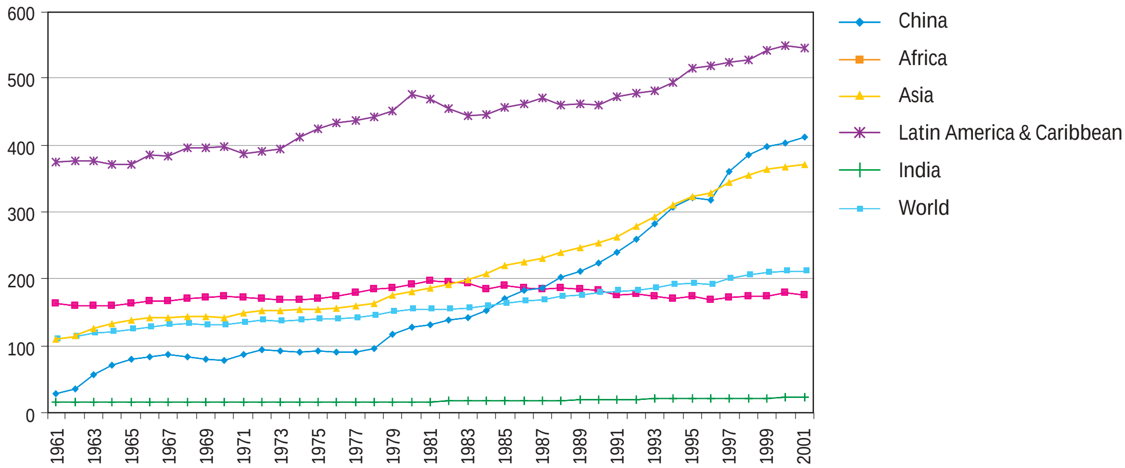
What people eat makes a substantial difference in water requirements. For example, diets based on meat from grain-fed cattle can deplete as much as 5,000 liters per capita per day, while vegetarian diets deplete less than half that much water (Renault and Wallender, 2000). Given this and the fact that in many western countries calorie intake significantly exceeds requirements, there seems ample scope to reduce water consumption in agriculture by influencing diets.

But is this a realistic option? Certainly it would be good for people to be more aware of the environmental consequences of their eating habits, but the idea that large numbers of people will change the way they eat because of water concerns seems unlikely.

And in Africa and in South Asia, where the pressure on water resources will increase most rapidly in the next 20 years, people actually need to be eating more, not less. In many sub-Saharan countries, calorie consumption remains well below acceptable levels. And world-wide 840 million people remain malnourished.

A positive trend in the developing world is that as living standards improve, food intake increases and diets diversify—usually shifting towards more meat and vegetable consumption (see figure 2). But this means more water, since meat and vegetables require more water to produce than most staple crops. Changes in diets of a growing and wealthier urban population will influence farm practices, and efforts to curtail unsustainable consumption patterns should be promoted (SIWI-IWMI, 2004). But, as a solution to water scarcity, influencing how much and what people eat may not be possible in much of the world.

Figure 2. Calories per capita met by meat products.



In the United States and Europe meat consumption has stabilized at around 25 to 30% of total calorie intake, whereas in African countries it constitutes of less than 10%. In Asia, meat consumption took off in the late 70s, quadrupling to nearly 15% of total calorie intake in 2001, and it is still rising—much of the increase coming from China. India remains largely vegetarian, because of cultural and religious reasons.

Trade in virtual water

It seems logical for countries lacking water resources to import staple food from water abundant countries, thus saving their scarce water resources for higher value uses. In this way food importers essentially buy water resources from exporters. This is commonly referred to as virtual water trade (Allan 1998, Oki et al 2003, Hoekstra and Hung 2002).

At the global level, trade can reduce water consumption in agriculture if exporters are able to achieve higher water productivity than importers. In most cases, the major exporters (USA, Canada and the EU) have highly productive rain-fed agriculture, while most importers would have relied on irrigation. Presently, cereal trade reduces annual global crop water depletion by 6 percent and irrigation depletion by 11 percent. Estimates that take into account trends in virtual water trade forecast 19 percent less irrigation use in 2025 than those that do not include trade (Fraiture et al 2004).

But the economic and political interests associated with agricultural trade cannot be ignored. Is it realistic to assume that countries will change trade policies because of emerging global water scarcity issues? Current data shows no relationship between countries' available water resources and their volume of trade (Ramirez-Vallejo and Rogers 2004). A rough estimate indicates that only 20-25 percent of all cereal trade takes place from water abundant to water-short countries (Fraiture et al 2004).

Extremely water-short countries have no choice but to import food. Others with a choice between increasing pressure on water resources and increasing dependence on imports, are opting to face the environmental consequences of the former, rather than the political and economic consequences of the latter. For countries such as China and India—with large, growing populations and increasing water problems—a certain degree of food self-sufficiency is still a national priority. Moreover, the question remains whether the countries that will be hardest hit by water scarcity will be able to afford "virtual water."

And even if they can, what about the impact on livelihoods and food security for rural poor? Without money or market infrastructure (roads, etc) to distribute food, a heavy reliance on trade would simply not work for many rural poor. For many countries, improving agricultural productivity and rural incomes will remain a priority and may even be a prerequisite for virtual water flows.

Although it is unlikely that water concerns will shape global trade flows, virtual water may gain in importance during the coming decades. Article 92 of the declaration issued by the 2002 World Summit on Sustainable Development states that agreements under the WTO should be evaluated on social and environmental impacts. In view of the adverse effects of intensive irrigated agriculture on the environment, monitoring virtual water flows associated with agricultural trade should be included in the evaluation.

Farmer using homemade diversion canal to channel wastewater onto his fields, Pakistan.

Exploring alternative sources of water

Using wastewater or low-quality water for irrigation is another option put forward for reducing our demand for freshwater. Wastewater use has the advantage of limiting the pollution of the rivers and other surface-water bodies that would otherwise be used as disposal outlets. And from the prospective of reducing poverty, wastewater provides small-scale farmers with a reliable source of water and nutrients. However, use of untreated wastewater comes with some serious risks—to human health and to the environment. Research suggests that there are low-cost ways to minimize the risks associated with wastewater irrigation and maximize the benefits to the poor (Scott et al 2004).

Farmers across the developing world already use untreated wastewater for irrigation and the number is growing. Cities are predicted to use 150 percent more water in 2025; this means more wastewater, but also less freshwater available for agriculture. In the future, use of wastewater may not be a choice for many farmers, but a necessity.

Use of saline water for agriculture is another practice that is out of necessity increasing. Because irrigation tends to salinize land and water over time, increased irrigated production often means increased salinity. Better water and land management can help prevent this, but in areas already affected there are various options for productively using this water. These include blending saline water with fresh, timing application of saline water to match with the least salt-sensitive stages in crop growth, introducing salt-tolerant crops, and using saline water to produce fish. From a poverty perspective, reallocation of water within irrigation systems to achieve greater equity in terms of water quality can improve the situation of poor farmers and make systems more sustainable.

Will use of wastewater and saline water reduce the need for freshwater withdrawals and “free up” more water for environment? In the final analysis using wastewater and saline water for irrigation may improve the quality of water available for ecosystems in basins where there is still some outflow. But in basins where water allocation is a zero sum game agriculture will have to use wastewater and saline water as urban and industrial demand grows.

Improving irrigation efficiency

Many people believe that reducing the amount of water "wasted" in irrigation could solve much of the world's water problems (Gleick 2001, Winpenny 1997). The logic is that if irrigation is 40 percent efficient, then the other 60 percent is wasted. Thus by increasing irrigation efficiency, you should be able to make the water that would have been wasted available for the environment or other uses. Taking this pathway means plugging the leaks by lining canals, limiting the amount of water applied to fields through water saving practices and precision irrigation technologies, and encouraging conservation by pricing water.

But taking a step back and looking from the basin perspective, we see that most of the water we thought was being wasted is actually already being recaptured by farmers. Or it recharges groundwater or flows back into the river system to be used by people and ecosystems downstream. In some cases, when irrigation efficiency is improved downstream users (often the environment) can actually get less water because water gained from farm-level efficiency increases is used upstream. In southern Sri Lanka, cement lining of canals led to reduced groundwater recharge and consequently several shallow drinking-water wells dried out (Boelee and van der Hoek, 2002). These shallow wells provide better quality drinking water than fluoride-laden deep wells in the area.

There are many good reasons for improving irrigation efficiency. It can help prevent agro-chemicals from polluting rivers and groundwater, it can reduce waterlogging and salinization, and in some cases it can save water—for example if irrigation drainage is flowing into saline aquifers where it can't be reused. And many of the actions associated with improving irrigation efficiency—canal lining, precision irrigation, water pricing—can have other advantages.[1] But what we need to keep in mind is that in many basins, especially those that are already experiencing water stress, there is little or no irrigation water being wasted. This due to the prevalence of water recycling and reuse. Egypt's Nile (Molden et al 1998, Keller et al 1996), the Gediz in Turkey (GDRS 2000), the Chao Phraya in Thailand (Molle 2003), Bakhra in India (Molden et al, 2001) and the Imperial Valley in California (Keller and Keller 1995), are all documented examples. The bottom line? There is less scope for saving water in irrigation than previously thought. For many basins, we're going to need other solutions.

Growing more food with the water we use

In terms of freeing up water for the environment and other users, improving water productivity seems the best solution. By improving productivity it is possible to reduce the need for investments in new water withdrawals—investments which many countries can't afford in terms of financial and ecosystem costs. And with a pro-poor focus, it can contribute to the incomes and food security of some of the world's poorest people.

In its broadest sense, improving water productivity means obtaining more value from each drop of water—whether it's used for agriculture, industry or the environment. Improving agricultural water productivity generally refers to increasing crop yield or economic value per unit of water delivered or depleted.[2] But it can also be extended to include non-crop food such as fish or livestock.

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[1] For example, canal lining gives irrigation managers more control over water supply, water pricing provides cost recovery and accountability, and precision irrigation can increase yields and improve water productivity.

[2] We can consider water productivity in terms of the amount of water depleted by crop evaporation, or, in the case of irrigation, the amount of water applied to crops. Also instead of yield, we can look at the economic value derived per unit of water—so from this perspective farmers switching to higher-value crops; or enhancing fisheries and other ecosystem services would also be increasing water productivity.

Most people think of improving water productivity in terms of irrigated agriculture, but efforts should not just focus on the 2,500 km^3 of water diverted annually to irrigation, but must also include the 4,500 km^3 depleted in rain-fed agriculture. 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 1 percent increase in rain-fed cereal production would have 1.5 times more effect than a similar productivity increase in irrigated cereal production.

Ideally, improving water productivity should allow farmers to grow the same amount of food with less water. The water that is "freed up" can go to ecosystems and cities, or it can be used to grow more food. Of course, water productivity gains do have an environmental cost. They will in many cases require more fertilizers and agricultural chemicals, which can have negative consequences for the environment. But we feel these negative consequences can be minimized through better water and land management practices and that the positive benefits for the environment far outweigh the negatives.

How much scope is there for improving water productivity?

A rough estimation shows that improving water productivity by 40% on rain-fed and irrigated lands can reduce the need for additional withdrawals for irrigation to 0 over the next 25 years. Currently water productivity varies enormously leading us to believe that there is also large scope for water productivity increases. The amount of grain farmers get per cubic meter of water consumed (evapotranspired) ranges from 0.2 kilograms—typical of rain-fed systems in sub-Saharan Africa—all the way up to 2.5, found in highly productive rain-fed systems in Europe (Zwart and Bastiaanssen 2004). In a review of 40-irrigation systems, Sakthivadivel et al (1999) found a 10-fold difference in the gross value of output per unit of water consumed by evapotranspiration. Differences between countries are also notable (Cai and Rosegrant, 2003).

Many rain-fed and irrigated systems in the EU, USA, China, most of the Mediterranean region, and Brazil are already operating at high water productivity levels (Cai and Rosegrant, 2003). Systems in Asia and Africa with low-productivity and a high incidence of poverty should receive priority for productivity improvements. In sub-Saharan Africa, doubling or tripling yields is quite feasible with improved tillage and supplemental irrigation (Rockström et al. 2003).

Why do such large differences in water productivity, even within irrigated areas, occur? Some of these differences are due to environment as crops in temperate climates evaporate less than in hot dry climates, while producing the same or higher yields (Tanner and Sinclair 1983). But land and water management practices, influenced by policies and incentives, are major factors in influencing water productivity.

What's needed to improve water productivity?

A range of practices and technologies on rain-fed and irrigated land can lead to improved water productivity (Kijne et al, 2003). At farm and field scales, improved crop varieties and improved soil fertility boost yields and water productivity. More precise irrigation application using sprinkler or drip technologies or improved surface systems, such as laser leveling, can also enhance yield, and require less diversions of water. In dry areas, deficit irrigation—applying a limited amount of water but at a critical time—can boost productivity of scarce irrigation water by 10 to 20 percent (Oweis and Hachum 2003). Giving farmers better access to water for irrigation through groundwater development and small-scale technologies can increase productivity and reduce poverty in both irrigated and rain-fed areas. Within basins, allocating supplies to various uses to enhance values improves water productivity. Modifying the landscape, for example livestock grazing practices or changing land use, influences water flows (Falkenmark 2003) and thus water productivity.

Along with technical solutions, strong supporting policies are needed. For example, agricultural subsidies in rich-countries may discourage farmers in Africa from investing in productivity-enhancing inputs because crop prices are too low for them to get a return on their investment. Firm land and water rights are needed so people will invest in long-term improvements. Good governance, and water management along the principles of IWRM, are necessary for water productivity improvement increases.

Increasing water productivity is necessary, but not sufficient. In practice, local gains in water productivity provide an excellent incentive for farmers to intensify or expand cultivated area. For example, using drip irrigation, a farmer can irrigate more land, get more production and money with the same amount of water delivered to crops. More crops and more production, even with the same amount of water delivered, leads to *more* evapotranspiration, and may lead to further ecological degradation. Therefore, along with water productivity enhancements on-farm, must come rules for allocating scarce resources to make sure that water released from agriculture is used to meet other purposes such as ecological restoration.

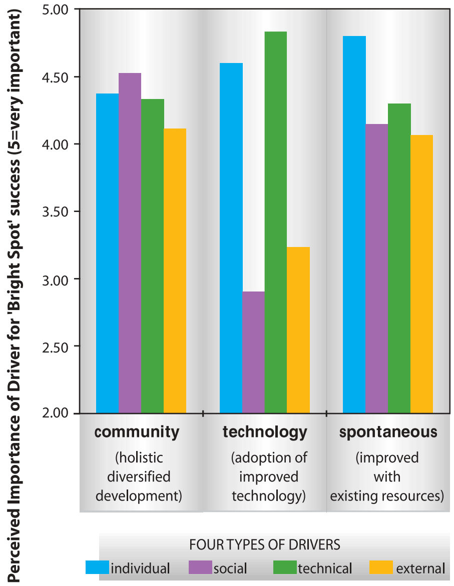
Reversing land and water degradation

Currently soil erosion, nutrient depletion, salinization and other forms of land and water degradation are putting the brakes on water productivity gains in many areas. World-wide 40 percent of agricultural land is moderately degraded and 9 percent is highly degraded—reducing global crop yield by as much as 13 percent (Wood et al. 2000). In rain-fed agriculture, land productivity is declining on an estimated 40 percent of cultivated area (Hansen and Bhattia 2004). Without reversing these trends, increasing water productivity will be impossible in large parts of South Asia and sub-Saharan Africa—regions particularly vulnerable environmental degradation.

But as with water harvesting and supplemental irrigation, we need to know more about how to spread positive examples. Research supported by the Comprehensive Assessment is looking at "bright spots"—where communities have managed to reverse both land and water degradation—to determine the major drivers of success (see figure 3).

In some cases, farmers may need incentives to make long-term investments in soil conservation and other land management practices—particularly when results from such investments do not have an immediate or direct impact on their incomes. Social and institutional factors such as land tenure also affect farmers' willingness to invest.

Figure 3. "Bright Spots" in reversing land and water degradation.



Research shows that it's not just improved technologies and practices that are needed to reverse land and water degradation—individual leadership and aspirations, social factors, and external factors, such as market opportunities, are at least, if not more important.

Improving irrigation service

Poverty remains chronic even in irrigated areas because of inequitable benefit sharing and poor irrigation performance (Hussain and Hanjra 2003). Improving water management for better equity and reliability in large-scale schemes through better service provision and conjunctive management of groundwater and surface water will increase water productivity and help those who have missed out on irrigation's benefits.

Perhaps the most important basic principle in irrigation is to deliver a reliable supply of water. In an uncertain environment, farmers will not invest in seeds, fertilizers, and land preparation, and consequently yields and water productivity will suffer.

Many past efforts in irrigation have focused on rehabilitation and modernization, or providing infrastructure to make sure that there is sufficient capacity to control water to provide more flexibility in supply for farmers. We feel that in many poorly performing irrigation systems, providing a stable, predictable water supply is a first priority, far above providing the capacity for flexible services. This may initially translate into relatively simple operating procedures and structures.

Guaranteeing women access to irrigation water and giving them a voice in water users association is another important, but often ignored, step in improving the productivity of many irrigation schemes (see box 2).

With increasing pressure on water resources, irrigation will have to respond to new pressures, and irrigation managers will have to shift from a narrow focus on supplying water to crops to managing water within a broader integrated water management context. Irrigation systems typically serve many uses well beyond crop production, and include water for fishing, bathing, small industries, livestock (Nguyen-Khoa et al forthcoming), and ecosystem functioning, but these are often not explicitly incorporated into designs and management plans. Managing water to meet all these needs will enhance benefits.

Box 4. Is large-scale irrigation still a good investment?

So what is the future for large-scale irrigation? Africa, in contrast to Asia, has very little irrigation, and a critical investment decision is how much more there should be? Views tend to be controversial and divisive, on one side pointing to the high investment, social, and environmental costs, and other side pointing to production, poverty and economic benefits.

That irrigation reduces is poverty has been documented in numerous studies (actual references). And according to the World Bank, each job created in irrigation sector costs $5,000 to $6,000 as compared to $44,000 in other sectors (World Bank 2004a, p 11). In terms of poverty reduction and job creation irrigation is still a good buy.

Secondary benefits of irrigation are also significant, and quite often exceed the primary crop production benefits. Non-irrigation benefits, often unintentional, are derived from the multiple uses of irrigation water (Meinzen-Dick and van der Hoek, 2001; Bakker et al., 1999). Rice systems, while often accused of consuming too much water, are also found to generate values well beyond rice production including ground water recharge, flood protection, preservation of cultural values (Matsuno et al, 2002, Boisvert et al, 2003).

On the negative side, the environmental costs of irrigation development have often been high, in terms of destroyed or degraded ecosystems. The World Commission on Dams (2000) studies point out the cost overruns and human costs in terms of people displaced from large dam projects. But given irrigation's proven benefits, there is a need to rethink and revitalize investments in large-scale irrigation to reduce investment, social and ecological costs. Rehabilitation, modernization, and participatory management need to embrace the opportunity to meet larger societal demands, including maintaining resilience of important ecosystems (Folke 2002).

Upgrading rain-fed systems

Globally, growing more on rain-fed lands means less need for irrigation diversion from rivers. And from a poverty perspective, upgrading rain-fed systems by introducing better soil/water management or supplemental irrigation has the most poverty-fighting potential. In South Asia nearly 75 percent of the poor depend on rain-fed agriculture for their livelihoods. In sub-Saharan Africa, over 60 percent of the population depends on rain-fed agriculture—which generates between 30 to 40 percent of those countries' gross domestic products (World Bank 1997, Rockström et al 2003, Wani et al. 2003). And agricultural productivity is generally very low in these regions, with yields hovering around 1 ton per hectare in many parts of sub-Saharan Africa, compared to the 6 to 7 tons per hectare common in rain-fed systems in the US and Europe. In these regions, investing in upgrading rain-fed systems can reduce poverty, malnutrition and environmental degradation.

Farmer using low-cost drip irrigation kit to improve yields and make the best use of scarce water.

Skeptics point out that rain-fed agriculture has been the focus of research for many years, that ideas have been in place for a long time, yet gains are not forthcoming, and thus rain-fed systems do not hold as much promise as claimed. On the other hand new small-scale, low-cost approaches such as treadle pumps, water bags, and water harvesting can provide the key to unlocking rain-fed potential and reducing poverty on marginal rain-fed lands.

Reducing vulnerability to drought

A major reason for low yields in marginal rain-fed systems is frequent short-term drought—no rain for two to three weeks drastically cuts yields (Barron et al., 2003; Hatibu and Mahoo, 2001). And farmers, understandably, are unwilling to risk investments in productivity-enhancing inputs such as fertilizers and higher-yielding crop varieties when their water supply is uncertain. In sub-Saharan Africa farmers run the risk of total crop failure due to drought once every five years and severely reduced yields once every two years.

Increasing water productivity in these regions focuses primarily on reducing vulnerability to short-term droughts. Options include water harvesting or groundwater development combined with small-scale supplemental irrigation technologies, development of drought-tolerant crops[3], and improved soil/water management practices.

Water-harvesting and supplemental irrigation have potential in areas where there is sufficient average rainfall over the crop season to obtain good yields, but where yields are greatly reduced by short-term (15- to 30-day) droughts at critical crop growth stages. Water stress at the flowering stage of maize, for example, will reduce yields by 60 percent, even if water is adequate during the rest of the crop season. Through water harvesting combined with supplemental irrigation, farmers can collect and store surplus water and apply it during critical crop growth stages if the rain fails. Studies by IHE-UNESCO suggest that with significant investments in water harvesting, conservation tillage and supplemental irrigation, yields of staple food crops could be more than doubled in many areas of sub-Saharan Africa (Rockström et al. 2003)

The technologies for the most part already exist; the challenge here is tailoring them to local situations and identifying the factors that influence uptake, including the necessary supporting institutions. Tools are also needed to assess the potential environmental impact of large-scale implementation of these small-scale solutions. Numerous small-scale water-harvesting and storage systems in a basin can have similar effects on river flows and aquatic ecosystems as a large dam and canal irrigation. For example, along the Yellow River, water conservation structures (bunds, gully-plugging) have been effective in encouraging agriculture and in reducing erosion, but there is evidence that these practices have reduced river discharge (Zhu et al. 2003)

What do we need to do to make these options a reality? More effective supporting institutions, in particular agricultural extension; the right mix of policies and incentives needed for farmers to invest—including land tenure and access to markets and credit; and more knowledge on how to spread positive practices and technologies and tailor solutions to local situations.

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[3]The Future Harvest Centers of the CGIAR have already released drought-tolerant varieties of several crops for evaluation by collaborating institutes and farmers. Crops include: rice (IRRI, WARDA), maize (CIMMYT), wheat (CIMMYT, ICARDA), barley (ICARDA), cowpea (IITA), groundnut (ICRISAT), lentil (ICARDA), and sweet potato (CIP).

Developing and managing groundwater

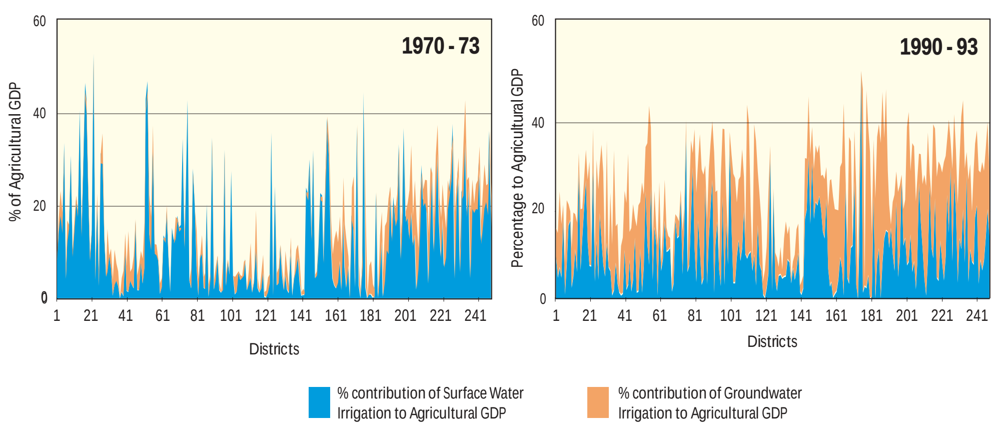
Groundwater can improve productivity by giving farmers access to water at the right time and in the right quantities. Because of this, groundwater irrigation can create several times more income per cubic meter than canal-based irrigation (Shah et al. 2001). And because it is available to anyone who can afford a pump in groundwater rich areas, groundwater has been a boon to poor farmers. Low-cost technologies such as the treadle pump helped fuel the groundwater boom in Bangladesh which turned the country from basket case to bread basket in a period of a few years.

Where investments in costly surface schemes haven't delivered, farmers have often invested in groundwater (figure 4). In India, farmers have invested around US$12 billion in groundwater pump structures—resulting in unsustainable use in many parts of the country. In sub-Saharan Africa, groundwater remains largely untapped, in part because of the costs of getting it out of the ground. But potentially it could provide a much needed source of water, especially for supplemental irrigation. Already farmers in Kenya, Niger, Malawi, Zambia and Zimbabwe are taking to the treadle pump.

But the challenge of groundwater is not how to develop it, but how to manage the resource sustainably. In large parts of South Asia and North China, groundwater tables are dropping as much as 2-3 meters per year. Poor farmers are hit first and hardest by unsustainable groundwater use—as it becomes more and more expensive to extract water as the water table drops. Wetlands can also be impacted by dropping water tables. Improving water productivity can help, but reducing groundwater depletion in some areas will likely mean less agriculture, less wealth and less jobs.

No country has completely solved the problem of sustainable groundwater management, but there are some examples of limited success. In India, community recharge initiatives have successfully reversed falling water tables (Shah 2000). In Mexico, aquifer management councils are providing farmers with education on sustainable groundwater use and a forum for dialogue on how to manage the resource sustainably (Shah 2004). In canal-based irrigation schemes, conjunctive management of groundwater and surface water can improve sustainability and help farmers with poor access to irrigation water (Hussain et al. 2004).

Figure 4. Change in contribution of groundwater and surface-water irrigation to agricultural GDP in India.



Investing in institutions

Water scarcity can be defined as lack of access to water to support basic human needs—including both health and livelihoods. The traditional supply side approach to dealing with water scarcity has been to build more infrastructure to tap more water resources. But in many instances, there is simply no new water to tap; or in other cases, water is managed so poorly that in spite of substantial water development people still lack access.

Several well-known authors have rightly questioned the sustainability of the current approach (Postel 1999, 2001; Gleick 2003, HRH Prince of Orange and Rijsberman 2000), calling for increased productivity of water along with better governance, institutional and policy reform instead of endlessly increasing supplies.

Various approaches to institutional reforms are being promoted by various organizations and development agencies: integrated water resources management, treating water as an economic good and water pricing, river basin management, devolution of management responsibilities to farmers through irrigation management transfer programs. While these hold promise and reform should be pursued, the experience in developing countries, particularly those with a high incidence of poverty, has been mixed at best, (Shah et al, 2002). Given this, it seems there is a need to take a hard look at recent experiences to see if new models for institutional reform or at least new approaches to implementation are needed.

It is also clear that providing more supplies to relieve scarcity will remain a necessity in some areas, especially sub-Saharan Africa. This is especially true in areas of economic water scarcity (IWMI 2000), where there is water available in nature, but financial and human capacity constraints limit its use. Here the question is not so much demand management, but rather how to make sustainable investments in additional water supplies that help the poor and how to set up institutions for sustainably managing the resource. Here small-scale infrastructure is highly appropriate because of its ability to target poverty and to give quick paybacks.

Finally, it is worth noting that policies outside of the water sector heavily influence how water is used. As discussed above, trade and water are intricately related. Roads and markets influence crop choice and thus water. Agricultural subsidies in developed countries have been identified as a major factor in keeping prices low for agricultural producers in developing countries.

Conclusions

There is too much complacency about water and food issues. Pressure from a growing population for more food also translates into more water and additional stress on our production and ecological systems. This increasing pressure will make it more difficult for the poor, who are most vulnerable to water scarcity and to environmental degradation. Continuing on our present path will mean more conflict, more environmental degradation, and the persistence of poverty and food insecurity. There are several alternate paths that could lead to a better future. However, some of the more popular solutions do not hold as much promise as previously thought. Diets and trade influence agriculture water use, but because water does not factor into decisions on diet and trade, it is difficult to manage these from a water perspective. Gains from increased irrigation efficiency—reducing “wastage” in agriculture—are a lot less than imagined.

The most promising approaches are gains in water productivity and upgrading rain-fed systems through better water management. Improving water productivity reduces the pressure to develop more water resources. And upgrading rain-fed systems in developing countries through additional water and water productivity gains can go a long way in reducing poverty and food insecurity for the rural poor. Better governance, policies, institutions and management will be essential to realize these gains.

Yet there remains uncertainty and controversy. For example, while there appears scope from improving rain-fed systems, we are not certain how far these can really go to provide food security. Controversy will remain just because people's values differ. But through informed dialogue, there is a chance of increasing consensus. The Comprehensive Assessment provides the opportunity to bring people and knowledge together to help resolve some of these burning issues of our times.

References

Acreman, M. 2000. Background study for the World Commission of Dams, reported in WCD (2000).

Alcamo, J., T. Henrichs and T. Rosch, 2000. World Water in 2025: Global Modeling and Scenario Analysis, in Rijsberman (ed), World Water Scenarios Analyses, Earthscan Publications, London.

Allan, T. 1998. Virtual water: A strategic resource. Global solutions to regional deficits. *Groundwater* 36(4): 545-546.

Bakker, M.; Barker, R.; Meinzen-Dick, R.; Konradsen, F. (Eds.) 1999. Multiple uses of water in irrigated areas: A case study from Sri Lanka. Colombo, Sri Lanka: IIMI. vii, 48p. (SWIM paper 8).

Barbier, E. B.; Thompson, J. R. 1998. The value of water: Floodplain versus large-scale irrigation benefits in northern Nigeria. Ambio, 27(6):434-440.

Barron, J., Rockström, J. Gichuki, N. Hatibu. 2003. Dry spell analysis and maize yields for two semi-arid locations in East-Africa. *Agriculture and Forest Meteorology* 177: 23-27.

Bhattarai, M.; Sakthivadivel, R.; Hussain, I. 2002. Irrigation impacts on income inequality and poverty alleviation: Policy issues and options for improved management of irrigation systems. Colombo, Sri Lanka: IWMI. vi, 29p. (IWMI working paper 39).

Boelee E & van der Hoek W (2002) Impact of irrigation on drinking water availability in Sri Lanka. ICID-CIID 18th Congress on Irrigation and Drainage, 21-28 July, Montreal, Canada. Q. 51, R. 5.04. International Commission on Irrigation and Drainage.

Boisvert, R.; Chang, H.; Barker, R.; Levine, G.; Matsuno, Y.; Molden, D. 2003. Water productivity in agriculture: Measuring the positive and negative externalities of paddy rice production. In World Water Council. Proceedings of Sessions on “Agriculture, food and water”—The Third World Water Forum (WWF3), 19 and 20 March 2003, Kyoto, Japan. Tokyo, Japan: Japanese Institute of Irrigation and Drainage. pp.203-215.

Cai, X.,and M. Rosegrant. 2003. World water productivity. In Kijne, J. W.; Barker, R.; Molden. D. (Eds.), Water productivity in agriculture: Limits and opportunities for improvement. Wallingford, UK; Colombo, Sri Lanka: CABI; IWMI.

Chapagain, A., A. Hoekstra. 2003. Virtual water flows between nations in relation to trade in livestock and livestock products. Water Research Report Series No.13. Delft, the Netherlands: IHE.

Falkenmark, 2003. Water management and ecosystems: Living with change. GWP TEC Background Report Nr 9. Global Water Partnership. Stockholm.

FAO. 1998. FAO factfile: feminization of agriculture. *http://www.fao.org/NEWS/FACTFILE/FF9806-E.HTM.* Last accessed July 2004.

FAO. 2003. World agriculture: Towards 2015/2030 – An FAO perspective. Eds Bruinsma. London: Earthscan Publucations.

FAO. 2004. Gender and Food Security. *http://www.fao.org/Gender/en/agri-e.htm.* Last accessed July 2004.

Folke, C. et al. 2002. Resilience and Sustainable Development: Building AdaptiveCapacity in a World of Transformations. Report for the Swedish Environmental Advisory Council 2002:1. Ministry of the Environment, Stockholm, www.mvb.gov.se and ICSU Series on Science for Sustainable Development No. 3, 2002. International Council for Science, Paris.

Fraiture, C. de, X. Cai, U. Amarasinghe, M. Rosegrant and D. Molden. 2004. Does cereal trade save water? The impact of virtual water trade on global water use. Comprehensive Assessment Research Report no.4 Colombo, Sri Lanka: International Water Management Institute.

Gleick, P. H. 2001. Safeguarding our water - Making every drop count. *Scientific American.*

Gleick, P (2003). ‘Soft Path’ solution to 21st-century water needs. Science 320(5650):1524-1528.

Gordon, L., Folke, C. 2000. Ecohydrological landscape management for human well-being. *Water International* 25(2): 178-184.

GRDS 2000.IWMI and GDRS (IWMI and General Directorate of Rural Services). (2000) Irrigation in the basin context: The Gediz river basin Study, Turkey. International Water Management Institute, Colombo, Sri Lanka.

Hansen, S. and R. Bhatia. 2004. Water and Poverty in a Macro-economic Context. Paper commissioned by the Norwegian Ministry of the Environment in preparation of CSD12, April 19-30, United Nations, New York.

Hatibu, N.; Mahoo, H. 2001. Rainwater harvesting technologies for agricultural production: A case for Dodoma, Tanzania. Unpublished report. Sokoine University of Agriculture. Department of Agricultural Engineering and Land Planning, Morogoro, Tanzania.

Hoeksta, A.Y.; Hung, P.Q. 2002. Virtual water trade: a quantification of virtual waterflows between nations in relation to international crop trade. Value of Water Research Report Series No.11. Delft, the Netherlands: IHE.

HRH The Prince of Orange and F.R. Rijsberman. 2000. Summary Report of the 2nd World Water Forum: From Vision to Action. Water Policy 2(2000):387-395.

Hussain, I.; Hanjra, M. A. 2003. Does irrigation water matter for rural poverty alleviation?: Evidence from South and South-East Asia. Water Policy, 5(5-6):429-442.

Hussain, I.; Mudasser, M.; Hanjra, M. A.; Amrasinghe, U.; Molden, D. 2004. Improving wheat productivity in pakistan: Econometric analysis using panel data from Chaj in the Upper Indus basin. *Water International*, 29(2): pages: 189-200.

IWMI, 2000. World Water Supply and Demand in 2025, document prepared for the World Water Vision, in Rijsberman (ed), World Water Scenarios Analyses, Earthscan Publications, London.

Keller, A.; Keller, J.; Seckler, D. 1996. Integrated water resource systems: Theory and policy implications. Colombo, Sri Lanka: IIMI. iii, 15p. (IIMI research report 3).

Keller, A. A.; Keller, J. 1995. Effective efficiency: A water use efficiency concept for allocating freshwater resources. USCD Newsletter, No.71:4-13; pp.5-19. (Winrock International. Center for Economic Policy Studies, discussion paper 22 / IIMI reprint 1).

Kijne, J., R. Barker, D. Molden. 2003. Water productivity in agriculture: limits and opportunities for improvement. CAB International, Wallingford, UK.

Koppen, B. van 2002. A gender performance indicator for irrigation: Concepts, tools and applications. Research Report 59, Colombo: Sri Lanka, International Water Management Institute.

Lemly, A. Dennis; Kingsford, Richard T.; Thompson, Julian R. 2000. Irrigated agriculture and wildlife conservation: conflict on a global scale. Environmental Management. 25(5): 485-512.

Lipton, M.; Litchfield, J.; Faurès, J. M. 2003. The effects of irrigation on poverty: A framework for analysis. Water Policy, 5(5-6):413-427.

Meinzen-Dick, R. S.; van der Hoek, W. 2001. Multiple uses of water in irrigated areas. Irrigation and Drainage Systems, 15(2):93-98.

Matsuno, Y, H. S. Ko; C. H. Tan; R. Barrer; G. Levine. 2002. Accounting of Agricultural and Nonagricultural Impacts of irrigation and drainage Systems. Working paper 43. . International Water Management Institute: Colombo, Sri Lanka.

Molden, D. J.; el Kady, M.; Zhu, Z. 1998. Use and productivity of Egypt's Nile water. In Burns, J. I.; Anderson, S. S. (Eds.), Contemporary challenges for irrigation and drainage: Proceedings from the USCID 14th Technical Conference on Irrigation, Drainage and Flood Control, Phoenix, Arizona, June 3-6, 1998. Denver, CO, USA: USCID.

Molden, D. J., R. Sakthivadivel, and Z. Habib**.** 2001 *Basin Level Use and Productivity of Water: Examples from South Asia.* Research Report 49. International Water Management Institute, Colombo, Sri Lanka.

Molle, F. 2003. Allocating and accessing water resources: Practice and ideology in the Chao Phraya River Basin. In Molle, F.; Srijantr, T. (Eds), Thailand's rice bowl: Perspectives on agricultural and social change in the Chao Phraya Delta. Bangkok, Thailand: White Lotus Press.

Nguyen-Khoa, S. , L. Smith, K. Lorenzen. Forthcoming. Appraising irrigation impacts on fisheries for improved development. Case studies in Laos and Sri Lanka. Comprehensive Assessment Research Report. Colombo, Sri Lanka: international Water Management Institute.

Oki, T.; Sato, M.; Kawamura, A.; Miyake, M.; Kanae, S.; Musiake, K. 2003. Virtual water trade to Japan and in the world. Proceedings of the international expert meeting on virtual water trade, eds., A.Y. Hoekstra; P.Q. Hung. Delft, the Netherlands: IHE.

Oweis, T. Y.; Hachum, A. Y. 2003. Improving water productivity in the dry areas of West Asia and North Africa. In Kijne, J. W.; Barker, R.; Molden. D. (Eds.), Water productivity in agriculture: Limits and opportunities for improvement. Wallingford, UK; Colombo, Sri Lanka: CABI; IWMI.

Polak. 2004.Water and the Other Three Revolutions Needed to End Rural Poverty. Prepared for the Stockholm Water Symposium.

Postel, S (2001). Safeguarding our water - Growing more food with less water. Scientific American February, 2001: pp. 40-45.

Postel, S (1999). Pillar of Sand: Can the Irrigation Miracle last? (Norton, New York).

Ramirez-Vallejo J., P. Rogers. 2004. Virtual water flows and trade liberalization. *Water Science and Technology*: 49(7): 25-32.

Renault, D., W. Wallender. 2000. Nutritional water productivity and diets. Agricultural Water Management, 45(3): 275-296.

Rijsberman, F. 2003. Can development of water resources reduce poverty? Water Policy, 5(5-6):399-412.

Rijsberman, F.R. and D.J. Molden. 2001. Balancing Water Uses: Water for Food and Water for Nature. Thematic Background papers. International Conference on Freshwater, Bonn, 3-7 December. Pp. 43-56.

Rockström, J., L Gordon, L. Falkenmark, M. Folke, M. Engvall. 1999. Linkages among water vapor flows, food production and terrestrial services. *Conservation Ecology* 3(2), 5, 1-28. *http://www.consecol.org/vol3/iss2/art5*.

Rockström, J. Barron, P. Fox. 2003. Water productivity in rain fed agriculture: challenges and opportunities for smallholder farmers in drought-prone tropical agroecosystems. In Kijne, J. W.; Barker, R.; Molden. D. (Eds.), Water productivity in agriculture: Limits and opportunities for improvement. Wallingford, UK; Colombo, Sri Lanka: CABI; IWMI.

Rosegrant, M., X. Cai, S. Cline. 2002. World Water and Food to 2025. Dealing with scarcity. Washington DC: International Food Policy Research Institute.

Sakthivadivel, R.; de Fraiture, C.; Molden, D. J.; Perry, C.; Kloezen, W. 1999. Indicators of land and water productivity in irrigated agriculture. International Journal of Water Resources Development, 15(1/2):161-179.

Scott, C., N. Faruqui, L. Rashid-Sally (Eds). 2004. Waste Water Use in irrigated agriculture. Confronting the livelihood and environmental realities. CAB International, Wallingford, UK.

Shah, T. 2000. Mobilising social energy against environmental challenge: Understanding the groundwater recharge movement in Western India. Natural Resources Forum, 24(3):197-209.

Shah T., M. Alam, D. Kumar, R.K. Nagar, M. Singh. 2000. Pedaling out of poverty: social impact of a manual irrigation technology in South Asia. Research Report 45, Colombo: Sri Lanka, International Water Management Institute.

Shah, Tushaar, Ian Makin, R. Sakthivadivel and M. Samad (2002) “Limits to Leapfrogging: Issues in Transposing Successful River Basin Management Institutions in the Developing World”. Charles L. Abernethy, Ed. *Intersectoral Management of River Basins*. Colombo: International Water Management Institute.

Shah, T.; Molden, D.; Sakthivadivel, R.; Seckler, D. 2001. The global groundwater situation: Opportunities and challenges. Economic and Political Weekly, 36(43):4142-4150.

Shah, T.; Singh, O. P. 2003. Can irrigation eradicate rural poverty in Gujarat? Gujarat, India: IWMI-TATA Water Policy Program. 7p. (Water policy research highlight 10).

Seckler, D., D. Molden, U. Amarasinghe, C. de Fraiture. 2000. Water issues for 2025: A research perspective. IWMI’s contribution to the 2nd World Water Forum. Colombo, Sri Lanka: International Water Management Institute.

Shiklomanov, I. 2000. Appraisal and assessment of world water resources. Water International 25(1): 11-32.

SIWI and IWMI, 2004. Water – More Nutrition per Drop. http://www.siwi.org/downloads/More_Nutrition_Per_Drop.pdf

Smakthin, V., C. Revenga, P. Döll. 2004. Taking into account environmental water requirements in global-scale water resources assessments. Comprehensive Assessment Research Report no.2. Colombo, Sri Lanka: International Water Management Institute.

Song, Y. (1999), “Feminization of Maize Agricultural Production in Southwest China.” *Biotechnology and Development Monitor*, No. 37, p. 6-9.

Tanner, T and Sinclair, T. 1983. Efficient water use in crop production: Research or Re-Search? *Limitations to efficient water use in crop production.*

Winpenny, J. T. 1997. Demand management for efficient and equitable use. In Kay, M.; Franks, T.; Smith, L. (Eds.), Water: Economics, management and demand. London, UK: E & FN Spon. pp.296-303.

Wani, S. P.; Pathak, P.; Sreedevi, T. K.; Singh, H. P.; Singh, P. 2003. Efficient management of rainwater for increased crop productivity and groundwater recharge in Asia. In Kijne, J. W.; Barker, R.; Molden. D. (Eds.), Water productivity in agriculture: Limits and opportunities for improvement. Wallingford, UK; Colombo, Sri Lanka: CABI; IWMI.

World Commission on Dams. 2000. Dams and Development A new framework for Decision-making. The report of the World Commission on Dams. Available from *http://www.dams.org*

World Bank. 2004a. Irrigated Agriculture in the Brazilian Semi-Arid Region: Social Impacts and externalities. Volume 1: Main Report. Brazil Country Management Unit. World Bank, Washington DC.

World Bank. 2004b. Agriculture and rural development website. *http://lnweb18.worldbank.org/ESSD/ardext.nsf/11ByDocName/AgricultureRuralDevelopment*. Last assessed 2004.

World Bank. 1997. World development Report 1997. Washington DC: World Bank.

Wood, S.; K. Sebastian; S. J. Scherr. 2000. Pilot analysis of global ecosystems: Agroecosystems. Washington, D.C.: International Food Policy Research Institute, and World Resources Institute. 110 pp.

Zhu, Z., M. Giordano, X. Cai, D. Molden. 2003. Yellow River comprehensive assessment: basin features and issues. Working Paper 57. Colombo, Sri Lanka: International Water Management Institute.

Zwart, S.J.; Bastiaanssen, W.G.M. 2004. Review of measured crop water productivity values for irrigated wheat, rice, cotton, and maize. *Agricultural Water Management.* Accepted.

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