Challenge Program on Water and Food Background Paper 4

Integrating Research in Water, Food and Environment

Contributors

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Introduction

Effective management of basin water for food production requires a better understanding of a complex set of water-related interactions that occur across spatial and temporal scales, and within various locations of a basin. A major problem in many basins worldwide is a lack of effective water governance structures that can put this understanding into action.

The purpose of this paper is to scope out the likely research issues that require an integrated water resources management (IWRM) perspective. The objectives are twofold. The first is to ensure that work undertaken in the other four themes is mutually coherent, and fits well into a framework of an integrated water- and land-resources management (figure 1). It will serve as a "reality check" on the trade-offs and synergies that are offered by the different strands of the Challenge Program (CP) research themes and test their relevance at multiple scales up to basin level. The second objective is to undertake research into key problems within the realm of IWRM that have particular relevance to the improvement of crop productivity and production, alleviation of poverty and enhancement of environmental security.

BACKGROUND

Increased water resources for agriculture provided the fuel for the green revolution. World food production has outpaced population growth,[1] and food prices have declined markedly. Rural farmers and the poor have both been beneficiaries of these gains.[2] But the task of providing food security to all is incomplete. Malnutrition persists in much of South Asia and sub-Saharan Africa —much in regions dubbed economically water scarce, meaning that while there is water in nature, sometimes abundantly, it has not been developed for human use. There is a significant weight to the argument that scarcity is caused by people not having enough access to water rather than to the absence of sufficient water (Soussan 2002). Areas of intensive agricultural water use tend to experience land and water degradation, resulting variously in salinization, declining water quality and groundwater and degraded

[1]This is especially true in the developing countries where food production increased 3.4 percent annually, exceeding the annual population growth of 1.5 percent in the 1990s.

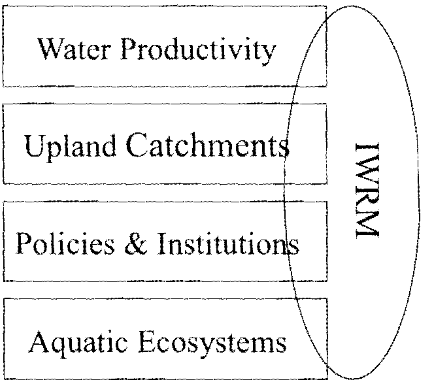
[2]A review of 585 irrigation projects by the World Bank found an internal rate of return of 15 percent. But many projects have underperformed or have had external social or environmental costs. The benefits, costs and impacts of irrigation remain controversial.

coastal ecosystems. The effects strike first and hardest at the poor and threaten the resource base on which food production depends.

Integrated approaches to managing water offer solutions. We use the definition of IWRM taken from the Global Water Partnership (GWP/TAC 2000):

> *IWRM is a process, which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.*

Figure 1. Integrating work of other thematic areas.



IWRM integrates *natural* and *human* systems and thus influences water quantity, quality, and use, and where and how many benefits are derived.

It is of critical importance that the Water and Food Challenge Program identifies the most important areas of integration that will mitigate the water crisis. The IWRM theme serves the dual purpose of using the IWRM framework to explore key areas of integration, and to provide a means to integrate the work of other thematic areas of the CP.

The problems of basins where water has been intensively developed and used are clearly different from those where people would like to abstract apparently ample supplies to relieve problems of water scarcity. The intensively irrigated North China Plains, or Pakistan's Punjab, have a different set of problems than where farmers need to organize to tap into water sources in the hills and Terai of Nepal, or on the African plains. In general, these two are the basic problems facing IWRM in the world today—exploiting water resources to relieve water scarcity and improve livelihoods, and second, to manage highly stressed river systems and yet promote sustainable development.

This can be illustrated by conceptualizing phases of river basin development (see Keller et al. 1998; Ohlsson and Turton 2000; Allan 2001 for similar discussion).[3] In its most basic form, water scarcity is a situation where people cannot access this water for drinking or to grow crops. As a reaction to water scarcity, people tap basin-water resources. Hydraulic structures, ranging from simple stone- and wood-diversion structures to complex dam, canal and drainage systems supply water from streamflow for drinking and industrial supplies, and for agriculture. Rain-fed agriculture converts land use from its previous cover (forest, grassland) to cropland, with varying impacts on the previous hydrologic balance.

At any course in time, we develop an available water supply, limited by the amount of hydraulic structures and rain-fed agriculture. When demand exceeds this available supply, one response is to provide more supply by expanding either hydraulic infrastructure or rain-fed agriculture. This supply approach is ultimately limited by the amount of land and water resources within a basin, the technical and economic limits we have in abstracting this supply (it would be difficult to divert the entire Amazon), ecological thresholds beyond which ecosystems cannot sustain land- and water-use practices, and societal desires about use of water, which change over time in response to the state of a country's social development and economy.

Figure 2 represents a typical progression of river-basin development over time with the original runoff and rainwater sources shown on the y-axis, and time on the x-axis. Over time, more water is made available for human uses from streamflow or groundwater by building structures (dams, diversions, groundwater pumps) yielding a stair-step pattern. Larger dam or diversion structures would yield a sudden jump in the amount of water made available. After a new dam is built, it takes time to deplete all available water by converting it into evaporation. Populations grow, wealth grows and demand increases, until depletion reaches the available supply, when possibly another structure is built. Similarly, conversion of land to rain-fed agriculture yields more water (directly from rain) for agriculture. Rain-fed expansion continues until a limit is reached. Figure 2 graphically illustrates three important phases of river-basin development implicit in the above discussion. The progression continues until the threshold is reached.

Development. In this phase the amount of naturally occurring water is not a constraint. Rather, expansion in demand drives the construction of new infrastructure and expansion of agricultural land. Institutions are primarily engaged in expanding facilities for human use. Among others, Turton and Ohlsson (1999) refer this to the supply-side phase.

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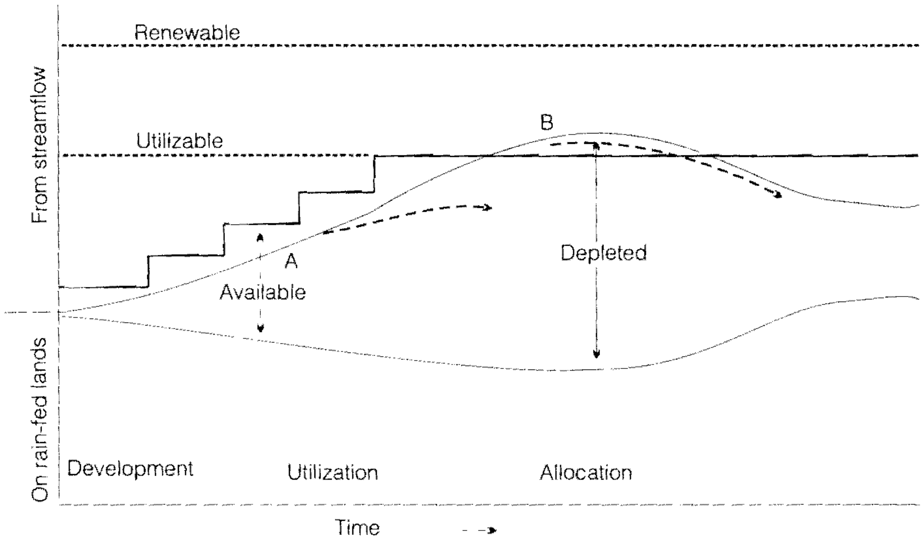
[3]Falkenmark uses "blue water" and "green water" to usefully describe these processes. In an undisturbed state, rainwater contributes to river runoff, termed "blue water," or vaporizes before reaching rivers through processes of evapotranspiration, or "green water" flows.

Figure 2. Phases of river basin development.



Utilization. Significant construction has taken place, and the goal now is to make the most out of these facilities. Water savings and improved management of water deliveries are important objectives. Early in this stage, inter-sectoral competition is minimal. Institutions are primarily concerned with sectoral issues, such as managing irrigation water, or managing drinking water supplies.

Allocation. When depletion approaches the potential available water there is limited scope for further development. We refer to this as a "closed basin." Efforts are placed on increasing the productivity or value of every drop of water. An important means of accomplishing this is to reallocate water from lower to "higher-value" uses. Valuation of water to achieve both sustainability and equity in allocations among competing demands becomes a major issue. Managing demand becomes increasingly critical. Infrastructure construction is limited to those that aid in regulation and control. Little scope remains for "real water savings." Institutions are primarily involved in allocation, conflict resolution and regulation. Several important management and regulatory functions gain prominence, including inter-sectoral allocation. National-level coping strategies include industrialization and trade for food, thereby importing "virtual water" (Allan 1996). Turton and Ohlsson (1999) refer to this as the demand-management phase.

Options at this point (**B**) are limited by the amount of water resources, and the amount of water that can be brought in by trans-basin diversions. Mining of water resources can, and often does, lead to depletion levels over the utilizable limit. Mining of groundwater in the North China plains is an example. Eventually though, human depletion must reduce to below-sustainable limits.

This progression of water use explains in part why IWRM is not common practice. During the initial development phase, a concern is to provide access to water, typically along sectoral lines, for irrigation, or for urban uses. Because there are apparently ample supplies at this early phase upstream-downstream impacts are not profound, and there is little felt need to think cross-sectorally, or in a whole river-basin sense. It is only later, when actions at one part of the basin start to affect someone else, that issues of allocation arise. Institutions, though originally designed to construct, do not easily make the transition to managing difficult issues of water delivery and maintenance to allocating scarce resources and managing adverse impacts. Water bureaucracies are very creative in maintaining their construction and supply-driven orientation even in fundamental institutional reform processes (Rap et al. 1999).

The issues that arise from growing pressure on the water resources relate to the integration of management of the resource, water scarcity, implications for the poor and the environment, and the rate at which the water-resources situation changes.

Water scarcity. Construction of facilities provides access to water, and relieves water scarcity. But even with facilities to provide access, scarcity can exist. A condition of institutional scarcity exists when laws, traditions, or organizations restrict access or are inadequate to distribute water to all, leaving some people with water scarcity. Physical or absolute scarcity exists when the demand for water outstrips the facilities to tap into resources. Physical scarcity exists, for example, in the North China Plains where there is no more water left for the next user who may wish to develop a new supply.

Water and poverty. Water scarcity in each phase of development has important implications for poverty (Sullivan 2001; Schreiner and van Koppen 2000). During the development phase, an important consideration is to identify the beneficiaries. Will infrastructure benefit poor people? Will more powerful people capture the benefits? The problems change during the utilization phase. Even though conveyance structures exist, management may not meet the needs of the poor. During the allocation phase, water is reallocated amongst sectors and people. When water moves away from agriculture to cities and industries will the poor and less-powerful be able to maintain their right or access to water, or will they find employment in other sectors? Will poor people be able to capture the economic gains when water moves to higher-valued uses?

Water and environment. Hydraulic infrastructure alters natural flow regimes and facilitates the change in landscape with growth in agricultural areas and cities. During the utilization phase, water use and depletion intensify, further removing water that has other important ecological functions. A common "solution" to scarcity is to eat into natural reserves of ecological significance for more water, resulting in damaged wetlands or loss of biodiversity in ecosystems generally. During the early phases of development, dilution can be sufficient to solve pollution problems. During the allocation phase, dilution is not an option, because there simply is not enough water. Clean-up at the source becomes increasingly critical.

Fast and slow variables. Water management is most often concerned with distributing supplies or responding to highly variable climatic conditions. We tend to look for the most expedient solutions to these immediate problems. Unfortunately, problems of groundwater, salinity buildup, nutrient mining and intrusion of saline water creep up unnoticed and suddenly become severe problems. They have considerable momentum and are therefore slow to turn around and may incur very significant costs and serious casualties on the way.

FUTURE CHALLENGES

We see two important future challenges. The first is for those river basins early in development phases but with pressure to use more water resources at position **A** (figure 2). The challenges are to use water more sustainably, and to avoid the institutional, environmental and poverty pitfalls of rapid development.

A second challenge is for those areas of the world already intensively developed, approaching or past sustainable limits to come back to sustainable limits (move from position **B** to a future point). Restoration is a key agenda.

In the first case, foresight and the ability to make early changes are required before "slow variables" become a problem. Adaptive governance arrangements that can respond to issues of scarcity or environment before a crisis hits are therefore necessary. We recognize that water use changes affect others within a basin, and more strongly as the basin approaches the allocation stage. Many of the issues of governance and scale fall across traditional sectoral or organizational boundaries, such as the critical water use interfaces of agriculture and environment; and agriculture and urban areas. These need a special focus. The most critical "slow variables" for agricultural water use have to do with the quality and quantity of groundwater.

Five key problem themes have been identified for special investigation within an integrated framework. All are underwritten by significant issues of governance, which are introduced in the section under **Governance: A Common Thread in IWRM.** Modeling and other decision support tools will be a fundamental component of almost all research methodologies and are discussed briefly in box 1.

Box 1. Decision support tools for integrated management.

> Although there is already an extensive literature and software for decision support, there is a need to adapt and develop tools to address complex water/food/environment problems, assist stakeholders in putting policy into action and to develop effective management strategies. Such tools would cover technical, social and economic aspects of land and water management at the basin scale. They would be applied to well-defined sets of intervention points, some of which are expected to emerge from the other working groups.
>
> Models will play an essential role in predicting outcomes ("what-if scenarios") and in understanding the possible consequences of interventions in terms of food security, poverty and vulnerable groups, ecosystem services and other important management objectives. They will also be required to scale up the expected impacts of field research, nested at different scales, to the basin scale, using a variety of assumptions on the ultimate uptake and spread of technologies, management packages and so on.
>
> The third use of models is in scaling down the likely impacts of policy and higher-level interventions (water rights registration, cost recovery pricing, etc.) at a more local scale.

The first problem concerns generic issues of land and water management and is encapsulated by "Upstream-downstream interactions and scales of analyses." The complexities of hydrology, land interactions and flow paths through the landscape are fundamental to the question of human development and use of water resources, and have many counterintuitive characteristics, which require careful analysis over multiple spatial and temporal scales. The subsequent topics are in some ways subsets of this first theme, but have specific characteristics that merit separate consideration.

The second, groundwater management, is a particular case, where there are two major problems in large but discrete areas of the world, severe overexploitation and degradation of aquifers (USA, Turkey, India, China, Mexico) and insufficient utilization of potential resources for agriculture (sub-Saharan Africa). The third, there is rapidly rising interest and action in implementing strategies to increase the production and productivity of rain-fed agriculture, through small-scale water harvesting technologies that are perceived to be pro-poor and hydrologically benign.

As these interventions are replicated, there is a need to evaluate their inevitable impacts on water availability at the catchment and basin scale.

The fourth focus falls on the dramatic extent and pace of urban development and the associated problems of managing the transfer of rural water to urban use, and on an important niche of urban and peri-urban agriculture and the use of wastewater.

Last, the problem of agricultural development and environmental sustainability requires broad-based and detailed research, to quantify ecosystems services, define and quantify impacts of agricultural development and management on them, and understand trade-offs so that appropriate solutions are offered to policy makers and users.

It is very clear that many issues of governance are central to each of the selected topics, and will be managed as a "hidden" theme, a common thread running through all four. The central focus of the Challenge Program is on the development of new solutions, and this requires the provision of appropriate tools and production systems that can be managed within practicable institutional frameworks and respond to well-contextualized needs. New solutions should be designed to provide opportunities for new policies and the substance to implement existing ones.

1. *Upstream-downstream interactions and scales of analyses.* All-too-frequently people are involved in actions aimed at improving the lives of a target group of people engaged in managing resources at a farm or a system. But a water-related action taken in one part of the basin affects other human and environmental uses elsewhere within the basin to varying, and often difficult-to-predict degrees. Even with best intentions, alleviating problems in one area, may exacerbate poverty in another area. Understanding of trade-offs between equity, productivity and efficiency, requires understanding of scale issues. A key challenge is to understand these complex relations, and integrate this understanding within governance structures.

2. *Groundwater.* Groundwater has proven to be a key source of water to improve the livelihoods of millions of rural poor globally, and potential remains for its exploitation. At the same time, depletion and degradation of the groundwater resource threatens this livelihood-sustaining resource base. Integrating both groundwater with other water sources and its use across sectors requires urgent attention, especially in developing countries where its use is rapidly growing.

3. *Enhanced rain-fed agriculture.* Equitable and productive use of rainwater requires a clear understanding of scale and needs to be accompanied and guided by sound governance procedures. The true effectiveness and equity benefits of rainwater harvesting and other enhanced rain-fed technologies need to be assessed and where necessary improved. In some situations, improvements in agriculture on primarily rain-fed land will be the key to production and livelihood gains, and relieve pressure on developing new sources of river water. On the other hand, the hydrological impacts of multiple small dams, water harvesting and increased infiltration on streamflow and groundwater recharge need to be investigated, so that the scale of such developments is planned and managed appropriately.

4. *The urban-agriculture interface.* Reallocation of water from agriculture or rural areas to urban areas is a commonly observed phenomenon. In 2025, urban and industrial water use is projected to grow by 87 percent compared to 1995, which will generate 182 km^3 of return flows, compared to an estimated growth in agricultural diversions of 440 km^3. Domestic return flows in 2025 are estimated to be 13-17 percent of total agricultural diversions (IWMI 2000; Shiklomanov 2000). If there is little expansion in agricultural supplies, it is likely that supplies to agriculture will decrease. Other growing trends are peri-urban agriculture made possible by informal irrigation, and including irrigating with urban wastes. Negotiating this reallocation, coping with reduced supplies in rural areas, and dealing with issues of health and pollution, all have strong health and livelihood implications.

5. *The agriculture-ecosystem interface.* We surmise that agriculture will lose water in the competition with urban areas because water will move from lower-to higher-valued uses. The lower-valued uses for agriculture and environment will be the residual users of water. Food and environmental security will be dependent on how this interface is managed.

Each of these topics is discussed in the following sections and provides a brief analysis of the situation, and the challenges that are present in general and also in the context of governance, natural science and resources management.

Box 2. The basin: The basic unit of integration within the Challenge Program.

River basins are chosen as the basic unit of analysis within the Challenge Program on water and food. This differs from an eco-regional approach, as a basin can cross several eco-regions, and this a priori selection may differ from an Integrated Natural Resources Management (INRM) approach, where water may not be the key entry point even though it is important.

The main reason for selecting basins is to allow us to consider all water uses simultaneously within the context of the natural hydrologic cycle of rainfall, runoff generation, use and disposal of water. Large amounts of water use by agriculture can be particularly detrimental to the natural hydrologic cycle and impact other uses. Without a basin context, it is difficult to catch these IWRM interactions.

Various programs can be integrated within the basin framework. For example, how do upper-catchment activities relate to downstream irrigation and fisheries, or how does drought-resistant bean breeding affect overall basin planning? Drought-resistant varieties, along with other rain-fed or mixed rain-fed and irrigated management innovations, may provide solutions that require less water in one location within a basin, leaving additional water for other uses. Answers to these questions will rely on how tools are developed to understand issues of scale.

By working at the same location we can capitalize on knowledge accumulated, facilitate the integration of ideas across disciplines and resource managers within the basin, and concentrate activities to make a difference to the communities dependent on basin water. Within a basin, for example, a group of people may be working on bean breeding, management of catchments, fisheries and with basin authorities.

Results found in different basins can be compared and contrasted to synthesize generic lessons. To do this, the integration group will set up a common data and analysis protocol across basins. Will solutions developed in one basin be applicable to other environments, or what adaptations are required? Working across basins, generic solutions can be identified, and the impact of research can be extended more broadly.

Information from basins conforming to an agreed data protocol will allow linkages for programs exploring regional and global processes and global change scenarios. For example, changes in land use will affect temporal and spatial patterns of evaporation and precipitation. Information on important demographic shifts from on-the-ground information can influence predictions of global models. Scenarios from global models on climate change or food prices can help planners at the basin level design for the future.

Where should the challenge program be focused? One means of selection is to include basins at various stages of development. Other considerations include environment—arid, semiarid, humid; and geographic focus—Asia, Latin America and Africa. Another issue is whether to select subbasins that represent key problems or processes, or whether to select larger international basins where cross-country negotiations become important. If we can master scale considerations, it is possible to choose relatively large international basins, using a nested scale approach to capture key relationships within various parts of the river basin.

If the Challenge Program research is conducted in Comprehensive-Assessment-reference basins, there will be a well-organized body of information and data and a solid baseline against which changes and impacts can be measured. In "new" Challenge Program basins, these baseline data will need to be collated and used as a reference for developing good adaptive management strategies over a 10-15 year period. A process of stakeholder identification and consultation will be required early in the development of work in the focus basins and catchments.

GOVERNANCE: A COMMON THREAD IN IWRM

In recent years, the notion of good governance has figured prominently in discussions amongst development planners, donor agencies and NGOs concerned with water. This has grown out of the widespread perception of "state failure:" the realization of the inability of the state to effectively address some salient problems of society. The current water crisis is often seen as a crisis of governance. The institutional strength of the state to efficiently manage water resources has been challenged from several different sources, particularly its failure to integrate policies and practices related to the management of water resources (Vermillion and Merrey 1998; World Bank 1993). Governance has emerged as one of the key challenges facing water professionals. Effective governance is a prerequisite to achieving IWRM.

With water scarcity and increasing competition for water, the need for more effective and adaptive governance and institutional frameworks for managing river-basin water resources plays an increasingly critical role.

The concept of governance is often not readily understood and may be used in different ways. The GWP defines Water Governance as *different political, social and administrative mechanisms that must be in place to develop and manage water resources, and the delivery of water services, at different levels of society.*

The experience of water reforms in the developed world has had a profound influence on the prescription of the institutional reform agenda in developing countries and in the specification of what constitutes good governance, with principles such as treating water as an economic good being enshrined in successive international meetings from UNCWE (United Nations 1992) to the second World Water Forum in 2000 (Briscoe 1996; Perry et al. 1997). Clearly, there is a gulf between the normative prescriptions of good water governance and actual practice in the developing (and developed) world. The emerging conventional wisdom in natural resources and environmental management focuses on the basin as the fundamental unit of integration, although Allan (1996) shows that the "closed" environmental system of the basin lies within broader and open political and economic systems, which can offer solutions through access to regional and global markets.

The degree to which such notions, prescriptions and innovations are translated into practice, and how they are modified, ignored and contested are of great practical merit in evaluating and developing design principles for effective institutions in land and water management in the developing world.

It is clear and logical that governance issues underwrite the context, analysis and development of research in each of the four themes for focusing IWRM-related research within the Challenge Program. Therefore, we propose that there is a governance and institutional-analysis component running with common thematic coherence through each of these research topics. The analysis will focus at the more local level of management, at basin and sub-catchment scale, and leave much of the broader global, political and market linkages to working group 5, covering global policies and institutions.

Governance inputs to the four research themes will set the institutional, political and cultural context at the local scale, define the setting of the research problem and describe the actual institutional framework and policy that exist on the ground. It will ensure that there is a satisfactory and representative interdisciplinary framework in each case. There will be opportunities to consolidate and generalize the findings in a more purely institutional mode on the basis of combined and varied, but specific experience.

Although specific governance concerns will be incorporated into each of the four research themes, there are common threads of institutional analyses that will be considered in all cases.

1. Institutional responses and adaptations to solving problems and implementing IWRM at different spatial and temporal scales, and in different stages of resource use and depletion:
   a. Institutional linkages between scales and generations.
   b. Understanding enabling and constraining conditions for institutional reform and change.
      - The role of crises as an agency for change.
      - The management of crises.
      - The development of long-range policy that responds to understanding of slow processes, such as i) global climate change, and ii) widespread salinization and land degradation.

   c. The relationship of technology and information on the one hand and institutional capacity to manage change on the other.
   d. Water rights—identification of actual use, recognition of de-facto and informal users, specification, negotiation and implementation. How can formal water rights systems be established ? Are there viable alternatives to
      specifying formal water rights systems and allocations? What are the costs compared to the benefits of the formalization of water rights? What are the institutional, economic and management implications of not establishing sound water-rights systems?

2. The dynamics and lessons of the "agency" of reform:
   a. What lessons are there to design effective institutions and develop good governance in IWRM?
   b. What is the actual institutional situation on the ground?
      - Is the agency for reform "push" (from international or national government) or "pull" from more "grass-roots" initiative and problems?
      - What are the response and accommodation of international or government initiatives in reform by lower-level organizations?
      - What is the nature of local participation and representation? What are the costs and benefits of different approaches to decentralization and public participation?
      - What are the local examples of reforms in other sectors, such as livestock management, which provide contextually relevant

alternatives or complements to international conventional wisdom on good governance?

3. The social, political, equity and economic dimensions of managing trade-offs:
   a. Efficiency and equity—rising water scarcity and competition for water imply rising economic value that, in turn, implies declining equity in distribution and access, which potentially aggravates poverty. In contrast, equitable access to water that "traps" users into sustained poverty is also clearly not desirable in welfare and economic terms.
   b. Equity and ecology—many in the developing world face hard decisions between maintenance of sustainable and viable natural ecosystems and the welfare of burgeoning rural and urban populations.
   c. Platforms for participation and negotiation of priorities, trade-offs and compensation.

UPSTREAM/DOWNSTREAM EFFECTS AND SCALES OF ANALYSES

Background

Effective integrated management of basin water resources is complicated by the fact that the use of water and land at one location affects how water is used at another location, often in counterintuitive or complex ways. Misunderstanding can lead to policies that adversely affect one set of users, while trying to improve conditions for others. There are at least two major dimensions to this—one is the consequence of upstream use on downstream availability and the other is how actions taken at one scale affect uses and users at other scales. For example, the degree to which field level interventions save water, or improve the productivity of water at the basin scale or the degree to which policies affecting basin allocation affect farm and community practices are often not clear.

Scales of analyses. Scaling up is the effect of changing the boundaries of analyses of water availability and water utilization.[4] Key scales we consider for water resources in agriculture are for an individual crop, a field, an irrigation system, a community, a river basin, a nation and the global arena. Key processes change as we move up and down spatial scales (Molden and Merrey forthcoming). While the boundaries between scales are fuzzy, one way to know whether two scales of analyses are distinct is to test whether key physical and institutional processes of interest are

[4] We do not use scaling up here to mean replication of an intervention.

different. For example, when considering a rain-fed agricultural field, key processes include infiltration, transpiration and evaporation. When we consider a river basin, key processes are, for example, streamflow and water allocation between multiple uses and for environmental flows. The problem is that we think of change processes at one scale but cannot easily perceive the impact this change will have on other processes at a larger scale.

The extent and quality of lateral flows to and from the scale of interest, and how these affect other uses, determine the importance of scale issues (van Noordwijk 2001). In water resources systems, there are significant scale effects because of the tremendous amount of lateral flow, and if we consider virtual flows of water (in traded food), the scale reaches beyond the river basin.

Upstream and downstream interactions. At one level, interactions between upstream water users and other users downstream are well understood. Few people within the irrigation field are unaware of head-tail differences in relation to access to water or to reduced water quality in tail-end areas in irrigation systems. In many cases, similar distortions can be found in river basins, even though flow should accumulate rather than dissipate from upstream to downstream. What is less well understood is how interactions may begin to change and increase in complexity as basins approach full exploitation of available water. When all water in a basin is exploited or allocated, then any change in water use by one user or sector will have an immediate impact on all other water users, either within the same sector or in different sectors (Seckler 1996). In a typical water-short basin, for example, not all water users will have sufficient water to meet the potential demand from their land. Well-intentioned programs to bring about water savings at one location[5] and transfer the "saved" water to other locations may actually have no impact on productivity, although equity impacts may be substantial. Rather than trying to save water, the management focus should change to increasing the productivity of water within each water use.

The Challenges

The key problem is that most investors, development agencies and water management organizations are not adequately equipped to make decisions that take into consideration issues of scale. Consequently, water-agriculture actions that are

[5]Recent studies have shown that while on-farm irrigation efficiency may be around 40–60 percent, whole irrigation systems or subbasins operate at greater than 80 percent efficiency (Nile Basin, Gediz, Chao Phraya, Bhakra, Chistian, Zhang He and Fu Yang.)

taken result in unexpected side effects, often to the detriment of poor people and the environment. This is not merely a problem of poor institutional design and function but is also a topic that is not well understood and requires further development of basic concepts and tools, especially for information-poor environments. There is often a lag between a scientific appreciation of water-agriculture-basin relations and its significance being grasped at the policy level, leading to delays in the development of responsive resources management strategies. There are several complicating factors related to issues of scale:

First, water demands for different sectors are not always quantified with the same precision. Diversion requirements of urban and industrial sectors are typically better defined than agricultural needs. Return flows are rarely well known; yet they represent an important source of water for many people. For other sectors, especially environmental needs, needs are less clearly defined. This makes the overall allocation process quite difficult, particularly when water rights (if they exist) do not change in response to changing demands and priorities.

The second complicating factor is that water allocations by sector have to account for multiple uses of the same quantum of water. For example, a single drop of water generated through natural ecosystems may serve hydropower, urban uses, fisheries, environmental uses, and then agricultural needs before it is ultimately depleted. Water management approaches may or may not take advantage of these possible synergies.

Institutional competition adds a third type of complexity. In many countries, some agencies or organizations are reluctant to collaborate with others. Organizations originally charged with the construction of large infrastructure seem particularly slow to respond to such concerns as environmental protection, water quality, gender equity, democracy and recreation. While the establishment of basin-level management organizations can greatly assist in the process of water allocation between sectors, the actual management of water often rests with individual agencies that still act in a unilateral manner.

Fourth, land-use decisions, or water uses that do not constitute direct streamflow diversions can have important ramifications. The amount of rain-fed agriculture influences the movement of both water and salts. For example, in Western Australia, replacement of native forest cover with rain-fed crops and pasture has resulted in additional recharge, and a mobilization of salts (*op.cit* Turral 1998). The National Land and Water Audit (2000) estimates that dryland salinity in 2050 will affect 17.5 million hectares, dwarfing the impacts of irrigation-induced salinity. Replacing grass with forests, or forests with crops influences streamflow hydrology. Groundwater use, or rainwater harvesting, may extract water that would otherwise flow into rivers and be available for downstream uses. It is not so obvious that these changes in use may affect other users, and the overall productivity of basin water resources.

Water institutions are typically closely related to the scale of analysis. Communities develop and manage water resources but in the context set by environmental protection agencies, or agreements on water sharing with a basin. Referring to the water resources development continuum in the introduction, two sets of key problems are identified. At point **A** in figure 2, scale and upstream/downstream affects are less pronounced, and local community and development activities can take place without much concern of scale. With more intensive development, scale becomes more important, and requires different institutional arrangements to solve (Molden et al. 2001). For example, communities able to manage small irrigation may be ill equipped to negotiate with cities that would like to utilize their water source, and governments may be ill equipped to handle the negotiation between those interested in large-scale water resources development and local communities (Donahue and Johnston 1998). At point **B**, in highly water-stressed situations, the same challenges above are likely to apply. In addition, governance structures that promote demand management, environmental protection and restoration, and protect water rights become increasingly important (Wester et al. 2001; Svendsen 2001).

GOVERNANCE CHALLENGES

- What models of river-basin management work in defined developing country contexts?
    a. What changes to state-run organizations and institutional processes are required to achieve more effective and transparent management of rivers and basins?
    b. How can effective water governance structures be crafted from the bottom up, that represent scale and human (welfare) concerns?
    c. Which governance arrangements facilitate scale-related synergies, and reduce negative impacts, and in which hydrologic and socio-political environment are they most effective?
    d. How can they be effectively promoted and evaluated?

- What analytical tools and processes are required to understand the livelihood impacts of actions taken in one locality on other parts of the basin? How do we integrate hydrological and productivity understanding with livelihoods and examine trade-offs in how they and the environment are affected?

- What is the socio-political context of national and local development? How can it be taken into account to counter short-term political expediency against long-term stewardship of resources and sustainable livelihoods (as in the case of the North China Plain where subsidies are still offered for tube wells despite catastrophic falls in water tables)?

- What are the sound processes for the specification and implementation of bulk water rights (to cities, irrigation districts, livestock systems, etc.) and what are the implications for equity and longer-term flexibility?

- What are good incentives for farmers to increase water productivity—how to achieve higher water productivity and maintain or increase production or find higher-value substitute-production systems?

Natural science challenges

- What are good methodologies for conducting water use and resource availability audits? How do we track and account for multiple uses and the relative value and productivity at successive stages of the hydrologic path? How do we account for the cumulative impacts of widespread "uncontrolled" small-scale interventions on water resources use and availability (for instance nested tank systems or on-farm storages)?

- What is a good conceptual basis for treating scale to account for site-specific and generic hydrological and agricultural consequences of water management actions?

- What techniques can be developed or adapted to substitute for poor but essential data required in assessment, modeling and development of future management options?

- What are the practical limits to potential production and productivity within basins and in basins lying in different eco-regions? What factors set absolute limits (i.e., solar radiation and temperature) and which are manageable (soil degradation, fertility, moisture regime, plant characteristics)?

- What are the hydrological consequences at larger scales of rain-fed and runoff agriculture?

- What livestock management practices positively influence water quality, quantity and dynamics?

Resource management challenges

- What are the means to assess the degree to which water-related actions at one scale or location affect other basin uses, in particular in data-scarce environments?

- How can concepts and analytic tools addressing issues of scale be mainstreamed into the investment and management decision-making processes?

- What are sound water allocation programs?

  a. How can bulk entitlements be defined and managed?
  b. How can land use be linked to hydrology in complex situations (surface water- groundwater interactions)?
  c. What are innovative methods for multiple use of water for maximum benefit?
  d. What are effective alternative strategies in water supply: for example substituting large dams with multiple small storages—economic, hydrological and ecological trade-offs?

- Can we develop a Water Balance Toolkit?

  a. What are generic methods for data substitution and data generation?
  b. What are generic techniques to incorporate temporal variation to get beyond the classic "average year" scenario of developing country hydrology?
  c. What global and regional indicators (such as ENSO – El Niño Southern Oscillation) can we use in different eco-regional contexts in resource and risk assessment?

GROUNDWATER MANAGEMENT AND DEVELOPMENT: POVERTY AND SUSTAINABILITY

Background

Groundwater will be an enduring gauge of this generation's intelligence in water and land management. [6] Honing this intelligence requires that science stays in

[6] The credo of the Australian Groundwater School at Adelaide.

constant interaction with policy and action; and in the South, there is too little of such interaction.

At the core of the groundwater debate are two opposing forces. The first is that groundwater development is a good thing—open, equitable, productive and a good instrument for poverty alleviation. The second is that many of the reasons that groundwater is in this position (energy and capital subsidies, open access due to limited or nonexistent licensing) result in the overexploitation and degradation of the resource.

At the same time, there remain considerable areas with underutilized groundwater resources (Southern China, Ganjetic Plain and Africa provide examples in different contexts, the first of probable low demand due to high rainfall and surface-water availability and the last due to capital and energy infrastructure barriers.) Research must also consider how to develop these sustainably, avoiding the trap of overexploitation and degradation widely experienced in India, northern China and the USA.

The Challenges

Throughout the world, regions that have sustainable groundwater balance are shrinking by the day; and the worst symptoms of these are showing up in South Asia, Mexico and the North China Plains. Three problems dominate unsustainable groundwater use: a) *depletion* due to overdraft; b) waterlogging and *salinity* due mostly to inadequate drainage and insufficient conjunctive use; and c) *pollution* due to agricultural, industrial and other human activities. Myriad consequences of unsustainable groundwater use are becoming increasingly evident. Problems in groundwater management include:

1. Water table decline and depletion of the resource
    - Increased costs of pumping, and capital to access water.
    - Land surface subsidence.
    - Intergenerational inequity—loss of resource.
    - Degradation of surface ecosystems, dependent on groundwater.

2. Groundwater exploitation: Barriers to poverty alleviation
    - Access to available groundwater in hard rock aquifers is restricted by capital cost barriers, poor institutional and policy frameworks, which provide little incentive to develop groundwater for poverty alleviation in Africa and elsewhere.

3. Water-quality degradation of the aquifer
    - Nutrient runoff and contamination from agriculture–especially nitrates.
    - Biocide contamination.
    - Mobilization of toxins: arsenic and selenium.
    - Salt mobilization and mixing: salinization.
    - Chemical pollution from industry and urban point sources.

4. Rise of water table and waterlogging (not necessarily a problem)
    - Accessions to water table from return flows from (inefficient) surface irrigation.
    - Changed up-catchment land-use resulting in long-term small increases in accessions.
    - Rise of water table from surface-water transfers.

5. Water table rise and mobilization in conjunction with surface-water systems
    - Accessions from inefficient irrigation, channel seepage, and changed land use, with mobilization of salt, either in the subsoil and substrata, or by concentration of salts from surface-applied water.

A typology has been identified below with five socio-ecological conditions that define the central groundwater governance challenges, shown in table 1. The rising dominance of groundwater in India is illustrated in figure 3.

Institutional, legal, regulatory and economic instruments for effective groundwater management (demand regulation and supply augmentation) that work are known, but their success is largely demonstrated in industrialized countries, and have evolved over long periods, as long as for 200 years (Blomquist 1992). Experience in developing countries has been much more negative and has been characterized as a problem of overcoming institutional inertia (Shah 2002). The barriers to adoption of known measures can be briefly summarized as:

- Limited water resources, poorly developed services and high population.

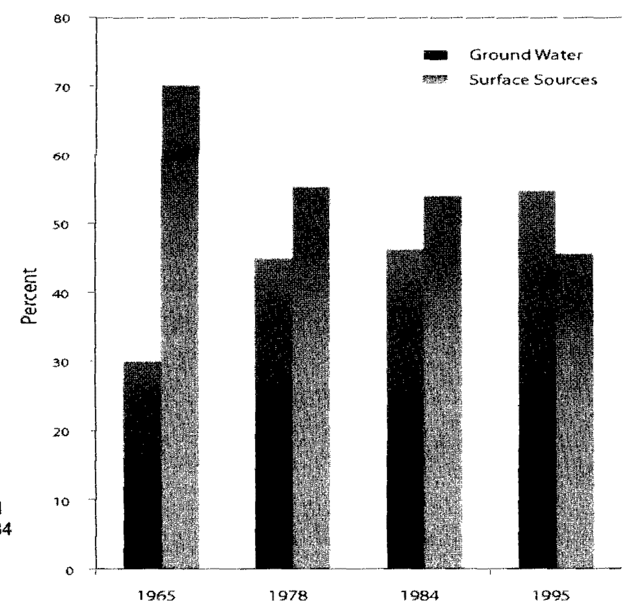
- Sheer numbers of farmers and wells, giving rise to enforcement problems, especially where agro-wells have become a major driver for growth (50-70% of Asian agriculture).

- Policies that increase supply but do not restrict demand, typically energy pricing.

Table 1. Groundwater socio-ecologies in the world (after Shah 2002).

Socio-ecology	Regions	Primary Challenge in Groundwater Governance
Secondary salinization of groundwater	Indus basin including Pakistan Punjab, Indian Punjab, Sindh, Haryana.	A refined system of conjunctive management of surface water and groundwater for controlling root-zone salinity
Groundwater depletion	Western and peninsular India, North China Plains.	Achieving long- term balance between groundwater demand and supply
Conjunctive management for poverty reduction	G-B-M basin including Eastern India, Bangladesh & lower Nepal	Sustainable groundwater development with focus on poverty reduction
Creeping growth in groundwater use in agriculture during 1990's	Sri Lanka, Thailand, Vietnam, Myanmar	Learning from South Asian experience and building proactive resource- management systems
Missed opportunities for development	Much of sub-Saharan Africa	Technical, institutional, policy and incentive support to promote pro-poor development.

Figure 3. Relative proportions of surface water and groundwater use in India 1965–1995.



Decades are represented by years 1965, 1978, 1984 and 1995, respectively

- The value of groundwater as insurance against drought tends to weaken regulatory measures at other times, and when irrigation is developed.

- Growing centrality of groundwater irrigation to agrarian livelihoods, through the miracle of the mechanical pump, especially cheap small units for shallow groundwater extraction.

The basic research premise is that good science and informed policy discussion can stimulate strategic players to forge groundwater governance mechanisms, which are suited to the South's contextual realities. Doing this requires that, as in research establishments in the North, science in the developing world focuses on the "bigger picture"—of policies, institutions and resources management strategies.

Governance challenges

- How are regulatory reforms negotiated in developing equitable and poverty-focused use of groundwater for irrigation? How are similar reforms negotiated to restore the balance when resources use has become unsustainable?

- What are enabling factors in the political and cultural landscape that allow for the development of actionable policies to manage groundwater.

- What polices and development models are there to allow sustainable and equitable agricultural use of groundwater in Africa.

- How do societies assess future policy outcomes and pathways in order to better negotiate groundwater management solutions with multiple stakeholders?

    a. Audits of resources use and actual institutional arrangements–can they be done? Are they worthwhile?
    b. Scenario building tools, including simulation models.
    c. How important is better knowledge and hydro-geological understanding to negotiating good institutional solutions?

- What is appropriate institutional development and effective participation in generating, adapting and implementing groundwater policy in specific socio-ecologies?

- What are the prospects and supporting policies for groundwater "banking" and drought "banking"?

- What are the quantified consequences of overexploitation of groundwater to crisis point in specific socio-ecologies, and what are the expected consequence, on resource use, welfare and poverty, environment, economic stability in incipient situations?

- What models of effective groundwater governance can be distilled for developing country socio-ecologies?

Natural science challenges

- What are the detailed hydrological interactions between surface water and groundwater, and what are the impacts of land use and land-use change on the position and quality of groundwater. How can we improve the physical understanding of recharge and discharge zones in the landscape and their quantitative relationships? Can we make progress with less-demanding data input?

- What is the role of groundwater in maintaining aquatic eco-systems?

- What techniques can we develop and apply to substitute for a lack of good data that enable understanding of the nature and behavior of complex aquifer systems?

- What is the long-term nature of groundwater response to climate change and its potential effects on aquifer recharge?

- What is the importance of groundwater to the maintenance of coastal marine ecosystems?

Resource management challenges

- What are the economic and environmental trade-offs in large-scale water transfers for groundwater recharge or substitution

- What are effective agricultural production strategies in more effective and efficient use of groundwater? Alternative strategies include new approaches to conjunctive use, supplemental versus full irrigation, analysis of the costs and benefits of using water now and foregoing it later (as in Gujarat in India and the Namoi Valley in Australia).

- What are the benefits and trade-offs of using surface water canal systems to recharge groundwater and developing conjunctive use strategies to effectively distribute water and radically improve flexibility and, hence, agricultural options and productivity?

- What is the impact of water-saving technology on groundwater abstraction and management?

ENHANCING RAIN-FED AGRICULTURE

Background

Under scenarios to double agricultural production by 2025 to meet world food needs, water use for rain-fed and irrigated agriculture would have to approximately double without significant improvements in water use efficiency and productivity (IWMI 2000).

The prime responsibility for researching technologies and management practices to enhance rain-fed agriculture lies with the working group researching the improvement of crop water productivity. However, there are substantial questions relating to the potential impacts of large-scale replication of enhanced rain-fed agriculture on the existing hydrological balance and on water use at the basin scale. There is much to be done in understanding and implementing effective solutions and trade-offs at the basin scale, and there is clearly potential for major policy realignment in basin-scale water management in some cases.

Rain-fed agriculture worldwide is practiced on approximately 80 percent of the agricultural land (the remaining is under irrigated agriculture). This ratio varies substantially between tropical regions, from approximately 95 percent in sub-Saharan Africa to 65 percent in Asia. Rain-fed agriculture will remain the dominant source of food production during the foreseeable future (Parr et al. 1990). Yields from rain-fed agriculture are often low, generally around 1 t ha^{-1} in semiarid tropical agro-ecosystems (Rockström 2001), which explains why rain-fed agriculture is estimated to contribute only some 60–70 percent of world grain foods (Alexandratos 1995). There is ample evidence to suggest that the low productivity in rain-fed agriculture is due more to suboptimal performance related to management aspects than to low physical potential (Agarwal and Narain 1997; Benites et al. 1998; Rockström and Falkenmark 2000; SIWI 2001).

In a first global estimate, Rockström and Jonsson (1999) calculated annual global values of water use in the form of evapotranspiration to sustain rain-fed agriculture at 4,500 cubic kilometers (km^3 yr^{-1}), compared to some 2,500 km^3 yr^{-1} estimated withdrawals for irrigated agriculture (Shiklomanov 2000). A new philosophy is emerging that suggests good opportunities to produce more food per drop of water if the focus is changed from the (downstream) management of in-stream and stored water to the upstream position where the rainfall enters the soil-plant system.

The major focal points for intensification of rain-fed agriculture are in Africa, where there is estimated to be significant untapped potential and in the Indian sub-continent, where there is both a long tradition of innovation in rain-fed agriculture and a nationwide movement to promote low-cost, small-scale technologies to improve livelihoods through better catchment-level water-management practices. Much of this initiative has not been dwelt on the implications at the basin scale.

The Challenges

Water-related problems in rain-fed agriculture in the water-scarce tropics are often related to the intensity of rainfall with large spatial and temporal variability, rather than to low cumulative volumes of rainfall (Rockström et al. 2001). Mitigating intra-seasonal dry spells is a key to improved water productivity in rain-fed agriculture in semiarid and dry subhumid tropical environments. There are three major avenues to achieve this:

- Maximize plant water availability (maximize infiltration of rainfall, minimize unproductive water losses [evaporation], increase soil-water-holding capacity and maximize root depth).
- Maximize the capacity of plants for uptake of water (timeliness of operations, crop management, soil fertility management).
- Bridge crop water deficits during dry spells through supplemental irrigation.

The technologies to do this include:

- Water conservation.
- Water harvesting and supplemental irrigation.

The key challenges lie in mitigating risk through technology, better management and better information that allow better management. Equally important is addressing farmers' perceptions of risk and adapting technologies, management strategies and policies that address their concerns.

Clearly, increasing the ratio of plant transpiration to soil evaporation and increasing the efficiency of transpiration are beneficial outcomes, which present little threat to catchment-level water balance. However, increasing transpiration at site (from stored soil moisture and captured runoff) clearly has potential, but as yet poorly understood and rarely quantified effects at the catchment and basin scale.

Governance challenges

- What are effective institutional arrangements to:

    a. Integrate enhanced rain-fed agricultural technologies and practices into basin-wide water management systems?

    b. Coordinate communities in the redesign and management of surface runoff to enhance rain-fed agriculture?

- What policy, investment and subsidy requirements are there to replicate and implement effective and equitable programs to improve rain-fed farming systems?

- What are the opportunities, benefits and problems associated with developing water rights for managed runoff and small-scale on-farm storage? How should such rights be specified and implemented?

- What strategies can effectively integrate and reshape the currently entrenched divide between irrigation departments and agricultural services that deal more with rain-fed productions systems?

Natural science challenges

- What are the likely impacts of large-scale intensification of rain-fed agriculture resulting in increased crop evapotranspiration on the catchment- and basin-scale water balance and on existing water allocations? How can modeling of likely scenarios be verified in practice?

- What are the long-term likely effects of climate change at basin scale on strategies to improve rain-fed farming?

- Development and adaptation of risk-management tools such as rainfall forecasting (e.g., the use of ENSO in "Rainman" in Australia).

Resource management challenges

- What are appropriate mixes of technologies and practices and scales of replication that both benefit local users and have minimum impact on the environment and downstream water users and rights holders?

- What are the trade-offs in terms of food security, pro-poor livelihood strategies, marketable surplus and economic efficiency of distributed small-scale water development compared to larger more centralized projects?

- Where are the most appropriate fits for different interventions in different agro-ecological and hydronomic zones?

WATER USE IN THE RURAL-URBAN INTERFACE

Background

Kofi Annan, UN Secretary General, recently stated that the world has entered the "urban millennium." Africa's population will almost triple by 2050 and this will be primarily in the urban and peri-urban areas and in West Africa; it has been estimated that within less than 20 years, two out of three citizens will live in urban centers. There are two immediate consequences for food production and security. The first is that water will be increasingly reallocated and redirected from rural water systems (principally irrigation) to meet rising urban and industrial demand (Rosegrant and Ringler 1998), as is already clearly happening in Malaysia and PRC (Hong et al. 2001). The second is that urban food demand will rise substantially and may not be satisfied due to insufficient appropriate production in rural areas. Increasingly, we observe in and around cities' farming systems, which that specialize in meeting urban food demand and dietary preferences, notably fresh vegetables and perishable goods. These farming systems are part of a phenomenon called *Urban and Peri-Urban Agriculture.*

Urban agriculture contributes to employment, poverty alleviation, urban food security and balanced diets. Moreover, during periods of economic or political crises urban agriculture has proved to be an important survival strategy in many countries. Despite recent international recognition, urban agriculture is rarely considered in national or urban planning, receives little support and is constrained by insecure land tenure and competition for land and water with other urban functions. There are different faces of urban agriculture. In Kumasi, for example, two of three households grow crops for home consumption in their backyards while urban market production is mostly found on lowlands along streams, which are unsuitable or forbidden for construction purposes, but favorable for year-round irrigation. In 1999, the United Nations Development Programme (UNDP) estimated that 800 million people were engaged in urban agriculture worldwide. Of these, 200 million were considered to be market producers, employing 150 million people full time.

Informal irrigation. It is paradoxical that government (and the water sector in general) focuses on formal irrigation, while an informal sector has emerged in the background as a self-sustaining farming system, driven by market forces. The dimensions and impacts are significant. In Ghana, for example, between 8,000 and 9,000 hectares of farmland are formally irrigated in more than 10 struggling governmental irrigation projects. Informal irrigation, carried out with watering cans, covers an estimated 12,000 hectares around the city of Kumasi alone. Despite the fact that most tropical soils and particularly urban soils are of low fertility and most rural smallholder farmers are struggling below the poverty line, urban vegetable growers studied by IWMI in West Africa, Pakistan and Mexico, generated good livelihoods. In West Africa, for example, with 10 vegetable harvests per year on just 0.1 hectare, producers gain about 10-20 times the income of traditional maize/ cassava cropping on the same area.

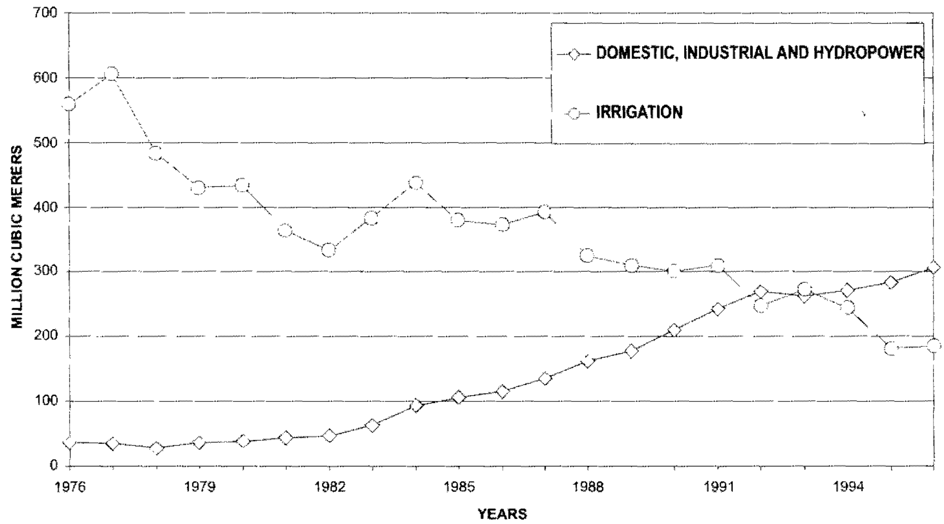
Transferring water and nutrients to urban centers. Increasing urban populations, rising urban income, and high-valued urban water uses tend to pull water from rural urban settings (figure 4, water transfers at Zhang He). Because only a small proportion of inflow is actually evaporated by urban use, large amounts of urban return flows are generated. The implications are that many irrigation systems will have to operate with reduced water supply, which (unless increases in crop water productivity are realized) will mean less production, reduced area, and possibly fewer farmers in business. There is evidence that many transfers take place by force, and farmers are not equitably compensated (Scott et al. 2001). Many institutions are ill equipped to handle this transfer. Increasingly, rural farmers will have lesser quality supplies, polluted by upstream cities. In the Gediz basin (Turkey), urban pollution of water constrains crop choice within the Menemen coastal plains (IWMI and GDRS 2000). While not well documented[7] there appears to be an important demographic change driven by water transfers, where areas of agricultural concentration and people are shifting from rural areas to peri-urban areas.

The Challenges

Such permanent cash crop systems require correspondingly high inputs, which are sourced cheaply and effectively from typical urban "resources" like *organic wastes* and *wastewater,* thus closing the rural-urban nutrient cycle. The provision of livelihoods to marginalized groups from urban conglomerations is another positive factor, which has not been sufficiently studied or quantified.

Wastewater is used because it is either the only source of reliable water supply (informal vegetable irrigators in Ghana), or for its nutrient value with attendant

Figure 4. A common trend–declining allocation to irrigation to meet increasing urban and industrial needs, Zhang He, Hubei, China (Hong et al. 2001).



savings in fertilizer (Asia). However, the associated health risks that producers and consumers face and other environmental impacts like pollution of groundwater from the application of human and livestock wastes are major threats against which research and management are required. Today, clean vegetables are the exception in city markets in Africa due to microbial and, sometimes, heavy metal contamination of rivers, drains and shallow groundwater.

This calls for *methods to prevent or minimize health risks,* without compromising the livelihoods of farmers. Possible "entry points" in the "wastewater chain" may be at the level of the local authority regulating pollution, at the treatment level, and in low-income countries with limited viable treatment options during irrigation or the post-harvest period. Thus, applied research on appropriate measures and realistic interventions that tackle the problem in a holistic, but situation-specific way, are required to support the informal irrigation sector and (peri) urban agriculture in general. Urban agriculture requires a multi-sectoral research approach, involving the active participation of various non-research agencies such as municipal stakeholders, especially in the planning and implementation of policies and action programs.

In parallel to required research, effort is required to achieve wider recognition of the scale of urban agriculture and the extent of existing use of wastewater. Decision makers and stakeholders need to be aware of the potential benefits and problems, so that they take informed steps to promote, assist and regulate such developments, to the economic benefit of municipalities and their citizens. We anticipate that the Comprehensive Assessment will provide some initial answers to these questions, where secondary data are available or primary data collection is not too demanding.

Governance challenges

- What are actual and potential mechanisms for rural to urban water transfer? How can these be brokered and negotiated equitably?

- What options are there for institutional and policy support towards appropriate water rights for smallholders in urban and peri-urban agriculture, for both freshwater and wastewater?

- What are the links between wastewater-use-related policies and bylaws on the environment, health and agriculture, and understanding the institutional arrangements that encourage or discourage more holistic approaches to managing risk in the context of urban and peri-urban agriculture?

- What are the roles of women and men in urban agriculture and their respective contributions to family livelihood and poverty alleviation?

Natural science challenges

- What is the difference between actual and potential health risk related to wastewater use, and how do we quantify them and their attendant economic risks and benefits to farmers, crop handlers and consumers?

- What are appropriate interventions for different entry points in the wastewater chain for maximum impact with reduced associated risks, in collaboration with the involved stakeholders?

- What are useful methodologies to quantify actual and potential water demand for urban agriculture? What methodologies and technologies can be developed that integrate these demands with conventional urban water supply and wastewater programs?

- What proportion of nutrients can be recovered from liquid, fecal and solid city waste for urban and peri-urban agriculture, and what viable and socially acceptable recycling options are there to do so?

- How can the efficiency of water and nutrient use be improved to promote higher crop and water productivity in (peri) urban agriculture?

Resource management challenges

In mediating and managing the transfer of water from rural agriculture to urban use, some relevant issues include the following:

- What are the expected dynamics and patterns of water transfer under different forecasts of urban growth? What are specific forecasts of municipal, industrial and urban agricultural demands for water in the sample cities?
- How much water will be transferred, and what proportion will be available for agricultural reuse, within, around and downstream of cities?
- What are alternative, environmentally beneficial uses of much larger flows of urban wastewater?
- What modifications and design innovations to urban wastewater systems are desired and possible to make maximum and cost-effective use of urban wastewater and storm flows?

With respect to urban agriculture:

- What is the extent and economic impact of informal irrigation and wastewater use around cities at the national, subregional and regional scale in comparison to formal irrigated areas? What are the proportions of different wastewater sources (domestic v industrial v urban runoff) in total wastewater production, percentage of wastewater collection and treatment?
- What are holistic approaches to safe wastewater use in agriculture, linking together various disciplines to identify the most appropriate *entry points* for interventions and capacity building along the whole pollution pathway (wastewater sources, treatments options, irrigation techniques and other farming practices, crop handling in markets and households, policies, education and capacity building)? Which of those entry points has the highest probability of success in the local context of *low-income countries* where conventional recommendations (water treatment) are difficult to realize?
- How do we value and reduce health and environmental impacts related to wastewater use in agriculture? What is the impact of land application of wastewater in urban agriculture to improve river health downstream of large cities?

AGRICULTURE AND ECOLOGY INTERACTIONS IN A CATCHMENT SETTING

Background

Natural ecosystems consist of biotic and abiotic components that are essential to preserving the conditions that allow life, as we know it, to exist. Plant and animal biodiversity in such ecosystems play an important role in helping to maintain the Earth's atmosphere, protect watersheds, renew soil and water, and recycle nutrients. Thus, the environment and people's lives are interlinked, a fact recognized internationally in Agenda-21 (UNCED 1992).

The focus of the problems considered here lies on the interactions between agriculture and aquatic ecosystems, and their interface with terrestrial ecosystems, such as water-generating forested areas and the margins of wetlands, which we define broadly to include rivers, floodplains, deltas, lagoons, marshes and more.

Freshwater is at the core of agricultural sustainability and natural ecosystem survival. It is the universal solvent, and the main pathway of nutrient and sediment flows. It is needed for all human activities, including food production, but is also vital to the survival of all other living creatures, especially those, such as fish and amphibians, that live in permanently watery habitats. Diversion of water for human use inevitably adversely affects its availability for other users. It is generally accepted that 70 percent of all diverted freshwater is used in irrigated agriculture, and agriculture in general is considered to be the major cause of degradation in more than half of the 1,000 or so internationally important Ramsar wetlands (Scott 1999). Large-scale diversion, storage and regulation of water limits or degrades the in-stream and near-stream habitat, may induce secondary problems such as salinity, and result in critical impairment of ecosystem functions and the services they provide (WCD 2000). In addition to water deprivation, natural ecosystems are burdened by the consequences of high intensity agriculture in the form of chemical pesticides, fertilizers and livestock wastes that poison land and water alike. Eutrophication and oxygen-depleted dead zones in aquatic ecosystems are particularly pernicious consequences of this pollution.

Humans are held to be responsible for three major waves of extinctions of species. The third wave, over the past 400 years, is from massive destruction of natural habitats as a result of land clearing for agriculture and other activities by a steadily expanding human population (reviewed in McNeely and Sherr 2001). Farmers destroy biodiversity in attempts to eliminate pests, disease, and dangers to livestock, and compete with crops for space, nutrients and water (McNeely and Sherr 2001). New agricultural expansions are more or less balanced by abandoned or fallow lands, although the expansions in agriculture are occurring mainly in high-biodiversity tropical habitats, with consequent losses in flora and fauna.

Ecosystem functions

Natural ecosystems perform ecological functions that provide benefits to people either directly or indirectly, through the provision of plant and animal-based food and medicinal products, and many livelihoods depend upon this function. Other natural products are used as materials for house construction, utensils, and in some instances, clothing. Aquatic systems are sources of water for domestic and livestock needs, and together with their associated biodiversity, often help purify polluted water through processes of sedimentation, filtration and bio-extraction. Natural resources areas, through their role as biodiversity refuges, can generate income for poor communities through ecotourism. They act as reservoirs of the natural enemies of crop pests, which can be mobilized for operational control through the application of Integrated Pest Management (IPM) principles. Natural resources areas play an important role in groundwater recharge. More controversially, wetlands are especially presumed to play a role in water storage and flood attenuation and maintenance of streamflow during the dry period. All of these functions have both intrinsic and economic values, which are presently poorly understood or defined. The Aquatic Ecosystems Group will be primarily involved in researching methodologies to define ecosystem functions and values. The application and management of these products will be undertaken in the integrating theme at working in a basin or subbasin context, and will be in the overall evaluation of the costs and benefits of agriculture.

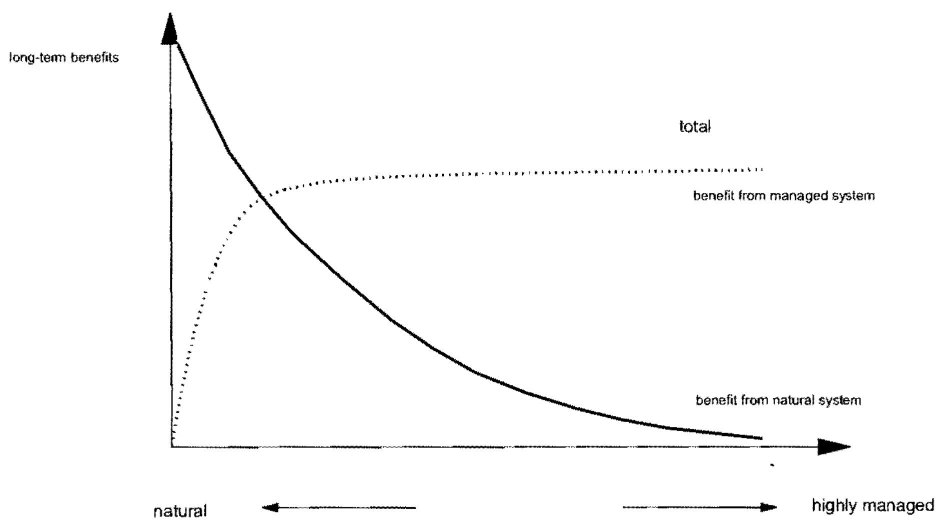
The Challenges

The challenge for research and action is how to achieve increased food security without further destroying natural ecosystems that are vital to the overall environmental health of the planet. This means producing more food on the same extent of agricultural land *with less water*. Given the reality that land already in use is unlikely to be allowed to revert to nature, it also means fostering this nature within the very agricultural systems that originally destroyed it. Or building new agricultural systems designed to foster nature from the very outset.

The dilemma of nurture versus nature forces us to confront one central challenge: *the trade-off between land for crops and land for nature; water for crops and water for nature.* In the context of integrated water resources management (IWRM), it implies developing the *technical capability* to determine and prioritize the water requirements of multiple users under differing climatic, agronomic and ecological scenarios, and the *institutional capability* to deliver the resource appropriately. Developing such a capability requires a multi-sectoral approach involving irrigation/agricultural managers, researchers, the state sector (wildlife/forestry/environmental) agencies, conservation/environmental/social service NGOs, and local community organizations.

Figure 5 shows the trade-off between natural and highly managed systems (Acreman 2001). As natural systems are modified more and more, the benefits of the natural system decline (solid line), e.g., hydrological functions, products and biodiversity are lost. At the same time, benefits from the highly managed system increase (dotted line), e.g., food production rises. The total rises to a maximum before declining. It is at this point that the balance between naturalness and level of management is "optimized." Obviously, the value that society places on goods and services and ethical considerations will determine the exact form of these curves. Indeed, the perceived benefits will vary between different groups and individuals. Therefore, it is essential that the costs and benefits to society of allocating water alternatively to maintain ecosystems and to support direct use in the form of agricultural, industrial and domestic uses are quantified.

Figure 5. Benefits from natural and managed ecosystems (Acreman 2001).



An extension of this challenge applies in managing water at the basin scale. The river basin is an important macro-ecological unit in IWRM, and the river system is at its heart. From an ecological perspective, the river system is more of a living entity, whose functioning can be encapsulated within two key concepts.

The first is the "river continuum" concept that takes in the linkages between the upstream source and downstream coastal zone lagoon and delta systems (Vannote et al. 1980). It encompasses changes in river flows, water quality, nutrients, sediments and biodiversity along this continuum. Nutrients and sediments generated upstream, for instance, are recycled and drive plant growth downstream. Animal species may migrate seasonally in either direction (e.g., anadromous fish, such as salmon and trout, and catadromous fish, such as eels). Engineering works, such as dams, barrages and sluices, break this continuity and radically alter both physical and biotic characteristics of the river.

The second concept is that of the "flood pulse," based on connectivity between rivers and their lateral floodplains (Sparks et al. 1990). Rivers provide the flood plains with their nutrient-rich sediments, and the flood plains provide breeding grounds for river species and purify water through sedimentation and absorption of nutrients and pollutants (Acreman 2000).

The two concepts encapsulate the longitudinal and lateral ecological dimensions of a river system, to which the vertical dimension of groundwater recharge can be added. The fourth dimension is that of temporal variability, which is intrinsic to the dynamics of natural ecosystems (Ward 1989) and which underwrites a significant part of the risk analysis that must be considered. One of the challenges is to maintain river ecosystem continuity and variability whilst meeting the water requirements for agriculture. Finding ways to maintain ecological continuity could be a key to sustaining the natural goods and services that river systems provide, and on which many human livelihoods depend.

Governance challenges

- Developing institutional mechanisms to foster the safeguarding and rational use of wetland and terrestrial natural-resources areas in basins. Developing awareness, ownership and mechanisms at community level that foster the rational use of ecological goods and services, and the conservation of natural-resources areas.

    a. Negotiation of scientific evidence-based decision making in demarcating and utilizing natural-resources areas.

    b. Reservation of environmental flows in "open" basins.

- Do environmental flows need to have priority over other users, particularly during the time of extended droughts, or should methods of "negotiating environmental flows" and "environmental water demand management" receive more attention?

Natural science challenges

- How does agricultural development and management affect biodiversity? How can agricultural pest and disease vector management be effectively achieved within the framework of the Integrated Pest Management (IPM) concept?

- What are the direct and indirect impacts of agriculture on ecosystem functions and services?

    a. Irrigation
    b. Dryland

- Using appropriate methodologies for the determination of Environmental Flow Requirements developed by the Aquatic Ecosystems Group, what are effective management and monitoring processes to implement them and how do they differ in the context of various information environments, regulation regimes, countries and aquatic ecosystems? What are the specifics of EFR estimation, implementation and monitoring in trans-boundary river basins? How should risk be assessed and incorporated into EFR analyses and specification?

- How can the longitudinal and lateral ecological continuity of river systems be maintained within the context of irrigation development, so that the health of the systems and the goods and services they provide can be sustained?

Resource management challenges

- How can water allocations be optimized on a basin scale in a typical condition of multiple users competing for the same limited resource, when environmental water needs represent the lowest limit for exploitation?

    a. What dam management regimes are required to implement environmental flows?

    b. How can end-of system targets of water quality and quantity be met, especially for the maintenance of coastal zone ecosystems.

- How can sediment flows and thermal regimes be better managed in regulated systems?

- What are the economic costs of maintenance of environmental flows?

- How can practical methods of trade-off analysis be developed and negotiated in a variety of developing country contexts?

CONCLUDING REMARKS

The functions of the working group are the following:

- To ensure that work undertaken in the other four themes is mutually coherent, and fits well into the framework of an integrated water and land resources management. It will serve as a "reality check" on the trade-offs and synergies that are offered by them and test their relevance at multiple scales up to basin level.

- To undertake research into key problems within the realm of IWRM that have particular relevance to the improvement of crop productivity and production, alleviation of poverty and enhancement of environmental security.

- To elaborate a common framework for comparing and contrasting the application of research at multiple scales, within a selection of representative river basins. This framework will inevitably make significant recourse to simulation modeling, in order to capture and understand the complexity and interaction at the basin scale. It will be supported by interventions at smaller scales, which are nested at successive levels within and across the basin.

- To implement a manageable strategy to harvest research requirements and disseminate and promote research findings as actionable programs for NARES, other extension agents and NGOs, and to harvest their feedback to provide some syntheses and analyses within the life span of the program.

The objectives of the research program are as follows:

- To develop designs for good governance of water for food and environment

- To identify and develop technologies, information tools and management systems that improve water productivity at the basin scale and minimize their ecological impacts.

- To integrate technologies and effective polices for sustainable and equitable exploitation of groundwater resources.
- To develop cost-effective technologies and management institutions that promote innovative strategies to derive the maximum benefit from urban water for food and environmental security.

- To understand and quantify the trade-offs between increasing food security/ productivity and ecosystem function and value at a range of spatial and temporal scales.

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