Research Contributions to the World Water Vision

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The International Irrigation Management Institute, one of sixteen centers supported by the Consultative Group on International Agricultural Research (CGIAR) was incorporated by an Act of Parliament in Sri Lanka. The Act is currently under amendment to read as International Water Management Institute (IWMI).

Contents

Introduction

This report Summarizes the research work and analysis that the International Water Management Institute (IWMI) has provided as input to the World Water Vision **pro**cess.

These inputs are a **part** of IWMI's ongoing science program, which focuses on the following research themes: Policy, Institutions and Management; Imgation and Water Resources; Applied Information **and** Modeling Systems; Health and Environment; and Gender Water and Poverty.

IWMI's contribution to the World Water Vision covers five areas:

- Global Water Scarcity Study—Water Supply and Demand: 1995 to ***2025***
- Increasing the Productivity of Water **through** Improved Water Management
- Water Scarcity and the Role of **Water** Storage in Development
- The Global Groundwater Situation: Overview of Opportunities and Challenges
- Poverty, **Gender** and Water

Some of these contributions are original strategic research initiated by IWMI scientists *(water scarcity)*. For others, we assess the situation as **a** starting point for more in-depth scientific analyses, leading to recommendations ***(groundwater, wafer storage, gender).*** Still others ***are*** the result of **work** completed as a part of the IWMI science program, and **have** grown into tools and knowledge that are being transferred to developing countries ***(increasing water productivity).***

To read the full text of IWMI's contribution to the World Water Vision, **and the** Institute's complete catalogue of scientific research outputs, point your browser to: www.iwmi.org

IWMI produces scientific research, tools and methods **to** help developing countries eradicate **poverty.**

IWMI is a member **of** the Consultative Group on International **Agricultural** Research (CGIAR).

Global Water Scarcity Study—
Water Supply and Demand: 1995 to 2025

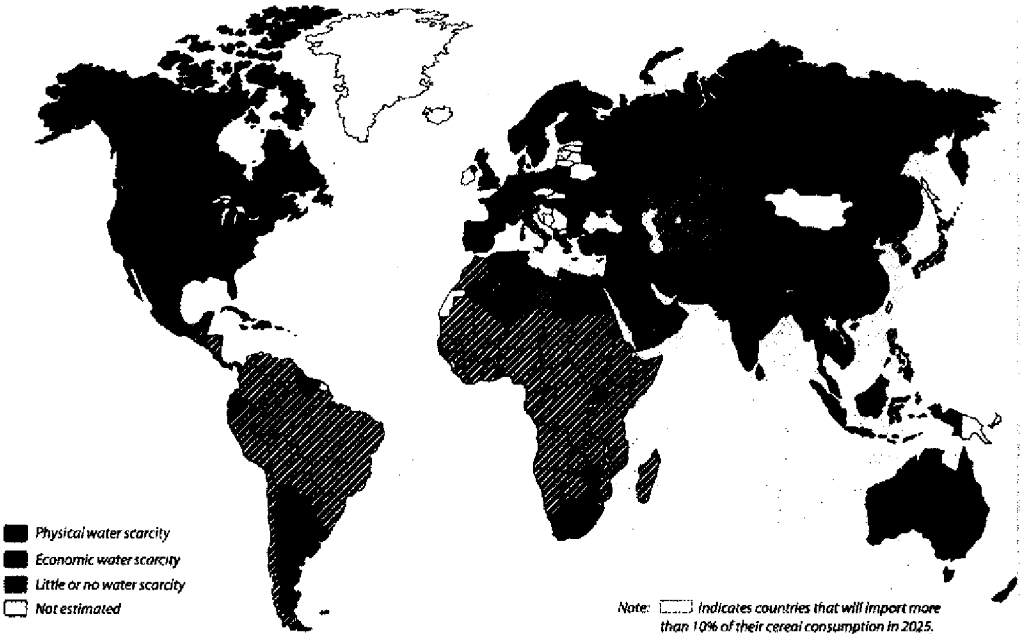
What will the world's water situation look 25 years from now, with at least one billion more water users on the planet competing for a finite supply of water?

Which countries will be the hardest hit by water scarcity, and what will be the impact of water shortage on food security?

How can developing countries best shape water policies that acknowledge and address the looming water crisis?

Over the past three years, the International Water Management Institute (IWMI) has addressed these questions by analyzing data and developing scenarios of water supply and demand for 2025. The purpose of this research is to encourage governments to act, by giving them the information about water scarcity and food security required to make appropriate policy decisions.

Figure 1. Projected water scarcity in 2025



IWMI's research **suggests** that if policy makers and planners act now. the world's food and water requirements can be met in 2025. But this can only be achieved through substantial changes in policies, technologies **and** water management systems in **many** developing countries. Even if they implement these changes, some countries will still require substantial food imports, partly or fully due to lack **of** water. There is sufficient production potential in exporting-countries to supply **this** food. But the underlying concern is how some net importing countries pinpointed by IWMI's research —specially those in sub-Saharan Africa—will be able to pay for these imports.

A Picture **of Water Scarcity in 2025**

IWMI began its water scarcity study in 1997. The study's most recent phase, completed in January 2000, considers **118** countries with an in-depth **look** at ***35*** countries that represent the major regions of the world and over 80 percent of its population. Water withdrawals for 2023 are calculated based on data estimating future domestic, industrial, and imgation demands in each country. Countries are then categorized into three groups, ranging from the relatively *water* ***secure,*** to those experiencing *physical water scarcity.* In between lies *economic scarcity,* which affects countries that have sufficient water resources to meet their needs in 2025, but lack the economic resources to develop the infrastructure needed to put this water to **pro**ductive use (figure 1).

This research also estimates the food requirement for each country in 2025, based on **data** from the Food **and** Agriculture Organization and the International Food Policy Research Institute. **It** then determines the quantities of food that are likely to be **pro**duced: given the water available for agriculture and other uses. and computes the deficit or potential surplus.

The IWMI Water Scarcity Study reveals that, by 2025:

- Nearly one-third of the world's population—some 2.7 billion people—will live in regions that will experience severe water scarcity.
- One-third **of** the populations of India **(464** million people) and China (508 million people) will live in regions that will face absolute water scarcity.
- The rest of the 118 countries included in the study will, theoretically, have sufficient water resources to meet their **2025** needs. But many **of** these countries will need to produce more than twice their existing water supplies. This means embarking on large and expensive water-development projects, which many will not be able to finance.

These country scenarios were developed using the Policy Interactive Dialogue Model (PODIUM), a policy-planning software tool developed by IWMI. PODIUM is designed to explore the technical, social and economic aspects of alternative visions of the future. It runs on a personal computer and enables policy makers and scientists to easily explore vital questions such as: *Can we feed ourselves in 2025? Do we have enough water to irrigate the crops needed* to *ensure future national food security?*

PODIUM shows a complete picture of a country's future food and water trends. A PODIUM scenario captures the technical and economic interactions of a country's water and food security situation. For example, some poor countries may want to see what the impact of grain consumption will be if their middle class grows and more people change from vegetarian food to a meat-based diet. The model helps generate any number of such visions.

A Vision of the Future: IWMI's Basic Scenario

The *basic scenario* that emerges from IWMI's analysis of water and food consumption trends is rather optimistic. The study suggests that the four objectives identified by IWMI can be achieved but that substantial investments and changes in policies, institutions and management systems will be needed.

The objectives are:

- An adequate level of per capita food consumption, partly through increased irrigation, to substantially reduce malnutrition and the most extreme forms of poverty.
- Sufficient water supplies for the domestic and industrial sectors to meet their basic needs and economic demands for water in 2025.
- Increased food security and rural income in countries where a large percentage of poor people depend on agriculture for their livelihoods.
- Strong policies and programs put in place to increase water quality and support the environmental uses of water.

Realizing these objectives in water scarce countries will require two things: substantially increased productivity of water resources, and the development of new water supplies. Water resources must be developed in a way that reduces social and environmental costs. In many cases, this will mean an increase in the financial costs of water resources development.

Major Findings and Recommendations

1. *The world's primary water supply will need to increase* **by** *22 percent to meet the needs of all sectors in 2025.* This value does not take into account that approximately 1 percent of the world's existing water storage capacity is lost each year due to sedimentation. Another important consideration is that **a** significant percentage of the world's water is currently provided through the unsustainable overdraft of groundwater resources. If we take these factors into consideration, the required increase in primary water supply nearly doubles to **41** percent.
2. *Seventeen percent more irrigation water will* ***be*** *needed for the world* **to** *feed itself in* ***2025.*** This anticipates significant improvements in irrigation effectiveness. **At** *current* levels of water productivity, a 34-percent increase in water **for** agriculture would be required.
3. *Nearly one-third of the population of developing countries in 2025, some* ***2.7*** *billion people, will live in regions of severe water scarciiy.* They will have to reduce the amount of water used in irrigation and transfer it to the domestic, industrial and environmental sectors. Many countries in the and regions of the world will depend on increased imports to meet the food needs of their people.
4. *The global community must invest in research to improve crop water productivity (crop per drop}.* The only alternative to increasing the productivity of water in irrigated agriculture is the massive and environmentally destructive conversion of forests and grasslands to rain-fed agriculture in agroclimatically favorable areas of Latin America **and** sub-Saharan Africa.
5. ***New*** *water infrastructure will have to be developed to meet future food requirements.* Investment in research can reduce though not eliminate the need for new storage.
6. *Groundwater reserves will be increasingly depleted in large areas of the world.* In some instances this will threaten the food security of entire nations dependent on highly productive agriculture, irrigated with **pumps,** such as India; it will certainly lead to major problems in food security and **access** to safe water for poor households in the affected regions.
7. *Salinization of soils, compounded* ***in*** *many cases* ***by*** *increasingly saline or* ***poisoned*** *groundwater, will continue to seriously affect land that has been highly productive in recent decades.* Salinity is especially serious in the semiarid and **arid** breadbaskets of Pakistan, northern India, northern **China,** and the **Central Asian** and **WANA** regions.
8. *The people* ***most*** *affected by* ***growing*** *water scarcity* ***will*** *continue to be the pool; especially rural poor; and among poor people, women and children will*

suffer most. If the **world fails** to **invest in** finding and **implementing** solutions, the **health, livelihoods, and incomes** of **millions** of **poor people will deteriorate.**

9. ***Better use* of *water in several large internationally shared river basins can contribute significantly to achieving food security and reducing poverty in developing countries.*** This **requires that basin countries reach** firm **agreements** on developing **and sharing these benefits.**

Increasing the Productivity of Water through Improved Water Management

The extent to which water constrains agricultural production, and the ability of the world to feed itself, are a function of the productivity of water. The more we produce with the same amount of water, the less need there will be for new development of water resources infrastructure. Consequently, there will he less competition for water which will enhance local food security, making more water available for nature and for domestic and industrial uses.

There is substantial potential for increasing the productivity of water. In many developing countries. the problem is lo physically reach the potential yield. There appears lo be scope to double water productivity in many cases, but some serious water management constraints must be overcome.

There are many opportunities for improving the management of water, which will lead to increased productivity of this resource. The first **task** is to understand where the opportunities are applicable. For example. with the increased consumption of water in **river** basins, the scope for water savings through increased efficiency of irrigation systems may be much more limited than expected. This *is* because downstream reuse of "lost" drainage water from irrigated areas is widely prevalent. The real gains arc to be made **by** increasing the productivity of water in irrigation. These gains can be achieved by providing more reliable supplies, through precision irrigation technology, and through management systems that include information feedback. Supplemental irrigation with low-cost precision technologies offers a means for poor farmers to produce more. With increased, and increasing, competition for water. implementation of solutions mill require significant changes in the institutions that are responsible for accomplishing the business of water management.

Increasing the Productivity of Water through Improved Water Management

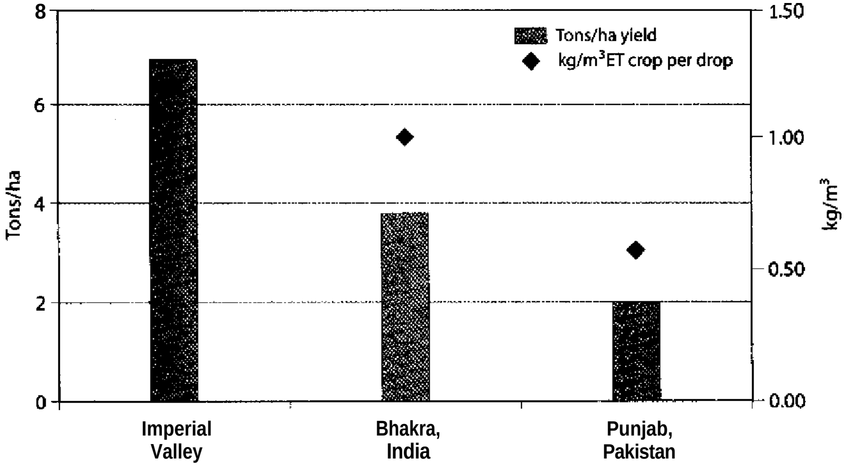
The most significant increases in productivity of water have come from improved plant varieties and agronomic practices. Growing more crop per drop is achieved by introducing shorter-duration and higher-yielding crop varieties. The increased use of fertilizers has increased yield and the corresponding water productivity. Combined with a stable irrigation water supply. productivity in agriculture has risen dramatically over the last 50 years.

There is still scope for improvement. In many areas, potential productivity is not realized, and this is largely due to poor irrigation management. Without stable irrigation, farmers cannot take advantage of the production potential.

Figure 2 shows yield and water productivity in three different locations with somewhat similar environments. India's Bhakra irrigation system constitutes a major part of India's breadbasket, and is situated across the border from the Pakistani Punjab. The Imperial Valley in California is also situated in a desert environment. The spread in wheat yields in these areas is from 2 to 6 tons per hectare, with a corresponding spread in water productivity from 0.5 kg/ET to 1.3 kg/ET. Within the Pakistani Punjab, there is great variability in yield with some farmers achieving productivity levels as high as those in California, and some farmers well below the average. Of course, production levels are dependent on environmental, market, soil and other conditions that are not equal across sites. In spite of this, there appears to be scope to manage resources to achieve greater productivity.

Raising the yield potential is a problem that is relatively more important for developed countries. For many developing countries, reaching the existing potential yield is a more pressing problem. How water is managed within irrigation and river basins is one major constraining factor for many farmers in the developing countries.

Figure 2. **Yields and water** productivity of **wheat** in California, Pakistan and India.



Sources: Molden, Sakthivadivel, and Habib 1999, Bastiaanssen et al. 1999; Mayberry and Holmes 1996; and IID 1999.

Options for Increasing Water Productivity

Improving water management can save water, enhance the environment, and directly influence the productivity of water, per unit used. There are several ways this can be done.

Water Savings through Recycling. While recycling occurs naturally in all river basins, increasing attention is being paid to recycling as an integral part of water management. For example, farmers in Egypt and other countries place small pumps in drainage ditches to recycle water, and the irrigation agency blends drainage water with freshwater to increase the useable supplies. Millions of shallow tube wells have been developed in the Indo-Gangetic plains that are recycling water and saving it from flowing out of the basin,

Another example is the finding of one of IWMI's scientists who developed a rather surprising theory, based on water balance studies, that the extent of irrigated land in the downstream portion of Kirindi Oya river basin of Sri Lanka could be doubled. This could be done with no more water and positive environmental benefits, by installing simple water recycling structures in the drainage system (Renault 1999). The Irrigation Department installed recycling structures, and it indeed happened! Consequently, the 6,000 farm families living in the area have seen their lives improve over the past two years; for some of the poorest families the improvement has been dramatic. We believe that there are many opportunities for similar achievements elsewhere where there is scope for water savings.

Reliability in Supplies. One basic principle in irrigation is to deliver a reliable supply of water. If farmers do not have a reliable supply, they do not know when the next irrigation is coming, they do not know how much water will come, and they do not know if there will be enough water for their crops. In this uncertain environment, farmers will not make investments in seeds, fertilizers, and land preparation, and consequently yields will suffer.

At Mahi Kadana in Gujarat, India, changes in the way water was delivered increased the water productivity by almost 100 percent (Sakhtivadivel and Gulati 1997). Before the change, a situation existed where water was supposed to be available at all times in the canal. But in reality, the amount of water in canals was so low that farmers could not get their supply A change was made to a rotational system with full supply flow, where farmers would receive water reliably at regular intervals. As another example, one of the reasons that the Bhakra system in India is more productive than many other irrigation systems is said to be its reliable water delivery program.

Poor reliability is often linked to weak institutions, incapable of, or uninterested in, operating infrastructure to provide a reliable service. A means of improving irrigation. even in the most basic irrigation systems, is to increase reliability. To do this requires the right mix of manageable technologies, the organizational skills required to use these technologies, and appropriate incentives to encourage this.

Precision Irrigation. Another important means of increasing the productivity of water is "precision irrigation," as we call it, As everyone knows, it is important to deliver the right amount of water to the crop at the right time. But it has only been in the past two decades or so that we have begun to see just how important it is to do *this* precisely: *exactly* in the right amount and at the right time. The various forms of precision irrigation—mainly sprinkler and drip irrigation systems—increase yields over good but ordinary irrigation systems by 20 to 70 percent, depending on the crop and other conditions, and they do *so* with much less water diverted to the crop.

Clearly, if we could convert the world to precision irrigation systems, the need for additional water for irrigation would decrease dramatically. There are m a y opportunities and difficulties on this path that need to be explored. For example, one of the simplest and most effective kinds of precision imgation is the "dead-level basin." Here laser-levelers are used to making fields as flat as possible. The results of dead-level basins, in terms of yields and water savings, are about the same as those of sprinkler systems. Yet they can be installed at low cost, around US$300 per hectare, on even the smallest fields. In ordinary non-leveled fields, because of poor water distribution, about one-third of the crop suffers frequent drought, another third is often waterlogged, and only one-third has something like the right amount of water most of the time! Dead-leveling radically improves the evenness of water distribution over a field.

Feedback Versus Feed-Forward Systems. All of these precision irrigation technologies depend on an instantly available water supply. This is because they operate on the cybernetic principle of feedback, responding quickly just before the crop is in danger of reaching a critical water supply state. Many irrigation systems operate on the "feed-forward" principle of trying to deliver water in *anticipation* of crop water needs, which is fraught with errors. This is why yields produced typically by tubewell irrigation systems in India are two to three times higher than those produced by canal irrigation systems.

Most of the potential gains of precision irrigation systems are lost without a reliable and responsive supply of water. With some major exceptions, most of the canal irrigation systems of India and other countries are about as reliable as rainfall. Even small tank systems, which could be managed precisely, often are not. In a case in Sri Lanka, the releases from the tank are highly and positively correlated with rainfall, with the result of oversupply during periods of rainfall and unnecessary shortages during subsequent dry seasons. As in most cases of poor management, one cannot believe how bad it can be until one actually sees it in action—or inaction, as the case may be.

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

Policies, Institutions and Incentives. Various water management practices we have discussed are appropriate for various settings. The effective implementation of these practices requires the right set of incentives for farmers and for water service providers—a function of policies and institutions. One difficulty is the fact that, as competition for water becomes more intense, how water is used in one part of a basin increasingly impinges on how it is used elsewhere in the basin. This requires that a coherent set of laws, regulations, and organizations govern water resources basin-wide. This is a topic of immense importance and complexity, but let it be said that we do not have ready-made solutions to change institutions for managing water in more productive ways.

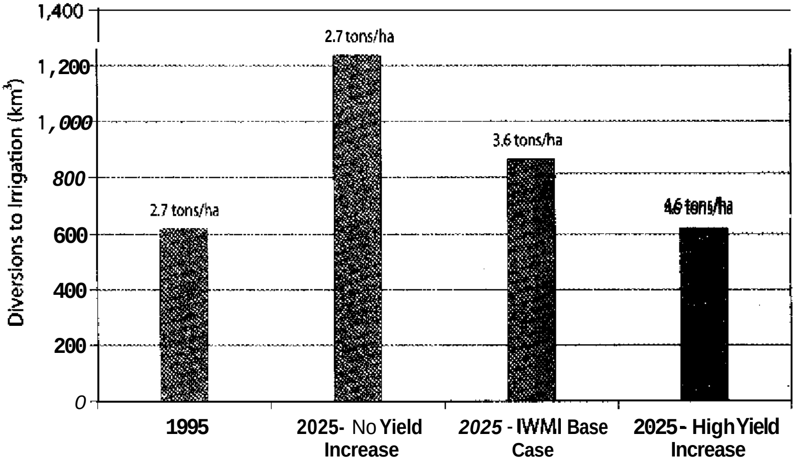
Water Productivity and Development of Water Resources

There is a direct relationship between increase in water productivity and the need for future water developments. The more productive agriculture becomes, the less is the need for water resources development.

To illustrate, consider water needs for India in 2025 (figure 3). In 1995, average grain yields were 2.7 tons per hectare. About 600 km^3 of water were diverted for irrigation. Considering the growth in population and improvements in diet, diversion requirements in 2025 were calculated for different settings. If there is no increase in grain yield, India will have *to* double diversions to irrigation.

In the IWMI basic scenario, yield increases to 3.6 tons per hectare, and associated diversion requirements increase by 14 percent to about 820 km^3. If average grain yields increase by 70 percent, to 4.6 tons per hectare, no more increases in water diverted to irrigation will be required. With the high yield increase, there will be no more need to expand area or intensity, and no need for more infrastructure to de-

Figure 3. Relationship between yields, and increase in diversions to agriculture for India



velop new water for irrigation but there would be a need to improve and add infrastructure to provide for more water control. Achieving this yield level would require major improvements in agronomic and water-management practices. This would require significant shifts in agricultural practices and policies and far more effective institutions.

Increasing Productivity of Water Consumed in Agriculture

Agronomic Practices

Crop varietal improvement: Plant breeding **plays** an important role **in** developing varieties that yield more mass per unit transpiration. For example, by reducing the growth period while keeping the same yield, production per Unit evapotranspiration increases. Changing the partitioning between green matter and grain yield increases water productivity when evapotranspiration is kept constant.

Crop substitution: Switching from a more to a less-water-consuming crop or switching to a crop with higher economic or physical productivity per unit of water consumed by evapotranspiration improves productivity of water.

Improved cultural practices: Better soil management, fertilization, pest and weed control often lead to more productivity of both land and, often, water consumed.

Water Management Practices

Improved wafer management: Better timing of water supplies **can** reduce stress at critical crop growth periods, leading to increased yields. By increasing the reliability of supply, farmers tend to invest more in other agricultural inputs leading to higher output per unit of watcr. Controlling salinity through water-management practices at project or field level can prevent reductions in water **pro**ductivity.

Deficit, supplemental and precision irrigation: With sufficient water control, it is possible to utilize more productive on-farm practices. Deficit irrigation **is** aimed at increasing productivity per unit of water by irrigation strategies that do not meet full evaporative requirements. Irrigation, supplementing rainfall, can improve the productivity of water when a limited supply of water is made available to crops **at** critical periods. Precision irrigation, including drip, sprinkler, and level basins, reduces non-beneficial evaporation, applies water uniformly to crops. reduces stress and **thus** can lead to increases in water productivity.

Reallocating of water from lower- to higher-value uses, for **example** from agriculture to municipal and industrial uses or from low-value crops to high-value crops, can increase the economic productivity or value of water. **As** a result of such reallocation, downstream commitments may change. In turn, reallocation of water can have serious legal, equity and other social considerations that must be addressed.

Water Scarcity and the Role of Water Storage in Development

Under all but the most optimistic scenarios, there is a dearth of freshwater storage. If climate change as a result of global warming manifests, the need for freshwater storage will become even more acute. Increasing storage through a combination of groundwater recharge and surface water facilities is critical to meeting the water demands of the twenty-first century This is especially so in monsoonal Asia and the developing countries in the tropics and semitropics.

This research discusses various options for storage, ranging from small facilities to groundwater to large facilities. In most cases, IWMI believes that the need for additional storage can be addressed productively by innovative combinations of small, medium and large facilities and groundwater recharge.

As an immediate first step to defining the precise needs and potential for water storage, the major river basins of the world must be assessed, whether they are *open, closed* or *semi-closed.*[1] The productivity of water as presently used must also be assessed to determine the extent to which increased demands for irrigated agricultural production can be met by increasing water productivity, and the extent to which increased demands will require increased consumption of water. The uncommitted discharges from those basins that are open or semi-closed can then be determined, and plans made to effectively capture and put this water to use. Combinations of small and large surface storage and groundwater recharge are generally the best systems where they are feasible.

There are four major ways of storing water—in the soil profile, in underground aquifers, in small reservoirs,[2] and in large reservoirs behind dams. Storage in the soil profile is extremely important for crop production, but it is relatively short-term storage, often only sufficient for a period of days. Here we concentrate on the three kinds of technologies that store water for periods of months, in small reservoirs, or years, in aquifers and large reservoirs. These three technologies are compared from hydro-

[1] *Open basins* are those that have an excess of water, over and above all committed ecological and environmental requirements, even during the dry season. In closed basins, there is no excess water flowing out of the basin; all water resources are committed to use. In semi-closed basins, there is excess outflow during the wet season, but not during the dry season. In these basins, storing water and reallocating it between seasons can achieve potentially large increases in the value of water.

[2] Structures with height less than 15 m and volume less than 0.75 million cubic meters.

logical, operational, social, environmental and economic standpoints. The two principle conclusions of this analysis are:

- Aquifers and small and large reservoirs all serve an indispensable role in water storage, and each technology has strong comparative advantages under specific conditions of time and place.
- Where it is possible to do so, substantial gains can be achieved by combining all three storage technologies in an integrated system.

Table 1. Comparative advantages, limitations, and key issues associated with groundwater, small reservoirs, and large dam water storage

Groundwater Storage	Small Surface Water Reservoirs	Large Dam Reservoirs
Advantages:	***Advantages:***	***Advantages:***
Little evaporation loss Ubiquitous distribution Operational efficiency Available on demand Water quality	Ease of operation Responsiveness to rainfall Multiple use Groundwater recharge	Large, reliable yield Carryover capacity Low cost per m^3 water stored Multipurpose Flood control and hydropower Groundwater recharge
Limitations:	***Limitations:***	***Limitations:***
Slow recharge rate Groundwater contamination Cost for extracting Recoverable fraction	High evaporation loss fraction Relatively high unit cost Absence of over-year storage	Complexity of operations Siting High initial investment cost Time needed to plan and construct
Key Issues:	***Key Issues:***	***Key Issues:***
Declining water levels Rising water levels Management of access and use Groundwater salinization Groundwater pollution	Sedimentation Adequate design Dam safety Environmental impacts	Social and environmental impacts Sedimentation Dam safety

Exploiting Complementarities between Types of Storage

In the past, economies of scale have been the main consideration in the selection of storage type, often at unacceptable social and environmental costs. Many large dams have been built because of their low cost per cubic meter of water stored, not because they were suited to the specific situation. If storage projects are to serve their purpose with maximum efficiency, then a variety **of** options should be considered. The complementarities among different types of storage should be exploited to improve conservation and productivity ***of*** water. Combining types of storage in an integrated system optimizes the advantages and minimizes the disadvantages of each.

Table 2 presents the characteristics of storage types for providing the needed conservation and operational efficacies. The suitable combinations of storage types depend on a number of factors including topography, hydrology, and the existence of suitable aquifers.

A number **of** combinations already exist and work satisfactorily. The combination of small and large reservoirs is nicely demonstrated by the "melons on a vine" irrigation schemes in China, Sri Lanka and other countries,

Here, a few large storage facilities supply water to numerous small reservoirs within a river basin. The small reservoirs act to dampen supply and demand mismatches from large reservoirs. In the **Imperial** Irrigation District in southern California, small regulator reservoirs **of** 500,000 m^3 save more than 12 million m^3 annually of canal flows **that would** otherwise spill to the Salton sea; this results in an annual 25 to 1 water conservation to storage volume ratio.

Complementarities also occur where surface storage, particularly in the form of micro-reservoirs, retards runoff and enhances groundwater recharge. With improved tube-well technology now available and within reach of small farmers, many storage reservoirs, which were **previously** used for irrigation in the arid and semiarid tracts of India, have now been converted to recharge ponds, and tube **wells** have taken the place of irrigation canals.

Table **2.** Characteristics of storage structures.

Storage Type	Conservation potential	Operational flexibility	**Adequacy**	**Reliability**
Large reservoir	H	L	H	L
Small reservoir	L	H	L	L
Groundwater storage	H	H	L	H
Large and **small reservoir** combined	H	H	H	L
Large and **small reservoirs** combined with groundwater storage	H	H	**H**	H

H = High; L = Low; Adequacy = Sufficiency of yield to meet needs of command area; Reliability = Assuredness of **water** deliveries.

These successful experiments indicate that combinations of big and small reservoirs along with effective aquifer management can provide efficient solutions for conserving water and increasing its productivity. Hitherto, this concept has not been effectively put into practice from the planning stage, although it has been practiced in many areas of the world. With water becoming scarce, the use of such integrated planning for conserving water could lead to higher water productivity while maintaining the ecological balance.

The Global Groundwater Situation: Overview of Opportunities and Challenges

The Challenge

Throughout the world, fresh groundwater resources are shrinking **by** *the day* **In** *addition to depletion, three other factors that threaten groundwater are salinity, waterlogging and the pollution of aquifers.*

Compared to surface irrigation, managing groundwater **is a** *different and far more complex affair. In groundwater-abundant areas, IWMI scientists are exploring how communities and villages can organize themselves better to manage and share water for irrigation. In areas suffering from groundwater overexploitation, IWMI's work focuses on developing* **new** *approaches to the problem. These include the combined use of groundwater and surface waters, rainwater-harvesting, groundwater recharge, local institutions, and the use of precision irrigation for* **more** *efficient water use.*

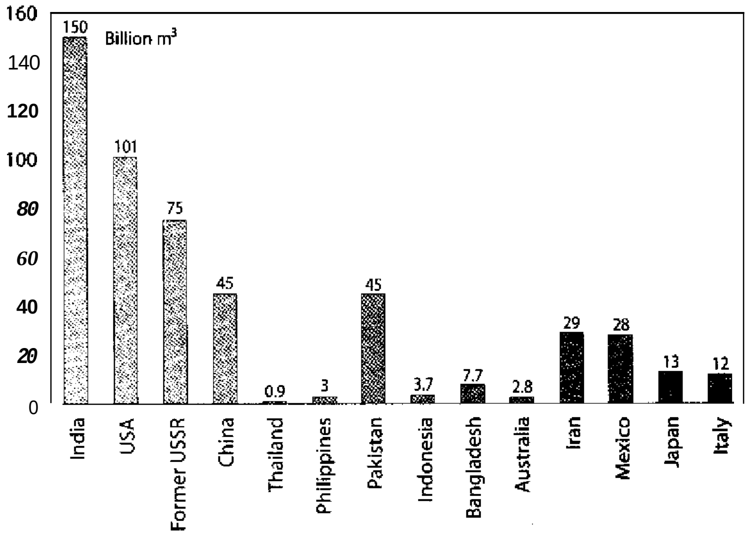
In North **China** **,** for instance, water tables declined between 0.75 meters and **3.68** meters during 1975–87. Waterlogged areas **in** India are estimated at **6** million hectares; in Pakistan, rising water tables and groundwater salinity are among the most important issues in the Indus river basin.

Unplanned groundwater exploitation can severely damage fragile ecosystems. In coastal areas, the most serious consequence of intensified pumping of groundwater **for** irrigation **is** saline ingress into coastal aquifers. Man-made pollution is another menace.

In the **Gediz** basin of Turkey, for instance, sgrochemicals have polluted the groundwater beyond use by the nearby cities, Groundwater **is** also emerging as a critical issue for cities and towns around the world. Some three hundred of China's densely populaled large and medium cities face acute water shortages. Bangkok, Jakarta and Mexico City have been facing serious problems because of groundwater depletion.

Taken together, the world's groundwater resources, at first glance, appear abundant. Groundwater constitutes over two-thirds of the world's freshwater resource, if we exclude glaciers and permanent snow cover. We have an estimated renewable supply of over 2.500 to 3,500 km^3 **of** groundwater annually—which Seems several times more than the estimated 750–800 km^3 per year the world uses today (see fig-

Figure 4: Groundwater use in selected countries in **the 1980s**.



Source: Llamas, Back, and Margat 1992.4; and Takeuchi and Murthy 1994, 14.

ure 4). However, this aggregate comparison is misleading, as the available water reserves are not located where they arc most needed.

The Opportunity

Groundwater has unique advantages over surface water supplies and offers an important opportunity for human development, Groundwater is accessible to a large number of users; it can provide cheap, convenient, individual supplies; it is generally less capital-intensive to develop, and does not depend upon mega-water projects. Its development is easy and largely self-financing.

When it is not degraded by human intervention, groundwater has high microbiological quality, arising from its situation below ground and the natural protection this affords. Compared to surface water, groundwater offers better insurance against drought because of the long lag between changes in recharge and responses in groundwater levels and well yields.

Groundwater irrigation offers big opportunities for enhancing the livelihoods of the poor. In South Asia, the emergence and spread of water markets has helped improve poor people's access to groundwater. Microdiesel pumps have become extremely popular with smallholders in Bangladesh. Among the most exciting innovations in small-scale irrigation technologies arc the low-cost treadle pumps—selling as *Krishak Bandhu* (Farmer's Friend) in South Asia and "Money Maker" in Africa.

Equally popular in this segment ate likely to be the new range of low-cost bucket-and-drum-based drip irrigation technologies that have recently begun coming into the market.

IWMI is currently investigating ways of bridging the gap between the manual pumpwhich appeals primarily to the vegetable growers with tiny garden plots—and the 5-hp diesel pump, the industry standard, which is too big and costly for most marginal farmers. This may turn out to be the biggest opportunity for irrigation to fight rural poverty in the region.

Points for Action

It is clear that the primary groundwater challenge is not in developing the resource, but in its sustainable management. Gearing up for resource management entails the following steps:

Information* System *and Resource Planning: strengthening the knowledge base in developing countries through systematic data-gathering on groundwater availability, quality, withdrawal and other variables in a format useful for resource planning;

Demand-Side Management: including a) registration of users through a permit or license system; b) creating appropriate laws and regulatory mechanisms; c) a system of pricing that aligns the incentives for groundwater use with the goal of sustainability; d) promoting conjunctive use; and e) promotion of precision irrigation and water-saving technologies and approaches;

Supply-Side Management: augmenting groundwater recharge through: a) broad-based rainwater-harvesting and groundwater recharge programs and activities; b) maximizing surface water use for recharge; and c) improving incentives for water conservation and artificial recharge;

Groundwater Management in the River Basin Context: like surface water resources, the groundwater resource too needs to be planned and managed for maximum basin-level efficiency. This will include efforts to understand the hydrology and economics of an entire aquifer;

Recharge with Imported Surface Water: possibilities include trans-basin diversions or market-based solutions to build groundwater to sustainable levels;

Recharge with Rainwater: *in situ* rainwater-harvesting and recharge. Water-scarce regions of Asia have age-old traditions and structures for rainwater-harvesting that can be revived; and

Domestic Rainwater-Harvesting: using both traditional and new techniques, supported by appropriate support systems and institutions.

Poverty, Gender and Water

More than one billion people are deprived of access to water of sufficient quantity and quality to meet minimum levels of health, income, and freedom from drudgery Poor women are particularly affected. It is primarily women who bear the daily burden of hauling heavy buckets long distances to meet the domestic water needs of their families.

In the world's poorest communities, women are also excluded even more so than men, from many income-generating opportunities that are dependant on water, such as irrigated farming. So water has never been a 'free good' for poor women.

Meeting the multifaceted water needs of **poor** men and women should be a priority in water policy at the international, national, basin and community levels.

Policy makers generally recognize the need for urgent action, but today there are no agreed concepts that integrate gender, poverty and water that:

- define the nature of the problem for poor people
- capture the multiple aspects and linkages of poverty and water deprivation in **a** comprehensive way
- analyze the different processes in society that contribute to the problem and perpetuate it
- support policy makers in their efforts to alleviate water-related poverty

This paper on poverty, gender and water aims to fill this **gap** by elaborating the concept of "water deprivation" and its policy implications, with a special focus on imgation. Another aim of the paper is to elaborate the gender dimensions of irrigation.

Defining "Water Deprivation"

The term "water deprivation" refers not only to a *state,* as in "*one* billion people live in a state of water deprivation," but also to the *processes* that contribute to the creation and perpetuation of that state Water deprivation is **primarily** human-made, not the inevitable result of natural scarcity To eradicate the state of water deprivation, it is necessary to short-circuit the processes behind it. Two fundamental questions must be addressed: What decision processes govern the development of physical infrastructure to distribute water resources to people's homes, fields, and enterprises—

to the benefit of some and the exclusion of others? What processes determine resource allocation in situations of water scarcity?

Water deprivation is "asset-related" in the sense that society's technological, institutional and financial resources for water infrastructure development and use hardly reach the poor. Water deprivation is also "direct deprivation" if the more powerful and larger water users consume scarce water resources and impose the needed savings on the poorer sections of society. To ensure that all people receive the water they need for basic well-being, policies need to address both aspects of deprivation.

Women and Irrigation: Promoting Women's Productive Businesses

Endowing poor women with imgation assets and water for their own farm businesses is an effective way to alleviate poverty, Women who are *dejure* and *de facto* heads of households and women who manage their own farm businesses alongside those of their male kin need direct access to irrigation water. Traditionally, irrigation agencies have tended to exclude women categorically from access to water. Recently, some agencies have developed approaches that are based on a sound understanding of the prevailing gender relations in irrigated agriculture. These agencies have made efforts to include both poor men and women stakeholders in the planning process for infrastructure installation and in the creation of water user associations. The impacts of these inclusive approaches need to be assessed and the lessons learned from successful programs need to be publicized for wider replication.

Fro-poor, Gender-Inclusive Policy: Points for Action

Defining and combating water deprivation start by identifying poor men and women; assessing their current water use for multiple purposes, including income generation; and tracing which needs are still unmet, and why. Because water deprivation affects various dimensions of well-being, strategies to meet basic water needs should be comprehensive and multipronged.

The following policy recommendations do not claim to be definitive, but offer some generic points for action, given what we know now. More site-specific and comparative research needs to be done to serve as a foundation for comprehensive strategies to combat water deprivation.

- ***Analyze poor women's and men's current water use for multiple purposes,*** identify their unmet water needs, and monitor any negative impacts of growing competition for water.

- ***Target new water infrastructure development and rehabilitation at the needs of poor women*** and ***men.*** This must be done by establishing clear, equitable water rights, appropriate technologies, inclusive management institutions, **partly** subsidized collective schemes on poor people's land, **and** competitive water markets that deliver **good** services at low costs.

- *Promote women's active inclusion* in irrigation infrastructure development programs and water user associations.
- *Establish a wafer reserve* to ***meet poor*** *people's* ***needs*** in closing and closed basins, where competition for water is growing. Poor men and women should have access to more water **of** better quality. The responsibility of water-saving **should** be borne **by** nonpoor users.
- *Require an ex-ante assessment of* ***new*** *water* ***policies*** *and programs* by national **and** international agencies to indicate a substantial positive impact on **poor** women's **and** men's water **use,** before approval. Monitor and evaluate implementation.
- *Prevent pollution of* ***surface*** *water* ***and*** *groundwater,* applying the "polluter-pays" principle, retroactively.
- *Promote information exchange, dialogue, capacity building, and training* ***on*** *strategies to combat water deprivation* **among** poor women **and** men, other water users, **urban** and rural local community organizations, civil societies, private water-delivery enterprises, government agencies, **and** researchers from all water sectors — from local to international levels **and** from user level to policy level.

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