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IMPACT ON FOOD SECURITY AND RURAL DEVELOPMENT OF REALLOCATING WATER FROM AGRICULTURE

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ABSTRACT

The competition for limited water resources between agriculture and more highly valued domestic and industrial water uses is rapidly increasing and will likely require the transfer of water out of agriculture. This paper reviews and synthesizes the available evidence of the effects of water transfers from agricultural to urban and industrial areas on local and regional rural economies; and analyzes the potential impacts of a large reallocation on global food supply and demand. It concludes with a discussion on the potential for water policy reform and demand management to minimize adverse impacts when water is reallocated from agriculture. It is argued that comprehensive reforms are required to mitigate the potentially adverse impacts of water transfers for local communities and to sustain crop yield and output growth to meet rising food demands at the global level. Key policy reforms include the establishment of secure water rights to users; the decentralization and privatization of water management functions to appropriate levels; the use of incentives including pricing reform, especially in urban contexts, and markets in tradable property rights; and the introduction of appropriate water-saving technologies.

Keywords: Water transfers; Water scarcity; Agricultural production; Projections of food supply and demand; Demand management.

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Mark W. Rosegrant and Claudia Ringler*

1. INTRODUCTION

Population and economic growth in developing countries will pose serious challenges for humanity in simultaneously meeting food requirements and water demands. Competition for limited water resources increasingly occurs between different stakeholders and at different levels: between farmers within an irrigation system; between irrigation systems in the same river basin; between the agricultural sector and other rural uses, such as fisheries or domestic water supply and drinking water; and more and more between agricultural and urban and industrial users and uses, and environmental uses. Agriculture still accounts for the majority of global water withdrawals, and is often responsible for 80% or more of total withdrawals for consumptive uses in developing countries. However, as this paper will show, it is likely that significant amounts of water will be reallocated from agricultural uses to higher valued domestic and industrial water demands. The impacts of the shift of water at the sectoral level, from agricultural to other uses, on household, local, national, regional, and global food production and food security have not been studied in an integrated manner. This paper reviews and synthesizes the available evidence of the effects of water transfers from agricultural to urban and

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industrial areas on local and regional rural economies; and analyzes the potential impacts of a large reallocation on global food supply and demand.

The following sections examine recent trends as well as projections of global food supply and demand that underlie future water demands in agriculture based on IFPRI's IMPACT model; describe the role of irrigation in global food production; and examine recent trends and projections for nonagricultural water demands. The paper then addresses the potential for meeting these future demands with an emphasis on the role of intersectoral water transfers; and discusses the potential for water policy reform and demand management to minimize adverse impacts when water is reallocated from agriculture.

2. RECENT TRENDS IN AND PROJECTIONS OF GLOBAL FOOD SUPPLY AND DEMAND

The world population is expected to grow to 7.7 billion in 2020, from 5.3 billion in 1993 (UN, 1996). In addition, total urban population is expected to increase to almost double, from 2.6 billion in 1995 to 5.1 billion by 2025; by then the majority of the population will live in urban areas (61%). Almost all urban population growth, about 90%, will occur in developing countries, where roughly 150,000 people are added to the urban population every day (WRI, 1996). These developments will have serious impacts on global food supply and on the structure of water demand.

2.1 PROJECTIONS OF GLOBAL FOOD SUPPLY AND DEMAND TO 2020

Projections of global food supply and demand have been made using the January 1998 version of IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT). The model covers 37 countries and regions and 17 commodities, including cereals, roots and tubers, soybeans, and meats, and is specified as a set of country-level supply and demand equations, with each country model linked to the rest of the world through trade. Food demand is a function of prices, demand elasticities, income and population growth. Growth in commodity production in each country is determined by prices and the rate of productivity growth, which in turn is influenced by advancements in public and private agricultural research and development, extension and education, markets, infrastructure and irrigation. Irrigation expansion directly affects area harvested and yields. The world price of each commodity is determined as the price that clears world markets. A full description of the model is beyond the scope of this paper, but see Rosegrant et al. (1995) for the detailed model structure; and Rosegrant et al. (1997) for a detailed presentation of the baseline results summarized below.

According to the IMPACT baseline scenario real world prices of food will decline, but more slowly than in the past two decades. Cereal prices on average are projected to drop by about 10% by 2020, and meat prices by 6%. Projected real prices of cereals will be nearly constant through 2010, but the continued slowdown in the population growth rate after 2010, together with declining income elasticities of demand for cereals, will reduce demand growth enough to cause cereal prices to fall. The tighter future price scenario implies that shortfalls in meeting the water demand for agriculture could put serious upward pressure on food prices. This issue will be explored below.

In developing countries, especially in Asia, rising incomes and rapid urbanization will change the composition of cereal demand. Per capita food consumption of maize and coarse grains will decline as consumers shift to wheat and rice, livestock products, fruits and vegetables, and processed foods. The projected strong growth in meat consumption, in turn, will substantially increase cereal consumption as animal feed, particularly maize. Growth in cereal and meat consumption will be much slower in developed countries. These trends will lead to a strong increase in the importance of developing countries in global food markets: 82% of the projected increase in global cereal consumption, and nearly 90% of the increase in global meat demand between 1993 and 2020 will come from developing countries. Developing Asia will account for 48% of the increase in cereal consumption, and 63% of the increase in meat consumption. The composition of food demand growth across commodities will change dramatically. Total cereal demand is projected to grow by 717 million metric tons (mt), or by 40%, with the largest increase in maize (35%) and wheat (31%).

How will the expanding cereal demand be met? Expansion in area will contribute very little to future production growth, with a total increase in cereal crop area of only 39 million hectares (ha) by 2020, from 700 million ha in 1993, 88% of which will originate in developing countries. The projected crop area growth represents the net effect of slow expansion in irrigated area (see below); slowly increasing crop intensity on existing irrigated areas; declining commodity prices that limit the profitability of investment in irrigation; and gradual loss of land to soil degradation and urbanization. The slow growth in crop area places the burden to meet future cereal demand on crop yield growth. Although yield growth will vary considerably by commodity and country, in the aggregate and in most countries it will continue to slow down. The global yield growth rate for all cereals is expected to decline from 1.5% per year during 1982-94 to 1.1% per year during 1993-2020; in developing countries, average crop yield growth will decline from 1.9% per year to 1.2% per year; and in developed countries from 1.3% per year to 0.9% per year. Even with these reduced growth rates, yield growth will account for 80% of growth in cereal production in developing countries, and for 94% in developed countries.

2.2 FOOD DEMAND AND SUPPLY GAPS AND WORLD TRADE IN FOOD

Two types of food gaps can be identified. The most devastating is the gap between actual food consumption and the quantity and quality of food required to sustain a healthy and productive life. By this measure, there will be little improvement in food security for the poor in many regions. Sub-Saharan Africa will have only small increases in per capita calorie availability as income growth will be only slightly in excess of population growth, and the number of malnourished children is projected to increase by 12 million during 1993-2020. Thus, even with relatively abundant food in the world, there will not be enough growth in effective per capita demand for food in Sub-Saharan Africa to improve the food supply situation. More progress can be seen for South Asia, home to more than one-half of the world's malnourished children, but nearly 70 million children will still be malnourished in the region in 2020.

The second type of food gap is the difference at the national level between food production and food demand as reflected in food imports. Growing imports are not a problem if they are the result of strong economic growth generating the necessary foreign exchange to pay for the food imports. In the case of some Middle Eastern countries facing extreme water scarcity and sharp population increases, the strategy of substituting food imports for irrigated agricultural production paid for by (water-based) urban and commercial growth has been called imports of "virtual water" (Allan, 1996). However, even when rapidly growing food imports are primarily a result of rapid income growth, they often act as a warning signal to national policymakers concerned with heavy reliance on world markets, and can induce pressures for trade restrictions that can growth and food security in the longer term. More serious food security problems arise when high food imports are the result of slow agricultural and economic development that fails to keep pace with basic food demand growth driven by population growth. Under these conditions, it may be impossible to finance the required imports on a continuing basis, causing a further deterioration in the ability to bridge the gap between food consumption and food required for basic livelihood.

World trade in food is projected to increase rapidly, with trade in cereals expected to increase from 186 million mt in 1993 to 349 million mt in 2020, and trade in meat products will likely almost triple, from 8 million mt to 23 million mt. Expanding trade will be driven by the increasing import demand from the developing world: net cereal imports in developing countries are projected to rise by nearly 150%, from 94 million mt in 1993 to 229 million mt in 2020, and net meat imports are expected to increase from less than 1 million mt in 1993 to 11 million mt in 2020. "Hot spots" for food trade gaps are Sub-Saharan Africa, and potentially West Asia and North Africa (WANA). Cereal imports in Sub-Saharan Africa are projected to increase from 12 million mt in 1993 to 29 million mt in 2020. It is highly unlikely that this level of imports could be financed internally, but instead would require international financial or food aid. Failure to finance these imports would further increase malnourishment in this region. In WANA, cereal imports are projected to increase from 38 million mt in 1993 to 65 million mt in 2020, with most of this increase expected to occur in the non-oil producing countries.

3. THE ROLE OF IRRIGATED AGRICULTURE IN GLOBAL FOOD PRODUCTION

3.1 CONTRIBUTION OF IRRIGATION TO GLOBAL FOOD PRODUCTION

During the 1950s to the 1980s, irrigation expanded rapidly and currently accounts for about 72% of global water withdrawals, and about 90% of water use in low-income developing countries. Such a major role for irrigation had been justified by the contribution of irrigation systems to stabilizing, then expanding national and world food supplies during the Green Revolution, especially in Asia (Svendsen and Rosegrant, 1994). Dramatic increases in yield during and after the Green Revolution were achieved, in large part, through the introduction and successful adoption of high-yielding varieties of wheat and rice that depend heavily on timely nutrient and pest control management as well as irrigation applications to secure and control soil moisture (FAO, 1996). Thus, irrigated agriculture was a major factor in achieving the yield growth rates described above.

In the mid-1990s, irrigated agriculture contributed nearly 40% of world food production on 17% of the cultivated land. In India, for example, irrigated areas (one third of total cropped area) account for more than 60% of total production. Over the next 30 years, as much as 80% of the additional food supplies required to feed the world may depend on irrigation (IIMI, 1992). Irrigation also furthers stability through greater control over production and scope for crop diversification. Moreover, in many developing countries, irrigation constitutes an important element of rural development policies, as it provides higher rural incomes and employment and allows for increased agricultural and rural diversification through secondary economic activities derived from extended and more varied agricultural production (as compared to rainfed agriculture). In addition, in arid and semi-arid areas, alternatives to irrigated agriculture are rare, and water reallocation can lead to rural-urban migration and abandonment of plots (Fereres and Ceña, 1997; Raskin et al., 1995; Wolter, 1997). Thus, irrigation plays a vital role in achieving food security and sustainable livelihoods in developing countries, both locally, through increased income and improved health and nutrition, and nationally, through bridging the gap between production and demand.

3.2 RECENT TRENDS IN IRRIGATED AREA

The development of new irrigation has slowed considerably since the late 1970s, due to escalating construction costs for dams and related infrastructure, low and declining prices of staple cereals, declining quality of land available for new irrigation, and increasing concerns over the environmental and negative social impacts of large-scale irrigation projects. Lending for large-scale irrigation projects from international donors declined sharply after the 1970s: loans from four major donors, the World Bank, the Asian Development Bank, the U.S. Agency for International Development (USAID), and the Japanese Overseas Economic Cooperation Fund (OECF) peaked in the late 1970s, but by the late 1980s were just over 50% of the 1977-79 level (Rosegrant, 1997). These declining expenditures are reflected in the declining growth in crop area under irrigation. Globally, the growth rate in irrigated area declined from 2.16% per year during 1967-82 to 1.46% in 1982-93. The decline was slower in developing countries, from 2.04% to 1.71% annually during the same periods, but the lagged effect of declining investment in irrigation will be increasingly felt through further slowdowns in expansion of irrigated area.

Declining investment in irrigation has been accompanied by a decline in the quality and performance of existing irrigation systems, with irrigated areas increasingly affected by waterlogging and salinization. It is estimated that salinity seriously affects productivity in 20 to 46 million ha of irrigated land, for example (El-Ashry [1991], Barrow [1991], Rhoades [1987], and Kayasseh and Schenck [1989]). However, with expansion of irrigation into new areas likely to be slow, the future contribution of irrigation to food production must come mainly from improvement in the productivity of the existing irrigated land base. This implies both the need to increase the efficiency of water use and the need to improve the quality of the resource base in irrigated areas, reversing the trends towards increased degradation through waterlogging and salinization of soil, as well as degradation of water quality and groundwater mining (Rosegrant and Pingali, 1994).

3.3 PROJECTIONS OF IRRIGATED AREA TO 2020

Rosegrant et al. (1997) assess future expansion in irrigated area, consistent with the underlying assumptions in the global food projections. The projections indicate a continued decline in irrigated area growth. In developed countries, irrigated area is expected to increase by only 3 million ha between 1995 and 2020, at an annual rate of growth of just 0.2%, compared to 0.8% annually during 1982-93. In developing countries, an additional 37 million ha of irrigated area is projected by 2020, at an annual rate of increase of 0.7%, compared to 1.7% per year during 1982-93. The largest increase is expected in India with 17.3 million ha by 2020, as public investment in irrigation has remained relatively strong and private investment in tubewells has been very rapid. However, even in India, the projected 1995 to 2020 rate of growth in irrigated area of 1.2% per year is well below the rate of 2.0% per year during 1982-93. Area under irrigation will remain very low in Sub-Saharan Africa, despite a potential increase of 50% to 7.4 million ha in 2020. Simulations suggest that increased investment in irrigation can make a significant contribution to food production growth in Sub-Saharan Africa, although the amount of land under irrigation and the potential area exploitable relative to total crop area may not be large enough to generate revolutionary increases in crop production (Rosegrant and Perez, 1997).

4. RECENT TRENDS IN AND PROJECTIONS OF WATER DEMAND

4.1 RECENT TRENDS IN GLOBAL WATER DEMAND

Given the current global use of water of around 3,700 billion cubic meters (BCM), the estimated 9,000-14,000 BCM of reliable annual freshwater runoff would be adequate to meet growth in demand in all sectors for the foreseeable future, if supplies were distributed equally across the world's population. However, freshwater is poorly distributed across countries (Canada is blessed with 120,000 m^3 per capita per year of renewable water resources; Kenya has 600 m^3; and Jordan, 300 m^3); across regions within countries (although India has adequate average water availability of 2,500 m^3 per capita, the state of Rajasthan has access to only 550 m^3 per capita per year); and across seasons (Bangladesh annually suffers from monsoon flooding followed by severe dry season water shortages) (Rosegrant, 1997). Moreover, with a fixed amount of renewable water resources supplying an increasing population, per capita water availability has declined from 9,600 m^3 to 5,100 m^3 in Asia, and from 20,000 m^3 to 9,400 m^3 in Africa between 1950 and 1980 (Ayibotele, 1992).

Tightening supplies have been accompanied by rapid growth in the demand for water. Between 1950 and 1990, water use increased by more than 100% in North and

Latin America, by more than 300% in Africa, and by almost 500% in Europe (Clarke, 1993). Global demand for water has grown rapidly, at a rate of 2.4% per year since 1970. In 1995, annual per capita domestic withdrawals ranged from a high of 240 m^3 in the U.S. to only 11 m^3 in Sub-Saharan Africa, a level that is just over one-half of the 20 m^3 per capita estimated by Gleick (1996) as required to meet the most basic human needs. China, India, and other South Asian countries are all at or just above this basic human needs level. Southeast Asia, Latin America, and WANA cluster at 56 m^3 per capita to 65 m^3 per capita. For developing countries as a group, per capita water demand was 33 m^3 in 1995, less than one-fourth the amount in developed countries. In addition to the basic water requirements for sanitary and other domestic uses, estimates of minimum water requirements for basic food needs range from 400 m^3 per capita per year (Postel, 1996) to 1,000-2,000 m^3 per capita annually (FAO, 1989). However, actual minimum requirements are often higher, especially in urban areas, due to higher living standards.

Environmental demands also gain higher priority with rising incomes. In a growing number of developed countries, environmental uses are even becoming the first claimant on available water resources; in developing countries, these demands are increasingly acknowledged, but honored usually only if local economic development is not hindered. However, the latent demands are expected to be served as incomes grow (Burton and Chiza, 1997; Franks et al., 1997; Grossman and Krueger, 1997).

4.2 PROJECTIONS OF WATER DEMAND TO 2020

Taking into account long-term growth in income, industrial expansion, and irrigation development, Rosegrant et al. (1997) project that global water withdrawals will increase by 35%, from 3,745 billion cubic meters (BCM) in 1995 to 5,060 BCM by 2020; thus, about one half of the accessible runoff will be accounted for. Most of the additional pressure on the water resource base is expected to occur in the group of developing countries, where withdrawals are projected to increase by a rapid 43%, from 2,347 BCM in 1995 to 3,350 BCM in 2020. In sharp contrast to past growth patterns in developing countries, the combined increase in domestic and industrial water demand will be greater than the increase in agricultural water demand, projected at 589 BCM (59%) and 415 BCM (41%), respectively, between 1995 and 2020.

5. POTENTIAL FOR MEETING FUTURE WATER DEMANDS THROUGH SUPPLY EXPANSION

Can the rapid growth in water demand, particularly in the domestic and industrial sectors, be met without massive transfers of water out of agriculture that could derail the projected growth in crop yield and area described above? This section examines the potential for expansion of water supplies through traditional and nontraditional means.

Development of irrigation and water supplies has become increasingly expensive. In India and Indonesia, for example, the real costs of new irrigation have more than doubled since the late 1960s and early 1970s; costs have increased by more than 50% in the Philippines; they have tripled in Sri Lanka; and increased by 40% in Thailand (Rosegrant and Svendsen, 1993). In China, Pakistan and Indonesia, irrigation has absorbed over half of all agricultural investment, and about 30% of all public investment in India. In addition, once established, irrigation projects become some of the most heavily subsidized economic activities in the world, both directly and indirectly. In the mid-1980s, it was estimated that average subsidies to irrigation in six Asian countries covered 90% or more of the total operating and maintenance costs (Repetto, 1986). The cost of supplying water for household and industrial uses is also increasing rapidly. In Shenyang, China, for example, the cost of new water supplies will nearly triple from US$0.04 to US$0.11 per m^3 between 1988 and 2000 because pollution of the current groundwater source will require a shift to water conveyed by gravity from a surface source 51 km from the city (World Bank, 1993).

Because of the high costs and increasing concerns about economic, environmental, and social impacts, it will be difficult to justify construction of large-scale dams and water supply systems, despite the fact that a review of the World Bank's experience with irrigation shows that there are in fact economies of scale in irrigation projects: the rates of return to large projects have been higher than returns to small-scale projects (Jones, 1995). However, these estimates do not take into account the full range of negative externalities generated by these projects, and also do not account for the economic, environmental, and social consequences if the projects are not developed. The heightened national and international concern over the broad environmental and human effects of large irrigation projects will make it very difficult to proceed with many of these projects.

Small-scale irrigation projects can have considerable advantages over large-scale projects. However, in many cases the bureaucratic mode of implementation has effectively eliminated the potential advantages, and big and small systems often share a number of common characteristics: high capital costs per ha and per farmer; bureaucratic, costly, and inefficient management; low technical efficiency, low settler incomes, and zero or negative returns (Adams, 1990). Farmer-owned and -controlled systems, on the other hand, have a better performance record. Experience indicates that it is not so much the size of the irrigation system that determines its success, but a host of institutional, physical, and technical factors. Every river basin is different, and the appropriate choice of system size and operational characteristics in any given basin is likely to be determined by conditions unique to that basin. A pragmatic approach to project design should be taken that ensures quantification of full benefits, including not only irrigation benefits, but also health, household water use, and catchment improvement benefits (Jones, 1995) and full assessment of, and compensation for, negative environmental and resettlement costs. Selective development of new surface water must still play a role in future water resource development.

Another important source for increasing water supply is desalination. However, given the high capital and energy costs for this technology, the substantial transportation costs involved to pump the desalinated water inland, and the potential environmental damages from generated wastes, this technology will likely remain concentrated in the water-scarce Persian Gulf and islands nations (Postel 1992).

Additional water can be conserved through recycling (reuse in the same home or factory) and, to a lesser extent, through wastewater reuse (collection of used water, treatment and redistribution to another locations). In developed countries, pollution control laws and incentive pricing ('polluter-pays' principle) have been a primary motivator for industrial water recycling. In the U.S., for example, total industrial water use fell 36% while industrial output increased nearly fourfold between 1950 and 1990 (Postel, 1992). Similar conservation efforts have also begun in water-scarce developing country cities. In Beijing, China, for example, the water recycling rate increased from 61% in 1980 to 72% in 1985; and between 1977 and 1991, total industrial water use declined steadily while output increased by 44% in real terms (Nickum, 1994).

The rate of expansion of wastewater reuse depends on the final quality of the wastewater and on the public's willingness to use these supplies. Worldwide, about 500,000 ha of cropland is irrigated by treated municipal wastewater, amounting to only two-tenths of 1% of the world's irrigated area. Israel undertakes the largest wastewater reuse effort in the world, treating 70% of the nation's sewage to irrigate 19,000 ha of cropland. Reclaimed wastewater is projected to supply more than 16% of Israel's total water needs by the start of the next century. Most of this would be used in agriculture to replace freshwater reallocated to nonagricultural uses (Postel, 1992). However, given the relatively high cost of wastewater treatment and transport to agricultural areas, it is likely that wastewater can make up an important share of agricultural water supply only in arid regions where the cost of new water supplies has become very high.

Water harvesting, the capture and diversion of rainfall or flood water to fields to irrigate crops, has been used for centuries in traditional agriculture to increase water supplies. Water harvesting can provide farmers with improved water availability, increased soil fertility, and higher crop production in some local and regional ecosytems. Water harvesting can also provide broader environmental benefits through reduced soil erosion. However, given the limited areas where such methods appear feasible, and the small amounts of water that can be captured, water harvesting techniques are unlikely to have a significant impact on global food production and water scarcity.

Interbasin water transfers have often been proposed as the best solution to solve acute water shortages in adjacent basins or sub-basins, particularly in arid and semiarid regions and where a large shift of water from agricultural to urban and industrial users is necessary. Plans for interbasin transfers were widespread in the 1960s and 1970s: the Soviet Union planned to divert Siberian rivers to reduce water shortages and the shrinking of the Aral Sea at least since the 1970s; the Middle Eastern countries had plans of Nile water diversions to replenish the Jordan river as early as 1902; and the U.S. planned to transfer large water quantities from Canada to the semiarid southwestern states in the 1960s. However, most of the larger-scale proposals never materialized due to huge capital costs; substantial scope for less capital-intensive alternative water savings; and increasing concerns about negative economic, environmental, and social impacts in the exporting basin, such as the potential cutting off of future development opportunities, social disruption, irreparable environmental damage, and rural-urban migration. China is an exception in that it realized several large interbasin transfers in the past and is committed to further large-scale basin transfers. The country recently decided to carry out the proposed middle route of the South-to-North Water-Transfer Project for agricultural development on the North China Plain and for the city of Beijing.

Micro-level basin transfers over short distances have proven to be viable options in some regions. Several states in the U.S. have drafted interbasin legislation in recent years (London and Miley, 1990) and Texas, for example, currently has about 80 active interbasin transfer permits, typically to serve the rapidly growing cities. However, as with large-scale transfers, the potential economic and social costs in the area of origin must be taken into account. A case where the constraints on future development in the exporting basin were not considered is the purchase of water rights by the city of Los Angeles in the Owens Valley of Eastern California. This purchase had a devastating impact on the Valley, one from which it has never recovered (U.S. Office of Technology Assessment, 1993). However, interbasin transfers do not always curtail production on irrigated lands: the Metropolitan Water District in California, for example, has a 35-year contract to pay for conservation projects in the Imperial Valley in exchange for temporary use of the conserved water. In this example, the exporting basin retains the water rights and suffers no reduction in levels of water use (Postel, 1992).

In summary, a portion of the growing demand for water will be met through new investments in irrigation and water supply systems, and some potential exists for expansion of nontraditional sources of water. However, in many regions, neither of these sources will be sufficient to meet the rapidly growing nonagricultural demands for water or to mitigate the effects of water transfers out of agriculture.

6. IMPACTS OF WATER TRANSFERS OUT OF AGRICULTURE

6.1 MICRO-LEVEL IMPACTS OF WATER REALLOCATION

Many economic studies suggest that the negative local impacts of properly managed water transfers from agriculture will be minimal, but popular perceptions (such as "draining the lifeblood of farmers") are typically more pessimistic. Transferring water out of agriculture can have impacts on a wide range of stakeholders, particularly if effective institutions to manage water transfers are not in place. Reallocation can decrease agricultural productivity and irrigated area, and change cropping patterns. In addition to direct impacts on agricultural production, water transfers can negatively affect business activities, local government fiscal capacity, and the quality of public services in areas from which water is being transferred, because of the reduction in irrigated area or production and associated reductions in agriculturally linked economic activities and in the tax base. In addition, permanent transfers of water rights may limit future economic development in the area of origin and induce out-migration (Rosegrant, 1997). Whereas the buyer and seller of water presumably gain from the transfer if the seller holds secure water rights, other parties can be negatively affected (and not compensated) through reductions in water availability and quality, and instream flows. Furthermore, water in irrigation systems is used for a wide variety of other purposes that are often not accounted for, such as hydropower generation, fishing, gardens, small enterprises, rural domestic water supplies, and livestock production, all activities that would be severely affected by reallocation (Howe et al., 1990; Meinzen-Dick, 1997).

Microeconomic and regional analyses suggest that the severity of economic impacts on the area of origin will differ according to (a) whether or not the destination of transferred water remains within the same area of economic activity; (b) whether or not transfer proceeds are reinvested in the area of origin; (c) the economic vitality of the area of origin; and (d) the strength of backward and forward linkages of the irrigated agriculture sector (Howe et al., 1990). In this section, the available (but quite limited) case study evidence on potentially adverse micro-level impacts on the area of origin of water transfers is reviewed. Whereas regional or national impacts of water transfers are usually positive overall, it is the area of origin -- usually rural areas in semiarid regions -- that may face adverse income and livelihood effects, particularly if water transfers are not appropriately managed. However, the evidence shows that the impacts of water reallocation are mixed and highly complex, and with the limited evidence available, it is difficult to fully identify the underlying conditions that determine the direction and the magnitude of these impacts. Care must also be taken in sorting out the effects of water transfers from the broader effects of dynamic change in the rural and urban economies. In many cases negative effects may not be attributable to water transfers, but rather may be the result of declining competitiveness of agriculture in a given region, with water transfers occurring as a byproduct of long-term economic change.

Urbanization and Water Reallocation to Urban Areas

The rapid expansion of urban areas can affect irrigation and food production in a number of ways, both negative and positive. Evidence from Chile, Indonesia, Thailand, the western U.S. and elsewhere clearly indicates that cities often occupy highly productive (irrigated) farmland; draw off skilled, young farm labor; compete with irrigation for the water sources to supply residents, industry, and power; and damage water quality for agricultural production through municipal sewage and industrial effluents (Hearne and Easter, 1995; Christensen, 1994; Kurnia et al. 1999; Howe, 1998). On the other hand, nearby cities provide farm households with markets and income that can be used to purchase more water-efficient irrigation technology and to diversify into higher-value crops. In the suburbs of Beijing, for example, both grain output and overall agricultural output value continued to increase at the same time that water had been diverted to the urban core and the overall irrigated area declined (Nickum, 1997). Hearne (1998) reports that one significant reason for the positive experience with agriculture-urban water transfers in Chile was that urban areas serve as service centers for the local agricultural areas, and that most large irrigators have houses and businesses in these communities and do not want them to be short of water.

Impacts of Water Reallocation from Agriculture on Rural Communities

Reallocation of water out of agriculture can have negative effects on rural employment possibilities, not only directly in the irrigation sector, but even more through multiplier effects on agriculturally related activities. If agricultural land and labor are idled and agriculturally related activities are reduced due to water transfers, the rural tax base will decline. It is not realistic to assume that idle human and capital resources will move quickly and without cost to new uses of equal or higher productivity. Therefore, costs of water transfer out of agriculture attributable to the area of origin should be compensated and, in the case of large transfers, measures should be undertaken for human capital to adjust (Howe, 1998). On the other hand, it has also been shown that careful reallocation of water resources can favor economic growth in both urban and rural areas, and economically-induced water transfers can increase the overall living standard of the poor. Changes in rural employment possibilities and migration to urban areas are usually based on a wide array of factors, but abandonment of irrigated farming may catalyze developments.

Hamilton et al. (1989) evaluated the minimum compensation that farmers in the Snake-Columbia river system, Idaho, would be willing to accept in a long-term option contract with a hydropower station. Such an institutional arrangement would switch the use of water resources from farmers to the utility in dry years. Results indicate that estimated hydropower benefits are 10 times greater than losses in farm income, making these contracts economically valuable. In California, indirect economic effects from water transfers using the 1991 California State Emergency Drought Water Bank were relatively small. Farmers who sold water to the Bank reduced farm operating costs by US$17.7 million, or 11%, and crop sales by US$77.1 million, or 20%. These reductions adversely affected the suppliers of farm inputs and the handlers and processors of farm outputs, but the effects were not large when compared with the agricultural economy in the selling region or with the direct benefits to farmers from the sales. Operating costs, crop sales, and agribusiness revenues dropped 2% to 3% in selling counties because of the Bank (Dixon et al., 1993).

Chang and Griffin (1992), in a study of water trading and reallocation in the very dynamic Lower Rio Grande river basin, Texas, find that water transfers have supported the growth in the value of agricultural production in the basin. Virtually all water transferred was from agricultural to nonagricultural uses, and 45% of all municipal rights had been obtained by transfer from the agricultural sector by 1990. Net benefits of average agriculture-to-urban transfers were estimated at around US$12,000 per 1,000 m^3 of water for the cities of Edinburg and Brownsville, indicating a sizeable aggregate benefit for the 94 BCM of water transferred from agricultural to municipal uses prior to 1991. Consultations with water sellers indicated that much of the agricultural water sold would otherwise have been unused by its owners, (sometimes due to prior conversion of agricultural land to other uses). Very rapid urban and economic growth in this area and reallocation of water over short distances likely helped prevent severe negative impacts on farm households.

A study of the impact of drought-related water reallocation from agriculture to urban uses in 1987-92 on a rural farming community in Mendota, California, found that irrigated cropland declined by 14%, and the number of farms by 26% (small farms by 70%). Agricultural land values decreased by 30%. Increasing reliance on lower-quality groundwater reduced yields by 37% in melons, and by 5% in staple crops. Labor demand decreased over-proportionately as compared to cropland, and farm and packing salary incomes declined by 14%. Three out of 7 wholesale produce firm went out of business in the area. City tax revenues declined both as a result of depressed business conditions and declining property values (Villarejo, 1997).

Keenan et al. (1999) report that residents of an agricultural area that typically exported water were more likely to oppose water transfers than residents of a water-importing area and that both these irrigation districts in the western U.S. had strong reservations about free markets as a means of allocating water.

Positive outcomes can be observed in several developing countries. Palanisami (1994) finds that farmers in Tamil Nadu, India, view water transfers from rural to urban areas positively. He reports that farmers sell water to urban residents to alleviate diverse labor problems (34%); to achieve higher profits (44%); to sell surplus water (23%); and to sell supplies inadequate for irrigation (9%). Thobani (1998) reports on new employment possibilities for farmers who sold their water rights in Chile and Mexico in water-intensive companies or in the larger, more profitable farms who bought the rights. Rosegrant and Gazmuri Schleyer (1994) also find evidence suggesting that area-of-origin impacts in Chile are small and that agricultural regions have benefitted substantially from water trading and sales. Farmers mostly sell small portions of their rights and maintain agricultural production with highly efficient on-farm irrigation technology for orchard or vegetable crops. However, Hearne (1998) documents that the sale of water rights by a few farmers still can have substantial negative impacts: when remaining farmers receive less canal water as seepage increases, or when canals cannot be maintained due to the decrease in members drawing water from the canal.

Sadeque (1999) illustrates that it is not always the irrigation sector that suffers from water reallocation. He shows that in rural Bangladesh, competition for the scarce water resources during the dry season has favored a transfer of water from the domestic to the irrigation sector. The increasing use of deep water table extraction technologies for irrigation by relatively wealthy farmers outcompetes the shallow hand pumps used by the landless for domestic uses, disproportionately affecting women and children, who are the water carriers. With food production being a high priority of the Bangladesh government the development of deep tube wells for irrigation has been favored to the detriment of domestic water supply.

Impacts of Reallocation on Water Quality and Environmental Degradation

There is substantial evidence on the adverse impacts of reallocation from irrigation water to industrial uses, and the pollution of water resources with industrial effluents, poorly treated or untreated domestic and industrial sewage, agricultural chemical runoff and mining wastes has become a growing environmental concern. In the Nam Siaw Basin in Northeast Thailand, for example, discharge and seepage of wastewater from rock salt mining made water unfit for human and animal consumption, and depressed rice yields in fields irrigated from the wastewater (Wongbandit, 1994). In China, about 80% of the population lives in areas surrounding seven major rivers and five large lakes. Untreated municipal and industrial wastewater of 35.56 BCM is discharged in these regions; 20-30% of the water is polluted, and the economic loss caused by water quality degradation has been estimated at US$4 billion. In the Yellow River and tributaries, wastewater discharge is 3 BCM, and water quality has fallen below the safe drinking water standard in 60% of the basin (Zhang and Zhang, 1995).

However, the impacts of water reallocation from agriculture to industrial and other uses are often more complex. Kurnia et al. (1999) show some of these dynamics in the case of West Java, Indonesia. In this very productive agricultural region, water conflicts, which used to arise between farmers within or between irrigation systems, have shifted to the level of conflict between various sectors. A cluster of 31 textile firms in the Ciwalengke irrigation system in Bandung District, West Java, for example, has severely compromised the availability and value of surface and groundwater for irrigation purposes, fishing, and even domestic uses. Factories have increased their water abstraction beyond their permits through illegal installation of additional intakes or pumps in the permitted intakes. In the dry season, factories (illegally) buy or rent additional water from close upstream farmers who receive some benefits, whereas downstream farmers suffer. Declines in yield from 7 to 4 mt per ha have been reported in rice fields irrigated with polluted water, and some fields have ceased to be usable. This development speeds the conversion of agricultural land to other uses. However, although many farmers lose out in agricultural production, some members of the farm household work in the factories, thereby increasing their living standards, and thus do not want factory activities to cease.

Evidence of reduced instream flows due to water reallocation with impacts on river habitat, instream and out-of-stream recreation and other effects has been reported in several states of the western U.S., and environmental demands on water resources are increasingly being acknowledged. California, for example, has implemented a new regulation that reduces exports from the Sacramento/San Joaquin Delta in order to meet federal water quality standards and to protect endangered species (Livingston, 1998). Hearne and Easter (1995), in a comprehensive study on water markets and water transfers in Chile, find no evidence of increased environmental degradation related to active water trading. In fact, by inducing conservation, institutional arrangements in Chile seem to help prevent environmental degradation in river basins. In addition, they postpone the need of dam and other infrastructure construction projects and their inherent potentially adverse environmental effects.

In summary, the evidence of the micro-level impacts on water reallocation indicates that the experience is negative for rural communities when the transfers are above the level allowing for continued farming or other opportunities in the area-of-origin; when farmers had no incentives to sell, but water was taken anyway; and when institutions and secure legislation to adequately compensate the sellers and third parties were absent. On the other hand, when sellers receive substantial benefits, sell only part of their water, have a stake in the economic development of the urban area, can rely on secure rights to their resource, are protected by adequate institutions and organizations, and have flexible tools (such as water leases or option contracts), the reallocation experience can be positive, providing economic growth in both rural and urban areas.

6.2 GLOBAL IMPACTS OF WATER REALLOCATION FROM AGRICULTURE ON FOOD PRODUCTION

This section explores the possible impacts on global food production of a large transfer of water away from agriculture assuming no reforms in institutions, policies, and technologies to achieve water savings and mitigate the impact of the transfer. The possible ramifications of this scenario are examined using IMPACT. This scenario is not presented as a likely outcome, but rather as an exploration of the potential effects that significant transfers of water could have on agriculture, if water savings are not simultaneously achieved through policy reform.

The transfer of water from agriculture is simulated using the following assumptions: (1) no increase in irrigated area to the year 2020, corresponding to a cutback in investments and loss of existing irrigated area due to degradation and urban encroachment to balance any current pipeline investment. Under this scenario, there would be 43 million ha less irrigated area compared with the baseline projection; (2) phased-in reductions in agricultural water use over the projections period for the 37 IMPACT countries and regions, consistent with the urban and industrial demand projections described above, assuming no improvements in water use efficiencies in agriculture and slow improvements in domestic and industrial efficiencies; (3) declines in crop area growth, in proportion to the reduction in agricultural water use; and (4) reduction in crop yield growth, in proportion to changes in relative water supply, based on the relative water supply/crop yield function approach (FAO, 1979).

The projected reductions in agricultural water withdrawals by 2020 are substantial, compared with the baseline 2020 values: for example, China, nearly 24%; India, 21%; and WANA, 20%; reductions in other developing countries range from 10% to 35%. This scenario shows dramatic impacts on demand in global food markets. In developing countries, yield growth for all cereals will slow from 1.20% annually in the baseline scenario to 1.07% per year, and area growth from 0.29% to 0.23% annually during 1993-

2020. Rice is hit hardest, because it relies most heavily on irrigation water: rice yield growth will decline from 1.08% to 0.89%. The adverse impacts on production would be much higher except that, as water is being removed from production, cereal prices begin to increase rapidly, thereby depressing consumption and, simultaneously, inducing production increases, that partially offset the water-induced shortfalls. The average rice price is projected to increase by 68% between 1993 and 2020, to US$480 per mt and would be 85% higher than the projected baseline rice price in 2020; the price for wheat would increase by 50%; maize, 31%, and other coarse grains, 40%, compared to the baseline projections.

Rising food prices depress food demand and worsen food security through widening the food supply and demand gaps described above. At the local and regional level, price increases of this magnitude would cause a significant decline in the real income of poor food consumers. Malnutrition would increase substantially, given that many of the poorest people in low-income developing countries spend more than half their income on food. Higher international prices also hurt at the national level, as poor countries will have to spend increasing resources to import a large portion of their food. Sharp price increases can fuel inflation in these countries, place severe pressure on foreign exchange reserves, and can have adverse impacts on macroeconomic stability and investment.

Developing country imports will increase significantly overall, putting greater pressure on foreign exchange. In China, projected wheat imports will increase from the baseline value of 22.4 million mt in 2020 to 36.1 million mt; the country would shift from an exporting position in rice to becoming a rice importer; and total cereal imports by 2020 would increase by 76%, from 41.3 million mt to 72.8 million mt. In WANA, total cereal imports would increase from 65.1 million mt to 74.8 million mt. An exception is Sub-Saharan Africa, where imports by 2020 would actually decrease, because high cereal prices would severely depress demand. Although these imports of “virtual water” would help to fill the demand gap created by reduced production due to water transfers from agriculture, the general rise in food prices will slow demand growth. This shows that a strategy of virtual water imports will have limited success if there is a general cutback in water supply to agriculture worldwide without countervailing improvements in water use efficiency and productivity.

7. WATER POLICY REFORMS TO SAVE WATER AND MANAGE REALLOCATION

The evidence presented here indicates that a shift in the future allocation of water among competing uses is inevitable, and that the global trend will be to reduce the share of water for agricultural use. Rapid nonagricultural demand growth is unlikely to be only met through the expansion of supplies, or through nontraditional sources. The key question will be how to accomplish the reallocation of water from agriculture in a rational and equitable manner that minimizes costs and avoids the potentially large negative impacts of the many ad hoc transfers today on both the rural economies from which the water is drawn and on the future growth of food supply and demand. The potentially negative implications of intersectoral water transfers can be mitigated through comprehensive policy reforms that save water in existing uses and improve the quality of water and soils through improved water demand management. In order to achieve this, greater attention must be placed on the institutions for water allocation and on the rights of water users and incentives for efficient use.

The policy instruments available for demand management include: (1) enabling conditions, that facilitate changes in the institutional and legal environment in which water is supplied and used. Policies here include reform of water rights, the privatization of utilities, and laws pertaining to water user associations (WUAs); (2) market-based incentives, which directly influence the behavior of water users by providing incentives to conserve on water use, including pricing reform and reduced subsidies on urban water consumption, water markets, effluent or pollution charges and other targeted taxes or subsidies; (3) nonmarket instruments, including restrictions, quotas, licenses, and pollution controls; and (4) direct interventions, including conservation programs, leak detection and repair programs, and investment in improved infrastructure (Bhatia et al., 1993). The precise nature of water policy reform and the policy instruments to be deployed will vary from country to country depending on the underlying conditions such as the level of economic development and institutional capability, the relative water scarcity, and the level of agricultural intensification. The mix of policy instruments will also vary by river basin, depending on the structural development of the different sectors in the region, prevailing rights to natural resources, relative water shortages, and other basin-specific characteristics. Therefore, no single recipe for water policy reform can be applied universally, and additional research is required to design specific policies within any given country, region, and basin. However, some key elements of a demand management strategy can be identified. The process of reallocating water from agriculture can be better managed through the reform of existing administrative water management organizations, through the use of incentive systems such as volumetric water prices and markets in tradable water rights, and through the development of innovative mixed systems of water allocation.

7.1 WATER RIGHTS, MARKETS, AND PRICES

The primary alternative to quantity-based allocation of water is incentive-based allocation, either through volumetric water prices or through markets in transferable water rights. The empirical evidence shows that farmers are price-responsive in their use of irrigation water. The main types of responses to higher water prices are use of less water on a given crop, adoption of water-conserving irrigation technology, shifting of water applications to more water-efficient crops, and change in crop mix to higher-value crops (Rosegrant et al., 1995; Gardner, 1983). In urban areas, the use of incentive-based policy instruments, such as higher water prices, secure rights to water, and devolution of services, can achieve substantial water savings and improve the delivery of services for both households and industries (Bhatia and Falkenmark, 1993; Frederick, 1993; Gomez, 1987).

However, in agricultural areas, attempts to establish administered efficiency prices through increases in water charges have been met with strong opposition from established irrigators because this mechanism is perceived as an expropriation of existing water use rights that would create income and wealth losses for established irrigated farms. This makes it difficult to institute and maintain an efficiency-oriented system of administered prices. The establishment of transferable property rights would formalize existing rights to water rather than expropriate these rights, and generate income for the water right holders rather than taxing them, and is therefore politically more feasible (Rosegrant and Binswanger, 1994).

The establishment of water rights and the transfer or both rights and responsibilities from centralized bureaucratic agencies to farmers and other water users has a number of advantages. The first is empowerment of the water user, by requiring user consent to any reallocation of water and compensating the user for any water transferred. The second is security of water rights tenure provided to the water user. If well-defined rights are established, the water user can benefit from investment in water-saving technology. Third, a system of marketable rights to water induces water users to consider the full opportunity cost of water, including its value in alternative uses, thus providing incentives to economize on the use of water and gain additional income through the sale of saved water. Fourth, a properly managed system of tradable water rights provides incentives for water users to internalize (or take account of) the external costs imposed by their water use, reducing the pressure to degrade resources (Rosegrant, 1997). Market allocation can provide flexibility in response to water demand, permitting the selling and purchasing of water across sectors, across districts, and across time by opening opportunities for exchange where they are needed. The outcomes of the exchange process reflect the water scarcity condition in the area with water flowing to the uses where its marginal value is highest (for an application of a water market, see Rosegrant et al., 1999). Markets also provide the foundation for water leasing and option contracts, which can quickly mitigate acute, short-term urban water shortages while maintaining the agricultural production base (Michelsen and Young, 1993).

Establishment of markets in tradable property rights does not imply free markets in water. Rather, the system would be one of managed trade, with institutions in place to protect against third-party effects and potential negative environmental effects that are not eliminated by the change in incentives. The law forming the basis for the allocation of water through tradable rights should be simple and comprehensive; clearly define the characteristics of water rights and the conditions and regulations governing the trade of water rights; establish and implement water right registers; delineate the roles of the government, institutions, and individuals involved in water allocation and the ways of solving conflicts between them; and provide cost-effective protection against negative third-party and environmental effects which can arise from water trades (Rosegrant, 1997).

7.2 MIXED SYSTEMS OF WATER MANAGEMENT

Centralized, public administrative management on the one hand and free market allocation of water on the other hand can be seen as the polar extremes for water allocation mechanisms. However, as could be seen even in the brief summaries in the preceding sections, water allocation systems in the real world will be much more complex and diverse. Systems will be mixed both in ownership (combining aspects of public and private ownership of water supply infrastructure and water rights) and in overriding water allocation principles (combining administrative/regulatory approaches with market/incentive-based approaches). Decentralization and privatization will increasingly create systems with public ownership and management down to a certain level in the distribution system and user-based ownership below that level. For water market systems to be efficient and equitable, judicious regulation will be required. The process of water policy reform should lead to mixed water allocation systems that are responsive to local institutions and conditions.

The mixed management systems that have resulted from adjudication of groundwater rights in California offer a promising model for developing countries. These diverse and decentralized management systems developed in direct response to the depletion of groundwater resources and the degradation of the environment and have resulted in the elimination of overdrafts, the impoundment of surface and imported water for aquifer replenishment, and have stopped saltwater intrusion (Blomquist, 1995). The adjudication process has resulted in a governance structure for the water basin that establishes water rights, monitoring processes, means for sanctioning violations, financing mechanisms for the governance system, procedures for adapting to changing conditions, and includes representative associations of water users (Blomquist, 1992). Central to the governance structures is a water management program which employs a combination of instruments to influence water demand, including pumping quotas (usually based on historical use), pumping charges, and transferable rights to groundwater. Key elements for the success of these governance structures are that they are agreed upon and managed by the water users; are responsive to local conditions; operate with available information and data bases rather than requiring theoretically better but unavailable information; and are adaptive to the evolving environment. These attributes make mixed systems highly appropriate for developing country conditions.

7.3 CONSERVATION THROUGH APPROPRIATE TECHNOLOGY

If improved demand management introduces incentives for water conservation, the availability of appropriate technology will be essential to generating water savings and higher crop production per unit of water. As the value of water increases, the use of more advanced technologies such as drip irrigation (utilizing low-cost plastic pipes), sprinklers, and computerized control systems, used widely in developed countries, could have promising results for developing countries. If the scarcity value of water is high enough, appropriate use of new technologies appears to offer both real water savings and real economic gains to farmers.

Continued increases in the value of water could make these capital-intensive irrigation distribution systems more widely feasible in low-income regions. However, adoption of high technology irrigation can have somewhat paradoxical impacts on water savings, and savings on a per ha basis may be limited. In the U.S., where detailed data is available, water withdrawals per ha of irrigated area increased by 35% between 1960 and 1975, declined nearly 15% from 1975 to 1980, increased again, and in 1990 were still higher than the 1975 level. In addition, reductions in water applications will likely be offset by increased water requirements for higher-yielding crops and increasing cropping intensities (Raskin et al., 1995). However, real water savings can be achieved with improved technologies through the increase in agricultural output per unit of water applied, or conversely, through reduction in the amount of water used per unit of output. The decrease of water (and land) per unit of production can also help to save on land resources under irrigated production, another major constraint for future global food production.

7. CONCLUSIONS

Water demand is projected to grow rapidly, particularly in developing countries. The increase in demand will be higher for urban and industrial uses than for agriculture. A portion of the growing demand for water will be met through new investment in irrigation and water supply systems, and some potential exists for expansion of nontraditional sources of water supply. However, supply expansion will not be sufficient to meet increasing demands. Therefore, the rapidly growing urban and industrial water demands will need to be met increasingly from water transfers out of irrigated agriculture. The management of this reallocation could determine the world's ability to feed itself. If such transfers take place without mitigating policy reforms in demand management the prices of staple cereals in global food markets could increase sharply, resulting in broadly negative impacts on low-income developing countries and the poor consumers in these countries.

The reallocation of water can also have substantial negative effects on rural economies, if supporting policy measures are not adopted. The evidence of the impact of transfers of irrigation water to urban and industrial uses on rural communities is mixed. In addition, interlinkages between urban and rural sectors and the importance of local, basin-level characteristics make it difficult to draw general conclusions about the impacts of transfers. However, some observations can be made: negative effects from water transfers can be mitigated through (1) the establishment of secure rights to water that are monitored and enforced by adequate institutions and organizations; (2) transfers of relatively small amounts from many irrigators, inducing conservation measures instead of plot abandonment; (3) reinvestment of gains-from-trade in the rural communities; and (4) adequate compensation of sellers and affected third parties. Flexible tools, in particular, markets in tradable water rights, when established in a participatory and rational manner, can facilitate and mitigate the potentially adverse impacts of water transfers, creating win-win situations for both rural and urban/industrial water users.

Comprehensive reforms are required to improve the incentives at each level of the water allocation process in order to improve the efficiency of agricultural water use and sustain crop yield and output growth to meet rising food demands while allowing transfers of water out of agriculture. Institutional and legal environment reforms must empower water users to make their own decisions regarding resource use, while at the same time providing a structure that reveals the real scarcity value of water. Key policy reforms include the establishment of secure water rights to users; the decentralization and privatization of water management functions to appropriate levels; the use of incentives including pricing reform (especially in urban contexts) and markets in tradable property rights; and the introduction of appropriate water-saving technologies. Failure to implement these reforms could significantly slow the growth in crop production in developing countries and could have devastating impacts on the rural poor.

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