CHAPTER 3

WATER RESOURCE MANAGEMENT AND THE POOR

PETRA HELLEGERS[#], KARINA SCHOENGOLD[##] AND
DAVID ZILBERMAN[###]

[#] *Agricultural Economics Research Institute (LEI), Wageningen University and Research Centre, P.O. Box 29703, 2502 LS, The Hague, The Netherlands*
[##] *School of Natural Resources and Department of Agricultural Economics, University of Nebraska, 307A Filley Hall, Lincoln, NE 68583-0922, USA*
[###] *Giannini Foundation of Agricultural and Resource Economics, Department of Agricultural and Resource Economics, University of California, 207 Giannini Hall, Berkeley, CA 94720, USA*
E-mail: zilber@are.berkeley.edu

Abstract. Water allocations as well as water quality and health concerns are often due to inadequate policies and institutions, which pose major challenges for policy reform. The necessary ingredients of such reform include four elements: rules to improve the decision-making process about water projects, principles to improve water allocation, incentives for water conservation, and incentives to improve water quality. The paper shows that improved policies and incentives can address many of the global water problems and lead to environmental sustainability while addressing distributional issues. Some of the reforms may hurt the poor in the short run through higher water prices, but may provide them better access to water and reduce the toll of unsustainable water use in the long run. The direct and indirect implications of increasing prices of energy for water reforms are also discussed.
Keywords. water management crisis; policy reform; distributional issues; higher prices of energy

INTRODUCTION

There is a perception that water use and allocation have been contentious for a long time. To quote Mark Twain, "Whiskey is for drinking, water is for fighting". There are frequent transboundary disputes about water, and water policies in many countries revolve around the allocation of water between industries, municipalities, the environment, and the agricultural sector, which often consumes 80% of total water. Nevertheless, Wolf's (1998) survey of international water conflicts suggests that in spite of the tensions, water conflicts tend to be peacefully resolved.

In this paper, we argue that much of the concern about water shortages and future availability is the result of inadequate policies and institutions. We establish

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several principles for policy reform, designed to lead to more efficient water allocation and resolve some of the tension about its availability and use. It is critical that general problems of water misallocation are improved, and this needs to be the first priority for policy reform. Therefore, the principles outlined are just as valid for both developed and developing countries, and for both affluent and poor areas. However, such reforms do have distributional implications. In this chapter we will discuss how water policy reforms impact the poor, and suggest mechanisms that can be used to reduce the negative impacts.

In addition, we will argue that a key challenge to water resource management in the future stems from the volatile situation in the energy market and the possibility of increased scarcity and, consequently, higher prices of energy. Thus, we suggest that the major challenges of agricultural and water policies are to reduce the inefficiencies and inequities of water and energy use in a sustainable manner.

In this paper principles of four elements of reform are suggested. Attention will be paid to the relationship between water problems and the global energy situation and we will try to link solutions to both.

THE TRANSITION TO MARKET AND TRADING

Political economic considerations are the major causes of the existing inefficiency and misallocation of water use. For millennia, water has not been a scarce commodity; therefore, markets have not been heavily used as a mechanism to trade water. Instead, governments have established a system of water rights, such as the prior-appropriation system to allocate water. The prior-appropriation system introduced in the western United States and similar systems introduced elsewhere are queuing systems that allocate water according to two principles: ‘use it or lose it’ and ‘first come, first served’. It is a homesteading system that was aimed to attract settlers to frontier areas in the United States, Latin America and even India. This system is very effective when water is abundant. But as water becomes scarce, it leads to inefficiency because it restricts trading and provides no incentives to adopt modern irrigation technologies and conserve water.

A reform to allow trading may require investment in infrastructure, institutional changes, have high transaction costs, and have significant distributional effects. For example, owners of water rights will strongly oppose a reform where the government reclaims the original water rights and starts selling water, but they will support the introduction of transferable rights that allow them to benefit from sales of extra water (the so-called grandfathering rights).

The introduction of incentives to control water quality problems has followed a similar evolutionary process. Initially when farming starts in a region, the waste products of a relatively small population of humans and livestock are disposed into a large body of water with minimal impacts on water quality. The polluters by their action establish *de facto* polluter rights. As the population and the waste it generates grow, water quality becomes a problem. A reform that will reduce pollution and improve water quality has to take into consideration the historical right established by the polluter, and its design is a tricky political economic process. In recent years, trading programs that focus on water *quality* instead of *quantity* have started to develop as a mechanism to improve environmental conditions. Woodward and Kaiser (2002) describe the use of such programs in the United States. The majority of the programs developed have focused on nitrogen, phosphorous or both, as these pollutants are frequent causes of water quality deterioration.

Political and legal systems are quite rigid. Reforming a water-rights system and the introduction of pollution control policies require overcoming substantial economic constraints. Rausser and Zusman (1991) and Shah et al. (1993) argue that a crisis may be required to trigger reforms in water systems. Indeed there are many historical examples that show that depletion of groundwater aquifers led to establishment of surface water projects. Droughts such as the California drought of 1987 to 1991 led to the introduction of water trading. The deterioration of a large number of important bodies of water in the United States preceded the introduction of the Clean Water Act in the United States.

The relative abundance of water in many systems throughout the world, the randomness of water conditions that may lead to quick swings from shortages to surpluses of water, and multiple stakeholders concerned about water systems suggest that reforms of water systems will be gradual and take a long period of time. There are already promising changes occurring in laws and institutions governing water use and allocation. Some of the major ingredients of reform and their implications are discussed below. These are based on both a survey of existing literature as well as observations from case studies of water policy reform. They include four elements*: 1) rules to improve the design of and decision-making process about water project development and maintenance; 2) principles to improve water allocation and pricing; 3) incentives for water conservation; and 4) incentives to improve water quality.*

Improve design of and decision-making process about water projects

Water projects are major investments that modify the landscape and are used to transfer water across locations, to store water, to protect against floods and contaminants, and to generate hydroelectric power. A large body of research on water projects suggests that some have provided immense value, but many others have had low and even negative rates of return. Frequently, water projects may be part of the political work that is distributed to contractors and water users for various forms of political support, for instance employment generation (Zilberman and Schoengold 2005).

One key element of water reform is to improve the process of decision making about water projects. First, it is important that water projects *pass a formal benefit–cost analysis* to assure that they meet some minimum feasibility criteria. Gradually, the World Bank, the U.S. government and other governments are introducing benefit–cost tests to assess new water projects. Indeed, the number of new water projects in the United States has drastically declined since the introduction of the benefit–cost analysis procedures defined by the ‘principles and guidelines’ to assess new projects (Frederick et al. 1997). Reform should go beyond employing the standard benefit–cost analysis. As the work of Arrow and Fisher (1974) suggests, decision making about new projects is done under uncertainty and often leads to irreversible outcomes. *Timing and information about new projects* make a difference. Thus, the decision about water projects should not only determine whether or not to build them out but also when to start them. The first period in which a proposed project has a positive expected net discounted benefit is not necessarily the optimal time to develop it. The timing will be decided in a manner that will maximize expected net discounted benefit.

Furthermore, project managers should pursue adaptive learning and conduct experiments to reduce uncertainty about key system parameters that will allow improved design. Another important element that bears consideration in project design and assessment is *incorporation of nonstructural solutions* in devising new water projects. Traditionally, engineers designed water projects and economists were responsible for making a choice among given alternatives, leading to an emphasis on structural solutions. However, sometimes water management can be solved more effectively by modifying behaviour; therefore, economists and social scientists should be involved in the early stages of project design, so that the project will contain a complete package including both physical structure and also institutional change that will take best advantage of it.

Finally, project assessment should consider both *market and non-market costs*, and develop systems that will be *symmetrical and minimize biases*. For example, if contingent valuation is being used to assess the environmental benefit of a new project, it should also be used to assess the environmental cost. This has not been the case in many situations, and it may lead to overestimation of benefits. Moreover, economic assessments of benefit and cost have to be applied to all projects without any exemption, and even though the final decision may be political, transparent assessment of the costs and benefits is important in the decision-making process.

Improved water allocation and pricing

The main reason for the misallocation of water is that prices water users consider are different from the social marginal costs of the water. However, water prices are elusive. Both actual and optimal pricing of water vary within and between seasons, by location, quality, benefits or value of usage, costs of supply, and institutional setting. For example, during the dry season, the value of water may be $0.12 per cubic metre, while during the wet season it may be $0.01 per cubic metre. The cost of water at two adjacent locations may be different if one location is 300m higher in elevation than the other. In one case, Pitafi and Roumasset (2004) show that the optimal price of water for consumers in Hawaii who live in the highest elevation category should pay over three times the price of consumers in the lowest elevation category. Tsur et al. (2004) present a series of fourteen guidelines designed to improve the pricing and economic efficiency of irrigation water use. The main ideas discussed below provide the same general recommendations.

As shown in Zilberman and Schoengold (2005), optimal water allocation requires that the price of water equal the sum of all associated costs. First, there is the cost of extraction at the source. Then, there is the cost of conveyance from the source to the point of use. Next, there is the environmental cost associated with diversion of water from its natural course. Finally, there is a future or opportunity cost which represents the cost that extraction of water at the present imposes on future consumption. When water prices are subsidized (sometimes through subsidizing energy), it leads to overuse of water with significant negative effects on the environment, as well as a reduction in available water for the future.

The subsidization of water is not accidental, while removal is painful. Political-economic analysis of water pricing suggests that cheap water is used as a policy to support farm income. However, this policy is paid by future generations, by the beneficiaries of environmental amenities, and by taxpayers who pay extra extraction and conveyance costs. Transition to optimal pricing may have negative distributional consequences as poor farmers could be required to pay higher prices for water. However, some of these negative distributional effects can be addressed by special pricing schemes, like tiered pricing, and others can be addressed by direct transfer payments. In addition, the transition to optimal pricing may trigger the adoption of conservation technologies, a reduction in acreage of low-value crops and rate of construction of water supply projects, and an increase in the supply of fish and other products of environmental use of water. It will also improve the long-term viability of the system.

The optimal outcome, where water is allocated so that marginal social costs are equal to marginal social benefits, can be attained by several arrangements with different equity implications. The first is *full marginal-cost pricing;* namely, the price per unit of water should be the sum of the marginal extraction, conveyance, environmental and future costs. A government agency may charge a tax equal to the marginal environmental and future costs, and that will be added to the marginal cost of extraction and conveyance. The high costs will have a significant negative effect on the welfare of many users, but the tax revenue generated *can be redistributed to support the poor*. Boland and Whittington (2000) show that in many cases, the poor are better off with a uniform price with rebate as opposed to an increasing block-rate pricing structure.

A second scheme that can address distributional effects is *block-rate or tiered pricing*. With this scheme, water is priced at a low initial rate up to a limited volume (block), and then it is charged at a higher rate for another block. Multiple blocks can be used, and the size and price of the blocks may either be constant or vary by season or other observable socioeconomic variables such as household size. Efficiency may be attained with two rates, where the second rate, which applies beyond an initial level, is equal to the social marginal cost of water. An excellent overview of the arguments in favour and against increasing block-rate pricing, as well as its practical limitations, is presented in Boland and Whittington (2000).

Block-rate pricing is used frequently in pricing urban water in developing countries (Saleth and Dinar 1997). One concern with block-rate pricing is discussed by Whittington (1992)who argues that in case of shared water connections and indirect purchasing in developing countries, block pricing may actually have an effect that is opposite to the intended equity objective. Since it is common for multiple households to share one water service connection, it can penalize poor households instead of helping them. Zilberman and Schoengold (2005) show that when the marginal cost of the water supply is very elastic, and the difference between the marginal and average cost of water is relatively small, the feasibility of using tiered pricing is reduced. Thus, in these situations, the use of tiered pricing requires an extra subsidy beyond what is supported by the water industry.

The initial block that is subsidized for consumers under tiered pricing can cause inefficiency in water use when the initial block is too large. In that case tiered pricing may lead to excessive consumption by individuals with low productivity of water use. In practice, political pressures often lead to initial blocks that cover much more than basic water needs. In a study by the Asian Development Bank (1993) of 17 utilities that use increasing block rates, the average size of the initial block for a household is 14 cubic meters per month. In comparison, a generally accepted standard is that the basic water needs for a family of five can be met with only 5 cubic meters. Only two of the utilities have initial blocks at or below this level.

A third approach to achieve efficiency and address distributional considerations is through *cap and trade systems*. In this case water users are given transferable rights to certain quantities of water and are allowed to trade those rights. The use of this approach is limited, but it is growing (Tsur et al. 2004). This method may entail high transaction costs and may require institutional changes and improved conveyance facilities and effective management and user training. Therefore, this system may be more feasible for facilitating trade between irrigation districts or industrial water users than for individual households.

A water-pricing reform that will reduce the consumptive use of water in the short run may have negative consequences on poor groups in society. For example, if higher prices of water will lead to reduction in supplies of food, the poor are likely to suffer. A reform that will reduce water availability and increase water prices will significantly reduce farm income. The short-run equity loss may lead to a long-run gain if the lower extraction in the short run enhances long-term supplies and leads to innovative activities that increase the productivity of water and the food system. Overcoming some of the political economic constraints and meeting distributional objectives may require transfer payments to affected consumers, farmers or members of other groups. A well-functioning welfare system may make it easier to reform water pricing.

Water is subsidized in developed and developing countries alike. Elimination or reduction of subsidies in developed countries may actually have a positive effect on poor farmers in developing countries, as it will improve their competitive position in global agricultural markets.

The subsidization of water is frequently associated with institutional and infrastructural deficiencies, and thus a reform requires more than establishing the right prices. Below we will address some *required changes that will improve efficiency* and which may have desirable distributional impacts.

Conveyance management

Much of the water is lost on its way from the source to the end user. Water conveyance losses of 50% and above are not uncommon (Wade 1997). As Chakravorty et al. (1995) show, profit maximization by individual producers leads to underinvestment in conveyance because each user is concerned with investing in a conveyance leading directly to his/her site, ignoring the benefit of improved conveyance to the individuals downstream. Thus, conveyance infrastructure has some public-good properties, as improved conveyance facilities benefit a large number of people that jointly utilize it.

One proposed solution to address underinvestment in conveyance is to establish an organization, such as a water user association (WUA), that will build and maintain the conveyance in a way that maximizes regional social welfare. Such an association would both build infrastructure and be responsible for the distribution of water. Globally, the number of WUAs has increased in the last twenty years, due to their support from international agencies such as the World Bank. Evidence has shown that WUAs provide better water delivery services and system maintenance than government agencies (Subramanian et al. 1997). In addition, water pricing should account for geographical differences, with users further away and higher up from the source paying a higher premium, which will lead to conservation downstream.

As shown in Figure 1, a transition to an optimal system will modify the allocation of water over space and expand overall production (Chakravorty et al. 1995). There may be positive distributional impacts from improved conveyance as well. Frequently, the wealthier members of society are located upstream, nearer to the sources of water, while the poorer farmers are located downstream. Introduction of an institutional setup that will improve conveyance systems may enhance the well-being of the poor directly by providing downstream farmers with better access to water and indirectly by increasing food availability.

Groundwater management

The improvement in pumping technologies led to a drastic expansion of groundwater extraction throughout the world. In many regions, for example, in regions of India, China, Mexico and Yemen, extraction rates are much higher than recharge rates, which may lead to temporary or permanent depletion of aquifers. In the past, depletion of aquifers has led to new surface water projects to replace groundwater use, but in many cases, it is either prohibitively expensive or simply infeasible. In most locations, groundwater is a renewable resource and can be sustained with the proper management. However, with groundwater pumping, we see the tragedy of the commons: many individuals share an aquifer, and people undervalue the future cost of excessive pumping in the present. In some cases, the impacts of groundwater pumping on neighbouring wells may be small, especially when groundwater wells are far apart from each other. However, in cases where the

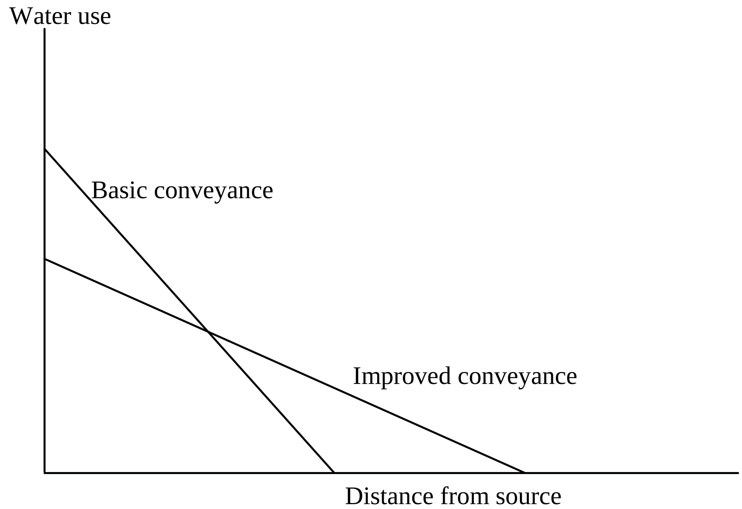

Figure 1. *Impact of socially optimal conveyance on spatial water use/distribution*

location of groundwater wells is unregulated and there are many wells in a small area, one farmer's pumping can have significant impacts on the pumping costs and availability for other farmers. For example, it is common for irrigation wells in the United States to provide water for more than 100 acres. However, a recent study in South India showed that on average, a single well irrigated only 8.6 acres, providing evidence that the common-property problem is much more pronounced in certain areas (Bhat et al. 2006). In some countries, such as India and Mexico, energy for groundwater pumping is subsidized, which may accelerate the tendency to over-pump.

Attaining optimal groundwater pumping may require introducing regional WUAs to monitor aquifer levels and control groundwater pumping. These associations may formalize water rights among users and determine the aggregate cap for regional pumping according to the state of the aquifer. Establishing such an organization requires a friendly legal framework as well as a strong capacity to monitor water use. There are some examples of central management of groundwater resources, such as in Israel. But even there, the decisions about pumping are not purely technical but also political, and may still lead to situations of excessive pumping (Feitelson 2005).

Pumping groundwater near oceans may lead to another problem: seawater intrusion. Again, individual extractors may not recognize the overall collective risk, and control of pumping in vulnerable coastal areas is of especially high priority. On the other hand, some coastal areas may augment their water supply by desalinization. So, while the depletion of groundwater inland may lead to the building of new aqueducts, near the coasts it may lead to desalinization efforts. In these cases, under-pricing of groundwater may accelerate depletion and/or seawater intrusion, and may lead to excessive investment in water projects. The introduction of controlled and reduced pumping may have negative distributional effects in the short run, but in the long run it will ensure sustainability.

Collective action and socially optimal management of aquifers may result in conjunctive use of surface and groundwater. A groundwater aquifer can play an important role as a buffer stock to be used only in periods of shortage. Thus, during wet years the aquifer will be replenished, and during drought periods it will be pumped to provide the needed water. Bird and Shinyekwa (2005) suggest that exposure to negative climatic shocks can actually increase the ranks of the poor as assets of households are depleted. The poor are already the most vulnerable to negative climatic shocks; therefore, building systems that reduce vulnerability to water shortages may be pro-poor.

Another advantage of conjunctive use and storage systems that reduce the volatility of water supply is that they provide incentives for farmers to take a long-term view and invest in high-value activities. Osgood et al. (1997) have shown that reduced uncertainty regarding availability of water and water rights is a significant factor in *ex-ante* decisions to adopt either perennial or specialty crops.

Water rights and trading

As mentioned earlier, rigid water-rights systems that ban trading have been a major source of inefficiency. The introduction of trading, while requiring investment in infrastructure (canals, monitoring, accounting systems, etc.), may expand aggregate production and lead to introduction of new industries. Thus, water reform is justified only if the efficiency gains from trading are greater than the costs of transition. There are not many studies on the benefits and costs of water trading and reallocation and their impacts on processes of rural development and settlement.

Frequently, the water rights belong to well-established individuals, and systems of trading may allow poorer farmers access to water. The transition to trading has to take into account that not all the water applied to a field is consumed in the field. The residual water that ends up as runoff or groundwater is up to 40% of the originally applied water. Others have used this residual water (positive externality); thus, when water trading is allowed, it is important to reduce the third-party effect by allowing people to sell only the rights to their consumptive use of water, rather than the rights to total application. The beneficiaries of residual water are likely to be poor, and assuring that they will be able to get their supply of water even after all primary rights are traded eliminates a possible negative distributional effect of trading.

Because of variability of water availability over time, water can be abundant in some periods while shortages exist in others. Trading may be appropriate in periods of shortage; therefore, regional authorities may prepare for trading by introducing options to buy and sell water that would allow quick adjustments to changes in availability. Water-right holders in Australia have proportional rights and the government determines a cap each year for the aggregate volume available.

The relative volume of trading may be small relative to the overall water use in a region, but the gain from trading may still be substantial. There are significant differences in value per unit of water consumed across agricultural products. For example, rice rarely generates a net return of more than $0.025 per cubic meter of water applied, while horticulture crops may generate 100 times that value. Even if 5% of the water is moved from rice production into horticulture during a drought, the welfare gains can be large.

Incentives for development and adoption of conservation technologies

Zilberman and Schoengold (2005) present evidence that shows that productivity of water systems varies with capital goods, management, and other inputs associated with water users. In particular, water-use efficiency, the fraction of applied water that is actually consumed, is dependent on irrigation technology, geographical characteristics such as land quality, and climate conditions. For example, water-use efficiency on heavy soils and flat lands with traditional gravitational activities may approach 80% to 90%, but gravitational technologies may have water-use efficiency of 30% on sandy soils and steep hills. Irrigation technologies such as sprinkler and drip augment water-use efficiency. For example, average water-use efficiency with gravitational technologies is about 60%, and it may rise to 80% with sprinkler and more than 90% with drip (Khanna and Zilberman 1997). While with drip and sprinklers higher capital costs contribute to improved water-use efficiency, there are low-cost technologies where extra labour contributes to improved water-use efficiency. The efficiency gains from adoption of improved irrigation technologies are especially pronounced at locations with poor land quality, as the irrigation efficiency of gravitational technologies on this land is low.

There is a large body of conceptual and empirical analyses that show that adoption of improved irrigation technologies tends to increase yield and reduce applied water (e.g., Caswell and Zilberman 1986; Schaible et al. 1991; Peterson and Ding 2005). It also reduces the residue of applied water that is not consumed by the crop. If this residue ends up as deep percolating water and has other negative effects, this reduction of residue may be a major source of benefits. The adoption of modern irrigation technologies can be enhanced by introducing appropriate incentives such as higher prices of water or the elimination of water subsidies. Allowing water trading or introducing restrictions or penalties on residue or drainage that collects the residue may also lead to adoption of irrigation technologies that reduce residue. The incentives for adoption may also initially include the subsidization of modern irrigation technologies, in order to enhance learning and trigger a diffusion process. Policies to disseminate knowledge about modern irrigation technologies, including the use of extension, may accelerate its diffusion. In cases where the residual water has positive impacts for the poor, who may be users of the water, distributional effects may need to be considered in a policy reform.

Increasing the price of water and enforcing stricter drainage penalties will not only lead to the increased adoption of modern irrigation technologies in the short run. It will also trigger investment in water-saving innovations and will result in the introduction of improved irrigation technologies and their adoption in the long run. Of course, irrigation technologies are not the only form of technologies that aims to improve water use. Improved efficiency of groundwater-pumping systems is another way to improve the efficiency of water systems. Introduction of weather stations and other monitoring stations that will improve the timing of irrigation may be another source of improved efficiency of water use.

Incentives to improve water quality

The poor are especially vulnerable to water quality problems. Lack of sewage systems and contaminated water that compromise hygiene are sources of water-borne diseases that kill millions. Investment in infrastructure to treat waste is very expensive and may not be affordable in many developing countries. The introduction of basic principles is important for improving water quality. Two sets of incentives are especially important. The first is the introduction of the *polluter-pays principle*, when it comes to source-point pollution. If the dumping of waste to public bodies of water is punishable, there will be private incentives to develop technologies and mechanisms to deal with the waste in an efficient manner. Economists have documented that incentives induce innovation, and build-up of an institutional and legal capacity to make individuals responsible for the waste they generate is a crucial element in improving water quality. In cases of nonpoint-source pollution, where it is difficult to identify the actual polluter (e.g., disposable of animal waste by industries consisting of many small farms), *activities that are correlated with waste generation should be regulated*. For example, requiring improved waste disposal practices from individual producers will reduce contamination risks. The regulation of nonpoint sources may be modified over time as information-gathering and monitoring technologies improve (Millock et al. 2002).

For political reasons as well as legal constraints, pollution control and reduction can be induced by ‘carrots’ instead of ‘sticks’ penalties. Programs that use *payments for environmental services* (PES) frequently provide subsidies for pollution reduction. PES are suggested as a means to induce poor peasants to disengage in activities that contaminate bodies of water or threaten wetlands, and there is a growing emphasis to promote PES as mechanisms that reduce poverty as well as enhance environmental quality (Pagiola et al. 2005). Empirical studies have shown that upstream marginal lands that are generally the focus of PES programs typically have higher rates of land users in poverty than in downstream areas (Pagiola et al. 2005). Other studies have shown that those watersheds that are the most hydrologically sensitive have high concentrations of poverty (Nelson and Chomitz 2004). One example of a PES program designed with a goal of helping those in poverty is the Mexican Payment for Hydrological Environmental Services Program (PSAH). The program targets regions with over-exploited aquifers (Alix-Garcia et al. 2005). Environmental services provided by forests include improving water quality and reducing runoff. The program design focuses almost exclusively on areas with communally owned forests[1]. There is a strong correlation between these areas and poverty rates (Muñoz et al. 2005), and therefore the program results in the desirable redistribution of income to those in poverty.

While this program shows how PES can help the poor, in other cases they may harm the interests of poor people (Zilberman et al. 2006). To evaluate the impacts, it is necessary to divide the poor population into three groups: urban, landless peasants and small landowners. PES activities that take land out of production or reduce supply may harm poor consumers by increasing the price of food, with the largest impact on the urban poor who rely on food purchases. However, municipal water requires a higher quality of water than irrigation demands, and thus the urban poor may see great benefits in water quality improvements due to PES programs. When the demand for food is elastic, PES activities that reduce the risk of flood or improve water quality are beneficial to the poor. Similarly, those activities that reduce production and thus employment may reduce the welfare of some landless poor. On the other hand, PES may enhance alternative employment activities. Thus, the distributional impacts of PES programs have to be analysed in the specific context in which they occur. While PES may not always be the appropriate tools to reduce poverty, they are important in improving water quality and enhancing environmental amenities that benefit all members of society, including the poor.

MIXING OIL WITH WATER

We have shown that the right incentives and management strategies can address many of the global water problems. Some of the solutions may increase water pricing and hurt the poor in the short run, but others will improve water availability in the long run and reduce the toll of water quality problems. However, most of the solutions discussed assume that prices of most inputs remain constant over time. Yet, water systems are energy intensive as water conveyance, purification and pumping demand significant amounts of energy. Modern irrigation technologies require energy for extra pressure. Increased water supply through the use of desalinization is also energy-dependent, but the global energy situation is subject to much pressure and uncertainty. On the one hand, there is concern about climate change and a desire to reduce emissions of greenhouse gases. On the other hand, rapid economic growth in China, India and other developing countries will lead to substantial increases in energy demands. Oil markets are very vulnerable to small changes in supply or demand conditions, resulting in unstable prices. High prices may lead to exploration and increased supply as well as some conservation. But as He and Roland-Holst (2005) suggest, the massive build-up of roads and automobile manufacturing in China and India and the rising incomes in these countries may lead to large increases in the demand for fossil fuels and increased pressure on energy prices.

Today the average Chinese consumes about 11% of what an American consumes, and in India the average consumption is 8% of an American's. These two countries have 10 times the population of the United States. It is reasonable to assume that the consumption of energy per capita in these countries will double in the next 10 years or so, as people start to own cars, computers and household appliances, resulting in the use of twice as much energy as the United States is currently consuming. Current trends suggest that energy use will also increase in the rest of the developing world.

The increased scarcity of energy will have both direct and indirect implications for water. The direct effect will come from higher energy prices, which will result in a higher cost of pumping, conveyance and desalinization. A higher cost of water will put pressure on water utilities, resulting in increased prices for consumers and a growing demand for reform that increases the efficiency of water systems. These impacts will also increase the value of water conservation activities. As we argued before, reform is triggered by crises; and while drought provides one type of crisis, high energy costs are another type of crisis that will trigger change.

The indirect effect will be in the form of demand for alternative fuels. We have already seen the increased production of ethanol and bio-diesels, and these technologies can be improved upon and are likely to become an important part of agriculture. Bio-fuels are attractive because they are feasible with currently available technology, and they are net contributors of minimal amounts of carbon to the atmosphere (they sequester carbon production). They provide new sources of income to farmers. However, the introduction of bio-fuels may lead to major challenges, as Figure 2 shows. Let D_0^F be the initial demand for water devoted to agricultural food production, and let S_0 be the initial supply of agricultural water. The demand for water is a function of the price of food and the price of energy. Increases in the price of energy will reduce the supply of agricultural water, shifting S_0 upward to S_1, and will reduce the demand for water for food from D_0^F to D_1^F. However, increased energy prices will generate demand for allocation of water to bio-fuel production. So, total demand for water will become D_1^T, which includes the sum of the demands for water for food and bio-fuels. The intersection of the integrated demand and the new supply results in price P_1 and quantity Q_1, where the new price $P_1 > P_0$, but the quantity Q_1 may be higher or lower than the initial quantity Q_0. One thing is clear – the amount of water going to food production will be lower, which will reduce food supply. With an inelastic demand for food, prices will increase for food. The net effect is that introduction of bio-fuels may increase water use but reduce food supply, and that may significantly affect the availability of food for the poor.

One solution to this problem is to increase the productivity of both traditional crops and bio-fuels. Introduction of new varieties, including genetically modified varieties can increase per-acre productivity of water and other inputs in food production that may lead, through markets, to increased production of food, reduction of food prices, and consequently a positive effect on the poor. As Cooper et al. (2005) argue, excessive regulation, intellectual property rights constraints and limited technical capacity have constrained the introduction of genetically modified varieties in developing countries, where they have increased crop yields significantly. At the same time, there is a potential to increase the productivity of

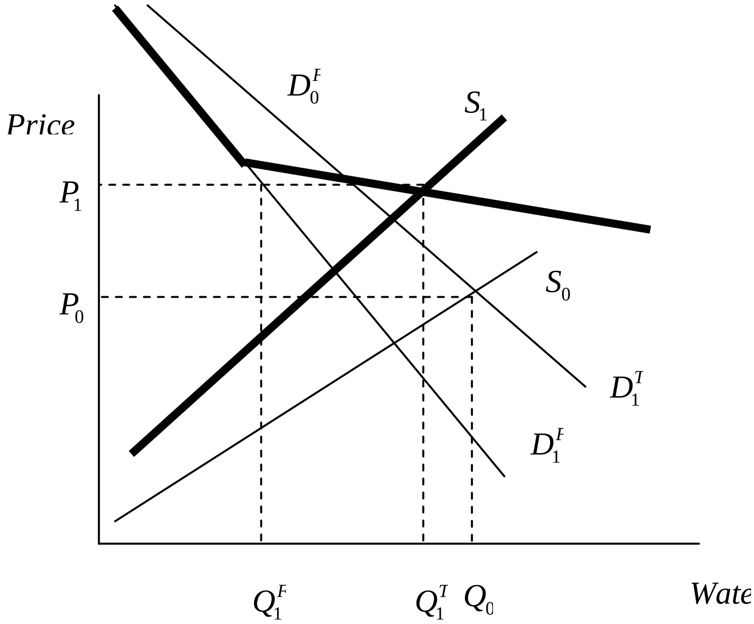

Figure 2. *The impact of higher energy prices and introduction of bio-fuels on water markets*

water used in the production of bio-fuels. Currently, there are two main types of bio-fuels – ethanol, produced from sugarcane in Brazil and other tropical countries and from maize in the United States and China, and bio-diesel, produced from soybeans, palm oil and other crops in Europe. As Ragajopal et al. (2007) document, the net energy gain from bio-fuel production using maize is rather small (less than 20%), while it is much higher with sugarcane. In both cases, the energy is produced from the plant sugars, rather than the cellulose. Ongoing research on conversion of cellulose to bio-fuels may lead to reliance on new crops, including switchgrass and miscanthus, which will increase energy production per acre, expand the possibilities for production of bio-fuels on marginal lands, and increase the sequestration of greenhouse gases.

Bio-fuels are an obvious example of increased energy demand putting pressure on water resources for the production of energy. Production of oil by coal gasification, by mining of tar sands and by increasing utilization of existing wells is also water-intensive. Furthermore, the use of water for oil production with these technologies leads to significant water quality and contamination problems. One avenue to address the pressure on water and other resources due to energy demand is to introduce incentives that reduce this demand, including taxation that reflects externality costs. These policies are likely to emerge and to have significantly negative effects on the poor. Thus, transfer policies may need to be established to offset these negative effects.

CONCLUSIONS

Poverty is widespread in many developing countries. Subsidized water or energy for pumping has been widely used to subsidize poor and not-so-poor farmers, but this subsidization is not sustainable. Groundwater aquifers are being depleted and the environmental and economic costs of existing water-use patterns are increasing. This paper presents the main elements of reform to address efficiency, equity and environmental concerns about water allocation and quality. The reform will emphasize careful application of a social benefit–cost analysis to evaluate infrastructure investments considering both market and non-market benefits and costs and structural and non-structural solutions. It will strive to establish mechanisms, including penalties for polluting activities and payment for environmental services, to improve water quality. Reforms will rely on market forces for water allocation, by allowing trading, and strive to introduce efficient pricing of water and at the same time use mechanisms that will address distributional concerns. Possible mechanisms include the allocation of tradable water rights among users and tiered pricing. Support for efficient water conservation does not directly impact the distribution of water resources, but does increase the availability of water for those needs that are the most critical such as basic health and sanitation (i.e., those needs with the highest value). Some forms of policy reform may hurt the poor in the short run, especially if prices increase and supply of water declines. However, it may lead to sustainability in the long run, and transfer payments should be used to cushion the cost of the transition. In addition, other reforms may provide better access to water for low-income households and reduce the toll of unsustainable water use and poor water quality in the long run.

Policy reforms that aim to modify traditional allocation systems and enhance trading and efficiency often have high transaction costs, and the efficiency gains from improved allocation have to be compared to the cost of transition (Shah et al. 1993). Since water resources are abundant in many locations and the costs of transition can be quite substantial, reform should not be pursued globally but only whenever and wherever it makes sense. Because water systems are subject to random forces, the economic and political feasibility of reform varies over time. Providing the guidelines for transition and economic education to policymakers and the public about possible gains from change is important, as it will provide the intellectual background needed to introduce reforms in moments of crisis or whenever it is most appropriate.

The economics of water has always been affected by other developments. Water scarcity is gradually becoming a problem because of population growth and economic development. Throughout history, water throughout the world was abundant, and institutions to manage it evolved accordingly. However, as demand increases, water becomes scarce, and that is the reason for the gradual transition to market-like solutions. The economics of water is also dependent on the energy situation. Many of the solutions to reallocate water and address water scarcity and water problems are energy-intensive. An increase in energy scarcity affects the capacity to address water problems. Furthermore, this paper shows that water may need to be reallocated to enhance the supply of energy. Thus, we will be challenged to attain sustainable, equitable and efficient solutions to both energy and water problems.

Bio-fuels are expected to be energy production by the poor, rather than energy production for the poor. The poor are increasingly urban as migration from the countryside continues, making the poverty impact of interactions between energy and food difficult to predict. The negative impacts on (poor) consumers of higher food prices may outweigh the positive impacts on (poor) producers of increased income for their food and bio-fuel crops, to the extent that these are not offset by higher input costs.

NOTES

[1] These communities are named *ejidos* and *comunidades*; both are types of communities that have been formed in the decades of land reform in Mexico.

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