ISSUES IN GROUND-WATER ECONOMICS

E. FANO and M.M. BREWSTER
Water Resources Branch, Natural Resources and Energy Division, Department of Technical Co-operation for Development, United Nations, New York, NY 10017 USA

ABSTRACT

This paper raises economic issues related to ground-water development for consideration by policy makers and technical specialists in developing countries. Those issues include: factors affecting the costs of ground water; the economics of conjunctive use and conservation; and, public vs. private development of the resource. Constraints to sustainable ground-water development are presented, as well as policies to overcome them, including cost recovery measures. Government policies which might be introduced to promote sustainable development are suggested including measures related to regulation, rationing and pricing.

1 INTRODUCTION

Economic issues related to ground water have become increasingly important in recent years with the widespread expansion in ground-water resources development throughout the world and the ensuing danger of depletion of the resource in some areas. The purpose of this paper is to raise important economic issues which must be considered by technicians and policy makers in the process of making investment decisions regarding ground-water development. In this regard, it is not sufficient simply to have an excellent source of ground water. Also present must be the infrastructure, population, natural conditions and markets to place the investment within an acceptable economic context. The costs and benefits of alternative methods of developing water resources should be compared and the optimum choice based on the prevailing economic and financial situation facing the country or the individual.

The types of economic issues which will be discussed include factors affecting the costs of ground water; the economics of conservation and conjunctive use; public vs private development of the resource; and methods of meeting the required costs, including pricing policies. Following the recession of the early 1980s and a contraction of funds available for international technical co-operation, no country can afford to waste its limited financial and natural resources. The task of supplying the world with adequate quantities of acceptable quality water would require the mobilization of greatly increased financial resources during a time of recession and heavy external debt. Cost recovery policies and financial planning are required at the national level, as components of water resources development.

1.1 The ubiquity of ground water in the world

Ground water is the largest source of fresh water available on the earth. The estimated amount of ground water to a depth of two miles into the crust of the earth, is about 18 million km^3 (United Nations, 1975). This ground water constitutes a vast and almost ubiquitous resource for satisfying water requirements of all kinds. Ground water is often the only source of water in arid and semi-arid regions of the earth, and in such regions it is of fundamental importance to any social or economic development. In humid parts of the world, where rivers and lakes have historically supplied much of the water needed by man, the value of ground water has tended to be overlooked. In recent decades, however, as surface-water supplies have been depleted or contaminated, ground water has become a major source of water supply, even in many humid countries. In some cases, where surface water had to be pumped through long pipelines for delivery to users, ground water has brought about savings on pipelines and treatment.

The technological improvements of the past 40 years constitute an important factor that has rendered possible the large-scale exploitation of ground water. Effective methods and tools are now available for hydrogeological research and exploitation and, therefore, for the understanding of ground water. The greatly increased knowledge of the geology and hydrology of the areas investigated, the more detailed understanding of the hydraulics of ground-water flow and recharge, the improved methods of hydrological analysis and the application of computer modelling and remote sensing to ground-water problems have led to a more accurate quantitative determination of the water resources stored underground and of the nature of their replenishment.

1.2 Advantages of ground-water development

Over the past few decades the economic viability of using ground water for water supply projects has led to rapid growth in its use, particularly in Asia. Tubewells are increasingly used for both public and private exploitation of ground water. Any area with a shortage of surface water sources and precipitation but with good quality aquifers can clearly benefit from ground-water development.

Ground water may be particularly valuable in augmenting surface water supplies during relatively short periods of peak demand, especially for agriculture. Wells can be sited adjacent to the area to be irrigated or the industry served, and, therefore, costly distribution systems can be avoided. Irrigation systems based on wells can be brought into operation much more rapidly and efficiently than systems based on reservoir construction and canals, which may take more than a decade to complete. Moreover, ground-water development can be phased with demand, avoiding costly excess capacity in the early stages of development. Ground water provides a reliable supplement to rainfall and surface water, and can be tapped whenever needed (Carruthers and Clark, 1983).

In community water supply, exploitation of ground water has been the main means to provide access to clean drinking water for populations in rural areas under programmes of the International Drinking Water Supply and Sanitation Decade, 1981-1990. Using low-cost technologies in many areas, ground water pumped by hand is an inexpensive way to improve the lives of millions of people. Not only has access to clean water (along with health education) had a positive effect on the health and well-being of the people, but it has also had a positive effect on income in areas where women freed from carrying water have used their time to generate income.

Industries located in developing countries often drill their own wells in order to have immediate access to a reliable water supply. If they had to depend on the public system, there might be delays, as well as interruptions in service. Moreover, the quality requirements for ground water used by industry may be less stringent than for drinking water supply. Since industries usually have some sort of electricity supply, the additional electricity required to pump the water entails very little cost.

1.3 Disadvantages of ground-water development

In many areas, ground-water resources are limited in relation to potential agricultural needs. Some ground water is of poor quality and the complex, costly technology for abstraction is often beyond the means of the users. Seldom do institutional means exist to ensure a fair distribution of the resource to all who need it (Carruthers and Stoner, 1981).

Ground-water irrigation is generally expensive and appears to be economic mainly in the case of high value, low-water-using crops. Pumps usually have to be powered by costly diesel fuel or electricity, and maintenance and repair costs for the equipment may be high. If returns to investment in terms of higher agricultural productivity and good prices are not apparent, users may not be able to sustain the high recurrent costs.

For urban water supply and industry, overpumping can lead to problems of land subsidence, salt-water intrusion and deterioration in ground-water quality, especially in coastal areas. Some industries have been induced to recycle water to save on production costs and reduce pollution.

For community water supply the main constraint to ground-water use is cost. People have traditionally used water from surface sources or shallow dug wells, which did not cost them anything. The introduction of a ground-water supply with a handpump or standpost entails costs for installation and equipment, as well as for repairs, operation and maintenance. Many rural people are neither willing nor able to spend money on water, which they consider to be a gift from God.

1.4 Role of the international community

The stated aim of external technical and financial assistance, other than emergency assistance, is to promote long-term self-sustainable development, which in time should diminish the dependence on external financing. The international community also has an important advocacy role to play in promoting selected important programmes such as the Mar del Plata Action Plan, resulting from the United Nations Water Conference in 1977, and the International Drinking Water Supply and Sanitation Decade (IDWSSD), 1981-1990.

The United Nations Secretariat has recognized the importance of ground water in the economic development of many countries since the early 1960s. Through its substantive offices specializing in natural resources (currently within the Department of Technical Co-operation for Development), the United Nations has been involved in a large number of projects relating to ground-water exploration and development. Over a period of more than 25 years the United Nations secretariat has carried out more than 200 projects in the ground-water field in 75 countries, with total expenditures of over $250 million in convertible currency.

Through United Nations projects, governments and populations have been made aware of the importance of ground water as a natural resource, of its value, its cost and its ubiquity, and of rational and economic techniques for its exploration and development. They have also been made aware of its limitations in terms of safe yields per well, quality, vulnerability to pollution and, in some cases, its finite availability.

Since the early 1980s, however, the domestic investments by the developing countries themselves that had been considered necessary for over-all water resources development by the United Nations system have not been forthcoming, because of adverse economic circumstances. External support as a percentage of over-all investments in the drinking water supply and sanitation sector, for example, increased, making developing countries more dependent on outside financing in 1985 than in 1979. While the IDWSSD has raised consciousness and stimulated programmes in drinking water supply and sanitation, rapid population growth has limited the progress made. Thus, the number of individuals unserved at the end of 1985 was probably the same as at the end of 1979. Without the Decade effort, however, the situation would have been much worse.

Contributions in the form of technical co-operation grants from the United Nations system (which includes the specialized agencies), as well as loans and credits from the World Bank and International Development Association (IDA) for water-related projects, rose rapidly from 1973 to 1983 but then began to level off at around $1.5 billion per year. Even if assistance from bilateral donors were included, the level of external assistance is wholly inadequate to meet the needs of developing countries for water resources development. The developing countries themselves have to become the prime movers for progress in the realm of water resources development. While the international community may act as a catalyst to ground-water development and conservation of the resource, a decreased dependence on external assistance is required for sustained development. Cost recovery, institutional efficiency and active participation from the outset by user communities need to be emphasized.

The United Nations system is increasingly recommending the use of lower-cost locally produced alternatives, particularly for rural water supply purposes. These technologies improve the possibilities for sustained development by reducing dependence on external financing. It is important for donors, banks and developing countries to accept that low-cost technologies represent viable solutions. Moreover, donors must ensure that provision is made for covering recurrent operation and maintenance costs, whether by direct contributions or through community participation. The international community could also play a catalytic role in assisting governments to devise suitable cost recovery and operation and maintenance schemes in the implementation of priority projects and the achievement of meaningful user participation.

2 ECONOMIC ISSUES

2.1 Factors affecting the costs of ground water

The total cost of a given ground-water project is comprised of fixed and recurrent costs. Fixed costs include the initial costs of exploration, data collection and analysis, drilling and installing a system, amortized over time, while recurrent costs include those for energy, labour, operation and maintenance and interest charges. In many countries, the general exploration phase has already been completed by a government or international agency. Detailed hydrogeological studies, based on piezometric networks and data gathering, can be expensive, however, and should be considered in the over-all costs of large-scale ground-water developments.

The more obvious economic elements to consider first are the costs of drilling and installing a system, which depend on such factors as the depth to the aquifer, the type of necessary drilling equipment, the diameter of the well, the well-screen length, the design discharge level and the available drawdown. The type of drilling equipment needed will be determined by the urgency of the situation and the hydrogeological conditions at the site. Carruthers and Stoner (1981) have developed a simple methodology to determine the costs of a well. These costs will be related to the type of pump to be used, which is another major fixed cost.

Related factors which will have to be considered when calculating fixed costs are the location of the well and the surrounding geology and the cost and availability of different types of energy. The latter is important for determining the best type of pump to purchase. Pump selection has a significant impact on total costs. Lower-cost pumps for shallow wells, some developed with United Nations support, are now widely available and are being produced in many developing countries. Recent technical developments regarding materials and their processing promise further reductions in costs.

For the same type of installation, costs of ground-water development will be lower in areas with favourable hydrologeological conditions and shallow water tables, where materials and skills are available locally, and where greater inputs are available from the user communities themselves. On the other hand, in arid areas underlain with hard rock, with dispersed population settlements and little infrastructure, such costs may be extremely high.

The costs of borrowing will be determined by the interest rate and repayment period. The willingness of banks to lend for such projects will also be related to the credit-worthiness of the borrower and the latter's ability to recover his costs. Moreover, in many countries, the amount of foreign exchange available may be less than what is required for certain types of equipment. This constraint has to be considered at the planning stage.

Finally, the operation and maintenance costs (recurrent costs) are very important components of total ground-water development costs. The costs for energy, labour and spare parts must be considered before the investment is made. If any one of these is difficult to obtain, recurrent costs may become too high to keep the equipment running properly. Where electricity is readily available, the investment may be facilitated as opposed to remote areas where diesel fuel would have to be transported to operate pumps. Renewable energy sources (solar, wind, etc.) may offer advantages in such remote areas because of their low operation and maintenance costs. Moreover, the technology has improved, resulting in lower initial costs and higher efficiency.

The total cost thus equals the annual payment for capital (duly amortized at the current discount rate) plus the annual recurrent costs for operation and maintenance. The total annual cost divided by the number of units of ground water produced gives us the cost per unit (i.e., $\$US/m^3$). For low cost ground-water technologies, it is useful to compare annual per user costs, which take into account the necessary capital investment levels spread over different populations. When the investment is made to extend an existing system, the marginal cost (cost of the last unit to be developed) must be considered.

2.2 Conjunctive use of ground and surface water

The decision on whether to use surface or ground water or a combination of the two has physical, economic and social dimensions. Often surface water is preferred by users: it may be the traditional water source; people are used to its taste; it is free. In some areas, surface water may not be available at all, however, and in others it may be contaminated or unreliable. With the related problems of population growth, overuse and contamination of rivers and streams, a switch to either ground water or conjunctive use for water supply may be necessary and indeed desirable, even though more expensive at times.

In the initial stages, tapping of ground water sources may be a boon to a water-short or depressed area. Since 1960 ground-water use in many parts of the world has expanded widely, often proving a more reliable and controllable supply for irrigation and water supply than surface water. Between 1960 and 1980 more than two million tubewells were installed in the North China Plain; the number privately installed in the Indus Plains of Pakistan rose from less than 5,000 to 200,000 and an estimated two million more were installed in India's Gangetic Plain. In areas where aquifers are shallow, seepage from surface water canals adds to the supply underground. Therefore, recapturing water through ground-water wells effectively increases irrigation supply and can also prevent the water table from rising and waterlogging the root zone (Postel, 1985).

To some extent conjunctive use has been forced upon countries where surface water irrigation sources have been fully utilized and further development involves supplementing surface sources by ground water, especially in those cases where there is a drainage benefit from ground-water pumping. This is the common feature of many projects in the Indo-Gangetic Plain.

Ground water may be used for irrigation by supplementing erratic rainfall in order to ensure adequate yields or by extending the growing season or providing water for an additional crop. Integration with existing surface water irrigation systems immediately suggests a further range of possibilities, such as the use of additional surface water which by itself would be insufficient for a crop. Such surface supplies might be sufficient when supplemented by ground water at either end of the season or at the peak (Carruthers and Stoner, 1981). The benefits derived from the addition of ground water in terms of income can be considerably higher than the cost of extracting it.

The wise use of ground-water resources can play a significant role in reducing the impact of drought in both urban and rural environments, saving large potential losses in agriculture and industry. Computer models can be used to estimate the volume of projected water requirements, volume of ground water that can safely be used over a long or short period, the annual recharge of aquifers related to precipitation and so on. There is a need to define the safe yield in a long-term statistical sense, so that greater withdrawals would be permitted in times of drought to minimize the impact on agricultural production. During periods of drought, the rate of ground-water recharge is usually insufficient to keep pace with withdrawals or discharges to rivers. Therefore, it is common for the ground-water table to fall several feet or more over a period of years, particularly where ground water use is high. Even following severe droughts, however, when rainfall returns to its usual pattern, the ground-water levels return rapidly to normal, generally within six to 12 months (Driscoll, 1986).

In a situation where both surface and ground water are used intensively, the impact on surface water economics may be considerable. For example, tubewell pumping that lowers the water table adjacent to a streamflow will induce increased seepage to ground water, and reduce downstream flows, to the detriment of the holders of surface flow rights downstream. In a situation where traditional downstream irrigators receive considerably reduced water supplies, serious social consequences may result.

On the other hand, users of ground water will benefit from seepage from surface water sources. Such seepage, which can be artificially induced, should retard the falling of the water table, salt water intrusion and the need to dig deeper wells. The key to wise conjunctive use is to use both ground and surface water within acceptable limits (which can be calculated and modelled).

2.3 Economics of conservation

Mounting pressure on the world's ground-water resources is evident from depletion of supplies, falling water levels and dry wells in areas such as Southern India, Northern China, the Valley of Mexico and the south-western United States. Increasingly widespread ground-water pollution further limits availability of the resource and points up the need to place ground-water use on a sustainable footing.

Even where recharge does occur, ground water is often pumped at rates that exceed replenishment, depleting future water resources. This "mining" supports only short-term prosperity and eventually leads to saline intrusion in coastal areas, increases in pumping costs or total depletion.

Rather than responding only by augmenting supply through drilling deeper wells, it is now accepted that conservation, or demand management, is the key to sustainable use of the resource. Without some restrictions on expansion, private developers may deplete reservoirs, causing other users to have to deepen their wells or drill to deeper aquifers at much greater expense for drilling and pumping. To prevent such economic consequences, there must be a con cious effort to manage aquifer systems, whether on a national or local level. This may entail restrictions on pumping rates, specific minimum well spacing, taxes or tariffs on water use, or limited issuance of permits to control withdrawals and restore a balance between pumping and recharge. Water pricing measures are discussed in section IV.

Areas where water is scarce and expensive are most conducive to restrictions on excessive use. Allocations of irrigation water can be restricted and supplies for industrial and municipal use can be rationed. Particularly during drought, people understand the necessity for conserving water.

2.4 Type of ownership

The economics of a ground-water development are also affected by whether the investment has been made by public or private entities. There are several, sometimes conflicting, arguments for each type of development, and the choice depends upon local conditions. In many cases a mixture of public and private development is optimal, e.g., public facilities for distribution of electricity and privately-owned wells (Carruthers and Clark, 1983).

(i) Public sector development. Under certain circumstances, public initiatives may be desirable for the development of ground-water irrigation, as well as community water supply. For example, public demonstration projects using ground water for irrigation or water supply, can initially be operated by a public water authority. These may stimulate initial interest and widespread development of ground water by the private sector. Public sector development may also be appropriate in very poor areas, where the communities cannot afford to invest in or maintain private facilities, or where equity goals require a rationing of scarce supplies.

A large public authority would also have a technological advantage in areas with difficult hydrogeological conditions or for large-scale ground-water developments and would have a political advantage in negotiating and accepting foreign assistance.

Most important to the future of ground-water development, however, is the involvement of the public sector in integrated management of the water resources of the country. Where ground-water quality has to be maintained for drinking water purposes, or when overexploitation of ground water resources may cause adverse economic, physical and social consequences, some government control or regulation over the resources is recommended. Public regulation can limit the number of wells and maximize ground-water exploitation (Carruthers and Stoner, 1983).

(ii) Private sector develoopment. The tremendous expansion in ground-water development in the 1970s was mainly a result of farmers' response to profit incentives. In Asia these developments contributed to the "green revolution" and self-sufficiency in grain production, but also led to overexploitation of water in some areas.

Farmers can obtain high operating efficiencies, because they adopt measures to avoid breakdowns and to obtain repairs quickly. Since private operators have the cost-saving incentive to use water strictly in line with needs, there is little wasted water, in contrast to publicly-managed projects.

Private initiatives have also led to very effective low-cost innovations which use locally-available materials and technology. Low-cost technologies, including various types of handpumps, have become the basis for current United Nations programmes promoting local manufacture of equipment for community water supply in rural areas.

On the other hand, uncontrolled private development, even with low-level technology, can lead to excessive investment per unit of area. In the effort for each farmer to have his own well, there are cases of 10 or more wells in an area which could easily be irrigated by one. If individual farmers withdraw what they consider optimal, it may not be optimal from an over-all or social viewpoint. Private development is unpredictable and difficult to manage. It is also difficult to mobilize effective back-up for complementary inputs such as agricultural extension and marketing services (Carruthers and Clark, 1983).

Another problem is that in practice only the large farmers can command the resources required to install wells. They subsequently increase their incomes but may at the same time create larger income disparities with the poorer farmers. Moreover, as larger farmers use increasing quantities of ground water, the water levels in aquifers fall, further affecting small farmers using shallow wells.

(iii) Mixed systems. In poor rural areas, individual users may not have the means to construct a well or operate and maintain it. Some form of co-operative or joint ownership may then arise, often with the initiative or financial support coming from the government. Government support often takes the form of a loan to the farmers' group or water committee, repayable on very favourable terms. Thereafter, operation and maintenance is the responsibility of the group.

Both public and private sectors thus have a comparative advantage for certain tasks. While farmers can operate wells efficiently, they are not equipped to manage an aquifer. Public authorities can manage an aquifer, but may not operate wells efficiently for their best use. Striking the right balance is not easy and certainly varies from project to project. In most countries, wells may have to be licensed in the future and, for a given aquifer, the number and discharge restricted to avoid overexploiting the resource. These types of functions will have to be handled by governments.

3 SUSTAINING GROUND-WATER DEVELOPMENT

The key to sustainable ground-water development is to maintain balance between pumping and recharge, between supply and demand, between efficiency and equity. While sustainable development remains a highly desirable objective, there are many constraints to its achievement. There are also many measures that can be taken to ensure a more balanced development of ground-water resources.

3.1 Constraints to sustainable ground-water development

While ground-water development is in many cases a technically-sound way to provide water supply to a community or area, it has not brought the expected benefits to many areas because of widespread breakdowns of systems, which have resulted from rigidities in the ways water supply is delivered to needy areas. Since the early 1980s, many countries have come to depend heavily on the international community to provide them with equipment for the provision of water supply to serve their people. In some countries the user communities have taken responsibility for paying the cost of local water supply systems, which has been shown to be the most viable means of sustaining development. It is desirable that developing countries themselves increase allocations of financial resources for water resources development to reduce dependence on external sources.

(i) The impact of foreign aid on technology. The amount and type of external assistance available has a direct effect on the size of the investment and the technology chosen for ground-water exploitation. Over the years, several problems have resulted from the requirements for "tied aid" in many donor agencies. Tied aid has often resulted in a proliferation of different types of equipment such as pumps and drilling rigs, which tend to overwhelm the capacity of a national agency to manage, operate and maintain them. Moreover, the equipment provided has often been unnecessarily sophisticated for the users, or oversized in relation to the demand. The problem arises from restrictive requirements within donor agencies to provide certain equipment from the donor country, as well as the inability of national agencies to insist upon standardization of equipment. Too often, the problems are worsened because there are too many separate channels of negotiations between donors and national agencies. By channeling such communications through a single national body, developing countries should be able to control the proliferation of different types of equipment and encourage technological standardization (United Nations, 1987).

Many developing countries, especially at the local level, do not have the financial or technical capacity to operate, maintain and repair a proliferation of sophisticated non-standardized equipment. Aid donors could contribute to an improvement in the performance of their projects by offering technology appropriate to the country's needs, as determined by national agencies in the water resources sector. Standardization of technologies within the developing country should be considered a priority. Local water authorities could survey, document and introduce their own local, simple and successful technologies to foreign consultants or donors for consideration with other alternatives in their feasibility studies.

(ii) Operation and maintenance. Besides availability of the resource, the main technical constraint to viable ground-water schemes in developing countries relates to the maintenance of pumps and motors. Mechanics with sufficient skill to maintain sophisticated modern machinery are difficult to find in many countries, especially in rural areas.

The technical problem then becomes an economic one, because the existing system is running well below its stated capacity and is not producing the expected benefits. It is therefore essential to build into cost calculations sufficient amounts for operation and maintenance of the equipment.

There are several economic aspects of operation and maintenance which should be considered when planning a ground-water investment. The first is whether it is possible to rehabilitate an existing system before building a new one. It has been demonstrated that in the ground-water sector the most economic use of public resources is to maintain, and failing that, rehabilitate existing projects (Carruthers and Stoner, 1981).

The second important consideration relates to the sources of energy available and their comparative costs. The main power choice is between electricity and diesel power. Water pumped by diesel units costs on the order of 1.5 to 2.0 times the cost per cubic metre of water pumped by electricity, and diesel pumps are far more troublesome. Where electricity is available, it generally provides a relatively low-cost supply of energy. Electricity supplies are often erratic, however, especially during peak periods. Diesel fuel can be purchased in advance and the energy supply is thus slightly more secure (Carruthers and Stoner, 1981). Where fuel costs are very high, an agricultural project based on pumped ground water can quickly become uneconomic. The example of farmers in the western United States pumping their own ground water can be cited. The costs of energy to those farmers increased almost four-fold between 1974 and 1980. That, combined with a falling water table, increased irrigation costs to prohibitive levels, causing many farmers to cease irrigation (Postel, 1985).

The third consideration is whether low-cost technologies, which can be produced and repaired locally would be appropriate for the given use. These technologies, being promoted under the World Bank-UNDP handpumps project, emphasize "Village Level Operation and Maintenance" (VLOM), which may make a considerable difference in cost effectiveness at the village level. If the village can take responsibility for the system and contribute to the costs of upkeep and wages for a caretaker, the system generally functions better than when the government is the responsible party.

The fourth consideration is whether private developers would be more effective in keeping a ground-water system functioning properly than the public sector. Where applicable, the government may provide over-all management and direction, while farmer groups and the private sector become responsible for operation and maintenance.

3.2 Recovering the costs of ground-water development

It is important that beneficiaries of a ground-water scheme, be it private or public, understand that water can no longer be treated as a free good. Even in cases where for socio-economic and cultural reasons the resource itself has to be considered as "free", the costs of development, treatment, delivery and management could be charged for and should be an integral part of the calculations for project financing. Moreover, the costs of depletion or deterioration of an aquifer should also be compensated by private developers.

It has become crucial to self-sustainable development that cost recovery policies be formulated and implemented, and that reasonable charges be imposed directly upon the beneficiaries, according to ability to pay, as a means of ensuring their interest and support. Any public scheme using ground water for community water supply or irrigation should include a provision for realistic cost recovery commensurate with local conditions, at least for the provision of labour and materials (United Nations, 1987).

At the same time, project formulation should be preceded by a sound evaluation of costs and benefits, based not only on expenses and revenue, but also on the costs of foreign exchange to the economy.

(i) Consumer categories. Governments may choose to impose different types of charges on different categories of ground-water users. Charges may be based on quantities or qualities used and on the purpose of water use. Generally, water laws include some type of ranking of priority uses, which comes into effect in times of water shortage.

The main uses of ground-water involve consumptive uses for domestic, municipal, industrial and agricultural purposes. In most water laws, top priority ranking will go to domestic use in times of shortage.

Domestic use may involve whole communities using piped water, standposts or handpumps, as well as individuals with their own wells. The priority to domestic use has also been the emphasis of the International Drinking Water Supply and Sanitation Decade and has become an integral part of many national development plans. In general, rural and peri-urban consumers have not been expected to pay the full costs of water services, which have been charged to the national budgets as social services for the poor. However, increasingly, communities have been required to cover the operation and maintenance expenditures and are asked to take full responsibility for the community water supply.

In many areas the preference accorded to domestic use also extends to municipal (urban) and industrial water supply, which can involve huge amounts of water and considerable waste. These uses may come into sharp conflict with irrigation through the exercise of the domestic-use preference in times of shortage.

The advantage that industrial and municipal users often have over farmers and rural consumers is that they can generally better afford to pay for the costs of water, including operation and maintenance of systems. Therefore, where the government controls the pumping of ground water, it may not want to jeopardize the revenues from these sources. In fact, urban and industrial consumers are often required to pay higher costs for water in order to subsidize rural users.

The regulatory body may encourage high water-using industries to pump lower-quality water from deeper aquifers, by charging lower prices for that water. Higher quality water is then released for domestic purposes. On the other hand, higher tariffs for industrial water use may encourage recycling, less wastage and reduced pollution.

The use of ground water for irrigation has become increasingly widespread, as mentioned in Section II.B. Much of the pumping for agriculture is done by private farmers, who benefit from the reliable and consistent supply of their own wells. The laws of some developing countries in Latin America have given water use preference (in times of shortage) to small farmers. Preference may be on the basis of size of holdings, larger farms receiving lower priority. In areas depending on subsistence farming, this priority is consistent with basic needs and domestic use goals.

Cost recovery strategies for ground-water projects involving small farmers may entail simply a nominal fixed charge according to farm size. After basic needs are met, ground-water use by large farmers can be controlled by regulations, charges, taxes or mutual agreement. As the costs of water increase, farmers may switch to crops requiring less water and to more efficient irrigation systems, in order to ensure an adequate return on their investment.

(ii) The role of prices. A government may choose to impose charges on ground-water use for a variety of objectives, depending on the situation. In determining how to allocate scarce resources efficiently, price can serve as an important instrument of policy.

The most immediate objective is the necessity to recover costs incurred, particularly from borrowed funds. When projects contain mechanisms for cost recovery and promise to be self-supporting, governments or international donors are likely to find the necessary finance. Such mechanisms might include direct collection of fees, revolving funds and others. When programmes are self-sustainable, more people can be reached and the government is not faced with an increasing debt burden.

When beneficiaries are required to repay the government for the benefits they receive, another objective is furthered: that of efficiency in use. Users will have an incentive to use only the water they need when additional quantitites entail higher costs. Water pricing on efficiency grounds can influence both the quantity and quality of ground water utilized. While higher prices may induce lower consumption, lower prices for lower quality should induce certain categories of consumers to use lower quality water.

Another objective of pricing systems is to promote distributional equity. This objective is often in conflict with the goal of economic efficiency, and attempts to achieve both involve compromises or trade-offs among objectives. The trade-offs can be evaluated by comparing the need for generating revenue with the importance of subsidizing water supply in rural areas or for poorer segments of the society. For very poor areas, it may not be possible to charge the people anything for water. But in most areas, some contribution in terms of labour, materials or a nominal fee for a reliable and accessible source of water should be feasible. The challenge for water administrators is to find a reasonably stable combination of regulations and prices that will lead to the efficient use of water, to capital recovery for investment projects and to an equitable redistribution of income.

Conservation of ground water is another objective which pricing may help to achieve. Charges may be imposed on industries for excessive use or for contamination of aquifers. Excessive-use charges may also be imposed on large farmers or communities to reduce wastage and conserve water.

3.3 Private sector approaches

At the farmer, or private sector level, a common response to overexploitation of ground water resources is the formation of a Water Users' Association or Water Committee. Generally users prefer to have some control over water allocations at the local level, and they can base their decisions on maximum efficiency, greatest need, equity or whatever they choose. Whatever the goal, it is likely that the Water Users' Association will put some restrictions on use by members and may impose fines where necessary.

Another response with a significant economic component is to vote for taxes on pumping. This may relinquish some control by farmers over local pumping, but it concedes that a more centralized control may be needed to manage water resources.

4 GOVERNMENT MEASURES TO PROMOTE SUSTAINABLE DEVELOPMENT

Ground water has served as an engine of growth in many areas of the world where surface water resources were inadequate or unreliable. While incomes and productivity have risen, however, in some cases water tables have fallen. Conscious management of the resource is necessary to forestall adverse effects on the economy, including land subsidence, salt-water intrusion, depletion of the resource and a deterioration in water quality.

The long term effects of ground-water mining may affect a whole region or country. In the United States, for example, 26 billion m^3 of non-renewable ground-water resources are pumped each year (one-fifth of the total pumped). The users of this water pay only the private costs of pumping, not the public costs. Nothing is charged for depleting the water reserve, even though such depletion diminishes the nation's future food and water security (Postel, 1985).

The various measures required to sustain ground-water development involve political, economic, legal and technical possibilities. They can be implemented by the public or private sector and at any level. They are generally introduced when a serious deterioration becomes evident, i.e., when wells run dry.

4.1 Institutional measures

The government through its policies can have a direct impact on the type and intensity of ground-water development. In the early stages, the government may encourage development through sponsorship of exploration and demonstration projects and by providing incentives (subsidies) to the private sector for ground-water development. Where overdevelopment threatens depletion of the resource, then governments should introduce some controls.

(i) Regulations and rationing. Two common responses of governments are regulation and rationing. Regulation of ground water pumping is related to legal rights of individuals. Control over water use may involve the issuance of permits to allow private developers to drill wells, in some cases specifying depth of aquifer and maximum discharge. Such a system aims at optimizing the number of wells in a given area for most efficient use.

Legal water rights vary from country to country, but governments can regulate rights in their efforts to control depletion. Detailed laws on transfer of rights and quantification of water use rights exist and can be used as examples.

A model attempt to balance water budgets in a dry region of the United States is Arizona's 1980 Ground Water Management Act. It requires conservation, calls for taxes on ground-water withdrawals and allows for the eventuality of the State to begin buying and retiring farmland (Postel, 1985). In Israel efficiency standards have been set for various uses and consumption above those standards may result in penalties. Appliances, irrigation and other water supply systems must be of the most efficient type available.

Regulations on water use generally imply that the government has fixed priorities among uses, with drinking water having highest priority. When water resources become seriously scarce, water may be restricted for low-priority uses such as landscaping.

Under extreme water scarcity conditions the government may have to resort to rationing of some or all types of water consumption. This is possible only where the government has control over the distribution system. It is more feasible where piped systems with meters exist.

Water can be rationed by volume or time. Volumetric rationing can involve interrupting service when a user exceeds his water limit or imposing fines when use is more than a given quota. Rationing by time is commonly used in developing countries where piped water systems or standposts are used. Often water is provided for only a few hours per day. One problem with that approach is that people tend to leave taps open, waiting for the water, which may lead to wastage.

(ii) Technical responses. Other measures involve technical improvements to the water distribution system. Modern leak detection devices can be used to identify where repairs are needed, repairs can be carried out and distribution system losses reduced.

Computer models have provided an important technical management tool to control ground-water allocations and use. They have improved the capability to manage a complex water balance in a country. Such models may link aquifer (and surface water) characteristics, farmers' responses and management decisions. There are two main types of models which link aquifer simulation with management decision making. Models aimed primarily at managing ground-water stresses such as pumping and recharge are classified as hydraulic management models. These models treat the stresses and hydraulic heads directly as management decision variables. Models which simulate the behaviour of economic agents, where the environment includes complex ground and surface water interactions and specific institutional content are classified as policy evaluation and allocation models. Such models can be used to address the very difficult co-ordination and control problems of efficient conjunctive use (O'Mara, 1984). They can be very useful inputs for a decision maker faced with a range of policy choices.

4.2 Pricing policy

The price of water must reflect its true value for highest use if conservation and the wise use of ground water are ever to be achieved. Economists generally recommend pricing water at its marginal cost -- the cost of supplying the next increment from the best available source. Consumers would thus pay more as supplies become more scarce. In reality water is rarely priced at its marginal cost; charges often bear little relation to the real cost and quantity of water supplied. In most countries rural communities and farmers using publicly-supplied water rarely pay the true costs of producing and delivering the water. When water users draw their own water from wells, they pay only the cost of pumping the water and delivering it to their house or farm.

It must be remembered that an accessible supply of water can not only increase a person's agricultural output and income, but it can also increase the value of his land disproportionately. The lucky farmers benefitting from accessible water are probably the richer ones to begin with, and such developments, public or private, may increase the gap between rich and poor. By charging users for the privilege, less water will be wasted and it may be distributed more equitably.

As water becomes more valuable, metering and monitoring become cost effective. Metering of water service inevitably drives down consumption because users become more conscious of costs. Metering may also provide data on the size of the aquifer system, and inputs into demand projections. For piped water systems in urban areas, charges per cubic metre used are commonly imposed in many countries. Generally speaking, charges are far below the costs of extracting, treating and delivering the water. In some countries, the price declines as consumption increases, thereby discouraging efficient use.

Tariffs can be used to reduce excessive use and conserve water. For example, the owners of wells in areas with falling water tables could be given incentives to exploit less. High marginal tariffs, representing the social cost of excessive use, could be charged for water withdrawn in excess of basic ground-water allotments.

(i) Irrigation water pricing. Regulations and prices of any type, including systems of quotas and marginal prices, for irrigation water reflect conflicting goals: (a) the need to encourage efficient use of water; (b) the desire to redistribute income towards agriculture; (c) the desire to recover capital costs from users; (d) the desire to favour small farmers; and (e) the need to minimize administrative costs.

Because no one system of allocation can be recommended for all regions or projects within a country, rigid prescriptions of policies would be inappropriate. Water laws need to allow for a variety of site-specific conditions.

Desires to subsidize agriculture reduce the possibility of efficiency pricing which would reflect the high value of water. One way to combine the dual goals of subsidy and efficiency is to use two or more prices combined in a system of permits or quotas plus progressive penalties for exceeding them. The system can use low-priced quotas plus high marginal costs for purchasing more than one's quota and rebates for using less than quotas. It is practical particularly when conjunctive use of surface and ground-water is intended. Economic efficiency will also be increased if quotas are transferable or exchangeable among users or if the state is ready to buy unused quotas.

The approaches selected for pricing water, including permits and penalties, have effects on both the distribution of income and the allocation of resources. Subsidized water rates are often used to redistribute income to particular groups. They have been used as a policy instrument to attract industry to selected localities and to provide potable water of acceptable quality to poor communities. The trend may be to price water using "progressive" block rates or systems with low-priced quotas and progressive penalties for using more than one's quota.

(ii) Households and industries. Since municipal and industrial water supplies have not traditionally been heavily subsidized, pricing on the basis of "users pay cost of service" would be more applicable to these sectors, with greater possibility of inducing economic efficiency.

When water is in scarce supply, metering coupled with effective pricing policy can conserve water and improve efficiency in use. Substantial reductions in the quantity of water used are possible when metering and appropriate pricing structures are introduced.

5 CONCLUSIONS

Ground water has provided an economic alternative to traditional surface-water sources in many areas where the latter were either inadequate in terms of quantity, contaminated, or where distance made the cost of conveying the water to points of use unduly high.

It is very important for governments to bear in mind, however, the importance of preventing overexploitation and the long-term depletion of the resource. In order to plan ahead for such eventualities, especially in water-short areas, governments should provide over-all management and direction for the development and use of ground water. Management of an aquifer will entail decisions on minimum well spacing, taxes and tariffs for water use, and rationing and permits to control water withdrawals in order to restore balance between pumping and recharge. The government could also set standards for efficient use, beyond which penalties will be imposed.

Within this framework, the private sector may develop ground water to meet its needs, where appropriate. Private sector developments tend to operate more efficiently on an individual basis and engender innovative technologies, but may not sufficiently take into account the interests and needs of the community.

At the community level, it is important for the local Water Users' Association or Water Committee to take responsibility for a ground-water supply system, especially its operation and maintenance. It is generally agreed that a community-owned and operated system functions better than a system under government responsibility.

Beneficiaries of a ground-water scheme must understand that water which is developed, treated, managed and depleted cannot be considered a free good. Water has an economic value, as do products which use ground water as an input to production. The people who gain economic benefits from a ground-water scheme must pay an economic cost for that privilege. Moreover, they cannot overexploit the resource to that point that others (including future generations) will be adversely affected. It is with this understanding that future development of ground-water resources can go forward rationally and economically.

REFERENCES

Bottrall, Anthony F., 1981. Comparative Study of the Management and Organization of Irrigation Projects. World Bank Staff Working Paper No. 458. Washington, D.C., The World Bank.

Carruthers, Ian and Colin Clark, 1983. The Economics of Irrigation. Liverpool (U.K.), Liverpool University Press.

Carruthers, Ian and Roy Stoner, 1981. Economic Aspects and Policy Issues in Groundwater Development. World Bank Staff Working Paper No. 496. Washington, D.C., The World Bank.

Driscoll, Fletcher G., 1986. Groundwater and Wells. St. Paul, MN, Johnson Division.

O'Mara, Gerald T., 1984. Issues in the Efficient Use of Surface and Groundwater in Irrigation. World Bank Staff Working Paper No. 707. Washington, D.C., The World Bank.

Postel, Sandra, 1984. Water: Rethinking Management in an Age of Scarcity. Worldwatch Paper 62. Washington, D.C., Worldwatch Institute.

_____________, 1985. Conserving Water: The Untapped Alternative. Worldwatch Paper 67. Washington, D.C., Worldwatch Institute.

Skinner, Andrew., 1983. Groundwater Development as an Integral Part of River Basin Resource Systems. Ground Water in Water Resources Planning. Volume II, Proceedings of an International Symposium convened by UNESCO at Koblenz, Federal Republic of Germany, 28 August to 3 September 1983. Available from United Nations Educational, Scientific and Cultural Organization (UNESCO), International Hydrological Programme, Paris.

United Nations Childrens Fund (UNICEF), 1987. UNICEF Co-operation in Water Supply and Sanitation: A Review and Perspective. Draft Board Paper. New York, UNICEF.

United Nations Department of Techical Co-operation for Development (UNDTCD), 1980. Efficiency and Distributional Equity in the Use and Treatment of Water: Guidelines for Pricing and Regulation. Natural Resources/Water Series No.8, Sales No. E.80.II.A.11. New York, United Nations.

_____________, 1987. Follow-up to the Mar del Plata Action Plan: Report of the Meeting. Interregional Symposium on Improved Efficiency in the Management of Water Resources, 5-9 January 1987, New York.

_____________, 1975. Ground-Water Storage and Artificial Recharge. Natural Resources/Water Series No.2, Sales No. E.74.II.A.11., New York, United Nations.

_____________, 1979. A Review of the United Nations Ground-Water Exploration and Development Programme in the Developing Countries, 1962-1977. Natural Resources/Water Series No.7, Sales No. E.79.II.A.4., New York, United Nations.