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DEPARTMENT OF TECHNICAL CO-OPERATION FOR DEVELOPMENT

GROUND WATER ECONOMICS

Report of a United Nations International Symposium and Workshop Convened in Co-operation with the Government of Spain

Barcelona, Spain

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NOTE

The designations employed and the presentation of material in this report do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

TCD/SEM.88/2
INT-86-R45

CONTENTS

Annexes

FOREWORD

The United Nations Water Conference, held at Mar Del Plata, Argentina in March 1977, adopted a Plan of Action embodying the recommendations and resolutions of the Conference. The Plan of Action was subsequently approved by the United Nations General Assembly (A/RES/32/158).

A recommendation on community water supply proposed the launching of an International Drinking Water Supply and Sanitation Decade between 1981 and 1990. The principal objective would be to ensure that all people would be provided with safe water in adequate quantity by 1990.

The Decade was launched officially on 10 November 1980 by the United Nations General Assembly, in a one-day ceremony attended by senior government officials, the Secretary-General, and Directors General of the United Nations organizations most directly affected. The Department of Technical Co-operation for Development (DTCD) of the United Nations is a major participant among the United Nations organizations involved in the Decade, with a major concern for the improvement of water supply conditions in poor rural areas, and particularly in arid, drought-stricken regions, such as the Sahelian belt south of the Sahara desert. In such areas, water supply originates from groundwater. To date, DTCD has executed some 150 projects for groundwater investigations and development.

The Department, which has major Divisions concerned with both Natural Resources and Development Planning, has been involved with with the economic feasibility and related aspects of groundwater development in developing countries for over 30 years. It therefore proposed to sponsor a Seminar on groundwater economics. The Government of Spain, where groundwater development has been given a major thrust in recent years, expressed its interest in co-operating on such a seminar as well as hosting it in Barcelona. The authorities in Spain have been promoting groundwater development in an attempt to meet the needs of the tourist industry, in the coastal areas as well as on the islands, and to develop irrigated agriculture, particularly in the southern provinces of Almeria, Cordoba and Sevilla.

The International Association of Hydrogeologists also expressed interest in the Seminar, and helped to provide the necessary impetus for organizing it into a major gathering of groundwater scientists, engineers and economists from different parts of the world. As a result, the concept evolved from a seminar to an International Symposium on Groundwater Economics held from 19 to 23 October 1987, complemented by a workshop, where the participants from developing countries could express and exchange views on the themes covered by the seminar.

In co-operation with the Spanish Organizing Committee, the United Nations contributed to the seminar by assuming responsibilities for preparation of the programme, and by supporting the participation of groundwater specialists from a number of developing countries.

The Spanish Organizing Committee benefited from the support of the following organizations: The Savings Bank of Barcelona; the Interdepartmental Commission for Research and Innovation in Metropolitan Barcelona; the Directorate General for International Technical Co-operation of the Ministry of Foreign Affairs; the Directorate General for Hydraulic Works; the Autonomous Government of Catalonia; the General Water Corporation of Barcelona; and the Polytechnic University of Catalonia (UPC).

In addition to the International Association of Hydrogeologists, the following collaborating institutions should be mentioned: the Municipality of Barcelona; the Department of Education, Autonomous Government of Catalonia; the Provincial Council of Barcelona; the Engineering School for Roads, Canals and Ports (UPC); the Board of Waters, Autonomous Government of Catalonia; and the Geological Survey of the Ministry of Public Works.

The Scientific Secretariat was established in the offices of the International Course for Groundwater Hydrology and the Executive Secretariat at the Centre for Water Studies and Research (CEIA).

The present report contains the conclusions of the Symposium, as well as a summary of discussions and conclusions of the Workshop, which emphasizes the participation of professionals from developing countries. The Proceedings of the meeting, including all papers presented, will be consolidated by the Organizing Committee and printed commercially.

The United Nations expresses its deep appreciation to the Government of Spain and to all the Spanish institutions for their most valuable support to the Symposium and Workshop, including the gracious hospitality provided.

Special thanks are due to the Organizing Committee for its excellent work contributing to the success of the Symposium and Workshop, in particular to its President, Dr. Professor Emilio Custodio.

I. SUMMARY OF PROCEEDINGS

This report summarizes the activities of the Symposium and Workshop on Groundwater Economics held in Barcelona from 19 to 23 October 1987.

The opening session was addressed successively by Mr. A. Millet, Savings Bank of Barcelona, the organization which hosted the Symposium in the conference room of its headquarters; Prof. R. Llamas, President of the International Association of Hydrogeologists; Mr. L. Garcia-Cerezo, Directorate for International Technical Co-operation, Ministry of Foreign Affairs; Mr. E. Fano, Deputy Director, the Division of Natural Resources and Energy (UNDTCD); Mr. J. M. Fons Boronat, Polytechnic University of Barcelona; Mr. S. Arlosoroff, World Bank, Washington, D.C.; and Mr. J. Tosas, Public Works, Autonomous Government of Catalonia.

The Organizing Committee was chaired by Dr. E. Custodio, Polytechnic University of Barcelona. Mr. R. Dijon, Interregional Adviser (Groundwater), UNDTCD, acted as General Rapporteur on behalf of the United Nations.

For three days the Symposium covered four main topics, dealing with: economic aspects related to groundwater exploration and assessment; groundwater exploitation and use; groundwater conservation; and the consequence of groundwater use.

Each session included the presentation of a key paper by a senior specialist and presentation of a paper by the rapporteur of the session, followed by a presentation of technical papers by their authors, and a general discussion.

The Symposium was followed by the Workshop, which was organized especially for the benefit of participants from developing countries, who were divided into two groups dealing with macroeconomic and/or microeconomic issues, respectively. In fact, as shown in the summary of the discussions and workshop conclusions, the distinction between the two themes was not particularly obvious. Nevertheless, valuable information and ideas were exchanged between the participants.

Numerous papers were contributed to the Symposium, the first of its kind to be held anywhere. Since many of the participants were mainly hydrogeologists, with academic background and professional experience almost exclusively in the field of science and technology, only relatively few papers appeared to deal specifically with the topics of the meeting. Elsewhere, the economic aspects were expressed in terms of costs of wells and water, and amortization ratios. However, the gathering provided a good opportunity for most participants to become acquainted with the economic imperatives of groundwater exploration development and use.

In addition to the technical sessions, a study tour was organized of the Llobregat valley and delta.

This short report concentrates on the conclusions of the technical session, on the five topics of the seminar, and on the discussions and conclusions of the workshop. The latter were read and approved by consensus at the concluding session of October after minor rectifications.

A listing of the 118 participants is presented as annex I; a detailed programme of the Symposium-Workshop is given in annex II; papers prepared by United Nations staff (DTCD) are also attached as annex III. A summary of papers presented by participants from developing countries whose attendance at the seminar was sponsored by the United Nations is given in annex IV. Some of these reports, which for the most part are country papers of a general nature, will be included in the volume of proceedings prepared by the Organizing Committee as a publication of the International Association of Hydrogeologists.

II. CONCLUSIONS OF THE SYMPOSIUM

A. Topic I: Economic Aspects of Groundwater Exploration and Assessment

An aquifer that is a geological formation containing water can be considered as (1) a source of water; (2) a storage environment; (3) an environment for improving water quality; or (4) a combination of these three functions. Management of aquifers may sometimes include additional functions, such as drainage, to avoid waterlogging and protect water quality from surface pollutants.

The purpose of groundwater investigations is to improve knowledge and information on features and characteristics of an aquifer which are relevant to its role in the water supply system or to other aspects of its management.

A basic initial level of hydrological information, such as small-scale hydrogeological atlases, is required without being justified by economic returns. However, beyond this level, investigations should be justified by the value of information gained. This value comprises the benefits and costs of the planned development, as affected by the investigation and the cost of the investigation.

Three main classes of water supply system may be identified in respect of benefits:

(1) Rural single-well (usually hand-pump) systems;

(2) Reticulated supplies or irrigation schemes based on single wells;

(3) Water supply and irrigation systems connected to well-fields.

The benefits on a cost-effectiveness scale are higher in the last class of water supply, whereas the social benefit in improving life conditions of the weak part of the population is usually higher in the first class.

Costs of investigations vary widely according to local conditions. They are lower in continuous, shallow and loose material aquifers. The investigation should be carried out in stages starting with simple and cost-effective methods. The skilled utilization and interpretation of available information can result in great reduction of the exploratory drilling expenditures. Therefore, the expenditures for skilled manpower include a high portion of the total investigation costs. It is therefore essential to upgrade local skills in developing countries through training and international co-operation, with the active involvement of developing country experts.

The cost-effectiveness of the hydrogeological investigations cannot be fully assessed, as it is not always possible to compare the results obtained through the investigations with the results which would have been attained without these investigations. In some cases, the benefits of the investigations are clearly demonstrated. It is well known that geophysical surveys can dramatically increase the rate of success of drilling operations in hydrogeologically difficult areas.

The level of detail and depth of the investigation should be related to the objective which is to be attained. The minimum to be considered in all cases consists of hydrogeological supervision and monitoring of water-well-drilling operations. It must be kept in mind also that beyond a certain level of investigations no concrete benefits are to be expected. It is therefore essential to have a feeling for the level to be reached and not exceed it.

Major benefits to be expected are those resulting from proper design and exploitation of well-fields. Through the three stages of groundwater exploration, and the development and management of such well-fields, hydrogeological studies are to be carried out very carefully.

The costs to be considered in hydrogeological studies are to be related to the development objectives. They may be in the range of $US 10 to 100 per square kilometre for general studies, and up to $US 100,000 per kilometre in very detailed studies, such as well-fields for urban water supply.

The information gained by investigation is expensive and usually valuable. Therefore it should also be accessible in the future. Data banks to keep results of investigations are important, especially in developing countries. National and external resources should be made available for establishing and maintaining these hydrogeological and economical data banks for the benefit of future development.

The problems existing in industrialized countries are quite different from those in developing countries, in areas subjected to extremely dry spells where water-wells have to be drilled on an emergency basis. In such cases, hydrogeological studies have to be reduced to a minimum. Conversely, in cases such as large-scale groundwater irrigation projects or metropolitan water projects, hydrogeological investigations should be carried out in great detail in order to determine the potentially harmful effects of intense pumpings and their potentially disastrous human and social consequences. In least developed countries, it may be more difficult to make authorities and populations aware of the risks of inadequate -- or the absence of any -- groundwater development planning, unregulated siting and exploitation of wells, as well as inadequate maintenance of wells and pumping installations.

It is essential to carry out extensive hydrogeological studies for groundwater irrigation projects in order to limit extraction to a safe level, thus preventing aquifer contamination, and especially salt water intrusion in coastal and arid areas.

In conclusion, some doubts can be raised regarding hydrogeological investigations. Are they to be considered of general interest or simply as a component in water resources planning exercises? Are they to be supported by the country concerned in consideration of possible economic returns or as an investment of basic knowledge of natural conditions, without considerations for such returns? Another question to be raised is: What is the proper time for carrying out a complete hydrogeological mapping work? In other words, what is the level of knowledge necessary to be able to engage in mapping?

Finally, it is extremely difficult to make a benefit/cost analysis for hydrogeological investigation without considering intangible social benefits and the general interest.

B. Topic II-A: Economic Aspects of Groundwater Exploitation

The papers presented at this session and the discussions which followed differentiate between two types of situations as follows:

- Groundwater works are intended to satisfy the elementary water needs of hundreds of millions of inhabitants in developing and least developed countries, with elementary extractive devices such as hand pumps.

- Groundwater works are serving the needs of urbanized populations in addition to the agricultural and industrial productive sectors by means of motor-drive pumping stations.

Although both cases present common aspects, it is necessary to realize their basic differences. For example, groundwater may be the only resource, or it may be used as an alternative source with surface water. The construction of groundwater works, wells and pumping stations should therefore be preceded by a study involving various potential sources of water, both surface and groundwater, which should take into account the objectives of the project and the nature of the demands to be satisfied.

Nevertheless, in the first case, the objectives and the social context require standard, durable, secure and reasonable solutions which may be applied to multiple sites and would not involve major maintenance problems. Benefits to be expected in such cases are not to be expressed in economic terms, but rather in terms of benefits to and improvement of the quality of life, in time saved for water collection and transport, which time may be put to better use for work or rest, and also in terms of improved health conditions.

In the second case, groundwater development can be assessed in terms of economics, although social benefits are also generated in many cases, especially regarding community water supply. The economics of groundwater extraction installations should therefore be closely looked into, although other considerations are also to be taken into account, such as the possible use of existing pumping stations to overcome temporary water emergency situations occurring in major water schemes, as well as the independence of certain well-fields as regards an integrated reticulated network supplied by other sources.

The realization of groundwater development schemes, from the point of view of economics should integrate and optimize all factors which intervene in the process. Site selection, the design of a project on the basis of the quantity of water to be developed and the uses to be served, careful execution of the project, its progress, the choice and installation of equipment and the pattern of operation may separately as well as jointly constitute decisive factors in the functioning of the installations, together with the quality of the work and the equipment to be used, and the adequacy of the maintenance, in its cost-effectiveness.

In many cases, however, well-fields cannot be considered in isolation. Independently of their own characteristics, they may be exposed to external harmful factors such as overdraft, contamination and saline intrusions, and, as a result, their production may overnight be reduced and consequently their expected benefit/cost ratio.

In some cases the process may be irreversible. In others it may be possible to reinstate the initial productive capacity of the well-fields by deepening the wells and installing new pumping equipment which will increase investment and maintenance costs.

The above considerations clearly demonstrate that the groundwater installations are to be considered not as a separate entity, but rather as part of a system which should also include preceding investigations and assessment operations and studies, including further management and monitoring activities; in other words, the economics of the system should also include the exploratory assessment phase and the operation phase.

In conclusion, it can be said that wells and pumps are only one element among the many to play an important role in helping to meet the demand for water supply. As far as their construction, installation and maintenance are concerned, there are many other factors which intervene and should be taken into consideration and optimized from the social and economic viewpoints.

C. Topic II-B: Economic Aspects of Groundwater Development and Use

Irrigated agriculture is by far the largest groundwater user. Depending upon agronomic and hydrological conditions, specific irrigation systems, technologies and methods are to be selected. The choice in fact is a compromise between three categories of factors: (i) the water resources factor, meaning the abundance or scarcity of groundwater; (ii) the human factor, which varies from one country to another: in some countries labour is costly or not available, while in others, for socio-political reasons, it is essential that manpower be largely utilized in irrigation agriculture; and (iii) the economic factor which depends on the cost of irrigation equipment.

Flood and furrow irrigation systems are inexpensive and do not require the use or import of sophisticated devices. Besides, they involve the participation of local manpower. On the other hand, they waste large amounts of water, which in some cases are pumped at high energy costs, and may have adverse effects on the environment.

Permanent-set sprinkler and drip irrigation are among the most expensive technologies. They also allow for minimal water consumption and minimal use of labour, whereas, centre-pivot irrigation practically eliminates irrigation personnel.

In fact, as the need for groundwater continues to grow, the more highly diversified becomes its utilization. Its economic value is also gradually increasing, and the activity of the groundwater industry is under the public eye, with its implications for the public interest and social welfare.

The performance of groundwater irrigation systems, especially public systems owned by central or local authorities, parastatal organizations and other public agencies, can be improved by means of economic and financial incentives offered to farmers, especially as regards pumping costs and loans for the purchase of irrigation devices.

Government decisions on public investment for groundwater development, especially regarding incentives for individual farmers should not be made only on the basis of political and social considerations. Sound financial and economic analyses should also be made, and their results should be taken into account.

However, such analysis should not be restricted to the benefit/cost ratio considerations, meaning the quantifiable aspects. Other factors should be taken into account such as the need for sound water resources management, especially regarding conservation of the resource in quantity, quality and availability; also, the need for the preservation of ecosystems.

Legal, regulatory and taxation measures aiming at the recovery of capital costs, collection and distribution of benefits, and the implementation of water policy guidelines are all important factors which should also be analyzed.

D. Topic III: Economic Aspects of Groundwater Conservation

The initial stage in the conservation and protection of groundwater resources is the creation of a governmental organization structure responsible for the establishment and implementation of a strategy and policy leading to legislation that would allow the management and control of groundwater development.

Groundwater abstraction should be controlled by a regulatory system (in the form of licenses or permits). Regulations are also necessary to protect the quality of groundwater. These services would control the disposal of wastes and should have provisions to penalize polluters.

Good management practice will lead to the proper conservation of groundwater resources. Management depends upon data, particularly relating to the amount of groundwater storage, and this must be monitored with an observation well network over a long period of time. Establishing and operating such networks must compete for funds against other requirements and, therefore, an obvious benefit from the investment must be visible. It must be clear that monitoring involves more than measurement -- it includes interpretation and its effect on individuals. Nevertheless, the benefits are difficult to quantify in financial terms. It is more likely to be in the form of greater operational efficiency and goodwill from customers; in other words, it is socially desirable.

The cost of observation-well networks and conservation measures, including operational costs, usually represents a small percentage of the value of the resource. In these circumstances, the investment can be allocated as a percentage of the value of the water supplied by the aquifer. The costs can be recovered as part of a direct charge for water.

Groundwater protection requires effective legislation and implementation of protective measures; for example, land-use controls, adequate provision for disposal of potential pollutants, and controls on fertilizers and pesticide use. The benefits are sometimes, or perhaps often, intangible; nevertheless, they are likely to be rated very highly by individuals when expressed in terms of health and quality of life. The costs represent the cost of protecting groundwater -- a socially desirable duty. In more tangible terms, the costs are actually significant, involving limitations on land use, reduction of crop yields, pretreatment of wastes before disposal, and provision of piped sewerage system. The overall objective is protection of the water environment and its ecology.

Conservation and protection of groundwater resources can only be implemented by a government or public organization that has authority for its actions founded in law. These concepts are more likely to be successfully applied where a unified water system provides the discipline necessary to control both water resources and quality, surface water and groundwater, waste treatment and waste disposal. Financial support is generally needed from governments. Non-market forces will increasingly assume importance in the future, as society becomes more aware of environmental impacts on health and the quality of life, and as standards of living improve.

Groundwater conservation projects should be introduced where and when a need arises. The projects should be designed to produce a positive benefit/cost ratio taking into account possible social benefits. Such projects include those designed to increase infiltration, such as artificial recharge.

The use of water can be controlled by a pricing system. The price should vary according to the use of water and should have the aim of preventing waste.

Conservation and protection must be long-term programmes integrated in the overall water management and national plan. The ultimate benefit would be the maintenance of the quality of groundwater as a source of drinking water, and hence the maintenance of public health.

E. Topic IV: Economic Aspects of Combined Use of Surface Water and Groundwater

All potential sources of water are to be considered to meet present and future demand. Their interrelationship, possible interference and various alternatives to their development require serious consideration as well. In most cases, and not only in arid and water-short areas, it may appear advantageous and advisable to consider combined development of surface and groundwater.

Initial investment for groundwater development is relatively modest, while operation and maintenance can be rather high. Conversely, investment costs for surface-water projects are high, while operation and maintenance costs can be significantly lower than those related to groundwater.

To evaluate various costs and benefits on a time basis, a discount rate has to be applied in order to actualize them. High discount rates will bring an advantage to groundwater development. Conversely, low discount rates will be more favourable to surface-water schemes.

From the point of view of economic efficiency, the choice of amortization rates is crucial when comparing various alternatives for water resources development. It is also appropriate to study the sensitivity of the various cost components to changes in the discount rate.

The major factor controlling investment costs is the amount of water which can be extracted annually from a well. Aquifers with high specific capacity and adequate construction design and technologies are prevailing factors in well productivity. If irrigated land is divided into small plots while the yield of individual wells is high, it is essential that the farmers be organized in associations exploiting a limited number of wells to attempt to minimize water costs.

The exploitation of alluvium aquifers is particularly profitable, as groundwater levels are shallow and aquifers are closely related to river water, induced recharge is allowed through pumping.

In order to compare costs of alternate solutions for the use of ground and surface waters, it is necessary to consider water costs from source to point of utilization rather than at the well itself or at the foot of the dam. Costs for water conveyance distribution and treatment are also to be taken into account in calculating overall costs. Also, losses through evaporation and losses in canals and pipes are to be considered.

In the economic appraisal of groundwaters it is necessary to take into account that they can be developed progressively through modest yearly extensions and adjusted to the demand, especially in the case of the initial phase of irrigation schemes.

Regarding surface water, it normally takes a period of 15 years from the time a dam is built for irrigation schemes to be entirely developed. Moreover, successive stages of studies, decision-making and construction usually take quite a bit of time.

In groundwater projects the following effects have to be taken into account and assessed in economic terms: influence of pumping on the lowering of groundwater levels; deterioration of water quality; possible intrusion of saline water; decrease in surface water and/or yields of springs; subsidence phenomena, and other possible harmful effects. On the other hand, groundwater development may in many cases alleviate or solve drainage problems which may result in important social and economic benefits, which are also to be assessed.

Induced recharge of surface water into aquifers generated by a temporary or permanent lowering of the piezometric level allows for the storage of surface water in the aquifers. In some cases it represents the only possible way to put surface water into storage as is the case close to the mouth of a river.

Conjunctive development of surface and groundwater allows for the utilization of waters of diverse quality, either by means of a mixing within the aquifer itself, or through the mixing of waters from different sources before utilization.

Aquifer recharge by means of surface water is a valid contribution to the efficient management of water resources. In many cases, however, recharge schemes are expensive and require the intervention of advanced technologies. It is interesting to explore the possibilities of inexpensive solutions for artificial recharge, which may include: the creation of artificial lakes in porous terrains; the use of canals devoid of lining; and the supply of irrigation water in excess of needs during periods or seasons of abundant surface waters.

Overexploitation of aquifers cannot be practiced indefinitely. However, temporary overdraft has been utilized as a way of delaying the use of alternative solutions which would incur not only high costs, but would also require extensive time for their study, design and construction. Many development projects can be initiated through a temporary overexploitation of the aquifers, with the understanding that during further stages other sources of water, surface as well as underground, will be added and will be operated jointly with the existing sources. Such a policy is particularly adequate in cases of hydrological uncertainties for surface and groundwater resources, and also uncertainties regarding costs and future demand as is the case in developing countries.

As far as conjunctive use is concerned, it appears quite justified to utilize primarily surface waters from dams or streams during humid years and groundwater during the dry years. With such schemes the groundwater component fulfils also the role of increasing the chances of sustained yields, thus creating an element of certainty. More importantly, considering the uncertainties of hydrological forecasting for surface water inputs, proper management of such schemes is crucial. Improvements in the forecasted results for mid- and long-terms may exert a positive influence on the economic efficiency of the operation of such schemes in which artificial recharge will play a secondary role.

The number of possible solutions, variations in hydrological inputs, uncertainties in economic and hydrological conditions, as well as in the demand make difficult the choice of the best solution from the technical, economical and social points of view.

Adequate methodologies and technologies for management, optimization and modelling may assist in securing the decision-making process at the various stages of development of such schemes.

F. Topic V: Economic Assessment of the Consequences of Groundwater Use

Groundwater resources planning and proper allocation are an essential component of water resources development, rational use, conservation and protection in any river basin.

The widespread occurrence and general accessibility of groundwater allow for its development by the private sector. However, government intervention is needed in order to secure a rational development of the resources, safeguard community interests, and protect rights which may be affected.

Direct execution of groundwater projects may be considered by central or local governments, especially if private investment funds are not available, or if such funds are concentrated in a few hands -- individuals or companies -- which will exert a monopolizing effect on the development of the resource, sweeping all benefits, thus creating flagrant social inequities.

Overdraft, conceived as a means of rapid mobilization of water reserves with a view to generating large profits within a short period of time, can be considered a rational strategy in the exploitation of aquifers, taking into account their basic character as storage facilities.

The pattern of overdraft, however, should be carefully planned in terms of yields, duration and decline of the resource, to be able to secure the amortization of investments and the optimal exploitation of water reserves in adequate quality and quantity. An efficient control of the process is to be established as, in fact, the rights to such a transitory development are to be reserved either for water development services of the government or for public entities which can be effectively subjected to controls.

Guidelines and general criteria for groundwater exploitation are to be part of a water resources planning exercise for the long- and mid-term, and should be realized at the regional level for various river basins. The study and monitoring of the effects of groundwater exploitation which, if possible, should involve system analysis and mathematical modelling are an essential component of the planning process.

Water laws and regulations should reflect the basic principles according to which external costs are covered by the activities which generate them. The implementation of compensatory measures in favour of users of river and spring waters affected by groundwater exploitation is justified not only from the point of view of ownership rights, but also as a measure intended to secure the rational use of the resource from the point of view of sound economics.

On the other hand, taxation cannot be considered a measure which would effectively prevent the waste of national resources or bring a remedy to the damages incurred by the users of a particular aquifer. Such objectives can better be achieved through the allocation of extraction quotas, the establishment of norms for well-spacing, taking into account political, social and economic criteria.

Among its priority interventions, the river basin authority (or any other water authority or council) should consider regulations aiming at the protection of water quality against sea-water intrusion, or the intrusion of saline continental waters. Detailed norms assessing authorized yields, spacing and design of wells, as well as an effective control of their implementation would constitute the only efficient preventive arrangements.

III. DISCUSSIONS AND CONCLUSIONS OF THE WORKSHOP

Within the context of the topics pertaining to the Symposium, developing country representatives had an opportunity to discuss issues and problems of particular concern to them in the course of a one-day Workshop, held on Thursday, 22 October 1988. Two groups were formed, dealing respectively with macroeconomic and microeconomic aspects of water resources development. The Workshop was also attended by representatives from some developed countries and monitored by some rapporteurs and United Nations personnel.

Within the macroeconomics group, representatives from Australia, Bangladesh, Egypt, India, Jamaica, the Philippines, Spain and the United States of America participated actively in the discussions. The conclusions of the group are listed below.

In the discussion on microeconomics, representatives from Australia, China, Costa Rica, Ecuador, Egypt, France, Jordan, Malta, Mexico, Morocco, Mozambique, the Netherlands, Spain and the United Republic of Tanzania played an active role. The conclusions of the group's discussion are also listed below.

These conclusions were then presented to the plenary session.

A. Group A. Macroeconomics

1. The development of groundwater follows an evolutionary process which can be divided conveniently into three phases: (a) exploration; (b) expansion; and (c) management.

2. The principal objective during the exploration phase is the drilling of successful boreholes. In the expansion phase, more and more wells are brought into production, and hydrogeological considerations such as the spacing of wells, the ultimate limitation of the resource, and possible side effects become important.

3. In the management phase, the exploitation of groundwater normally reaches, and in arid regions often surpasses, the safe yield, and thus needs to be planned and controlled.

4. The investigator, planner, operator and external decision-maker need to take into account the economic considerations in each phase.

5. A basic level of hydrogeological information is initially required, the acquisition of which cannot be readily justified by economic returns. Investment in the initial stages of groundwater investigation is very much risk capital.

6. Moreover, initial groundwater investigation should be regarded as a public good, whose benefits extend beyond the interested party, and should accordingly be subsidised. Once some boreholes have been drilled, and hydrogeological conditions evaluated, it will be easier to site subsequent production boreholes more successfully. Tax on later developers could be levied to recover subsidies paid to those initiating groundwater development.

7. Beyond the initial exploration stage, investigation needs to be justified by the value of information likely to be gained, in terms of the economic benefits from the improvements in development efficiency which will follow the application of a given method of investigation in a given environment.

8. In the absence of adequate information to apply a more objective method, it is common practice to allocate for investigation expenses an arbitrary minor proportion of the economically justified sum for water provision. This proportion is normally higher than that invested in site investigation for surface-water development, but appears to vary widely in the range of 5 to 25 percent.

9. Investment on investigation can generally be reduced and phased if an integrated, flexible approach to groundwater development is adopted. High-cost activities within an investigation programme need to be critically examined to see whether they can be reduced or deferred, without compromising on data requirements.

10. Particular attention should be given to increasing investigation cost-effectiveness. Close hydrogeological supervision of production borehole drilling and better integration of groundwater evaluation and development are judged to be most beneficial in this respect.

11. Every effort should be made to store and to make accessible all the costly data collected by investigation. Data banks are especially important in developing countries, where much of the groundwater information may have been collected by numerous parties.

12. A full and expert utilization and interpretation of pre-existing information, including hydrogeologic maps, can result in great reductions in the cost of exploratory drilling. Thus the expenditure on skilled manpower inevitably comprises a high portion of total investigation cost. Therefore, there is an urgent need to upgrade national professional skills in developing countries through training and international co-operation.

13. Groundwater resources lend themselves to step-by-step development. This enables development to be closely synchronised with rising demand, which is highly desirable.

14. It is relatively easy to quantify the benefits derived from the exploitation of groundwater resources, when they are used for a production process, be it agricultural or industrial. Difficulties

arise in the case of community water supply, especially in rural areas, due to uncertainties about the quantification of social benefits. However, economic assessment is still possible through evaluation of opportunity costs, such as time saved in water provision and expected decrease of public-health expenditure.

15. The cost of groundwater production is greatly affected by choice of the appropriate drilling and pumping technology and by the efficiency of well design and construction. Improvement in this respect can lead to major financial savings.

16. The design of major groundwater abstraction works should be preceded by a financial analysis of possible alternatives, including development of surface-water resources.

17. In addition to the expected benefits, the strategy of groundwater exploitation should take into consideration and economically assess the following: aquifer depletion, deterioration of water quality, possible salt-water intrusion, depletion of surface-water supplies, subsidence and other undesirable side effects.

18. Any aquifer overexploitation, conceived of as a rapid heavy abstraction of groundwater resources in order to generate economic benefits in a short time period, is a policy that always requires careful planning. The intensity and duration of overexploitation have to be carefully considered, bearing in mind both quantitative and qualitative aspects, and also any externalities that are likely to be generated. Occasional periods of overexploitation are valuable to postpone the introduction of other more expensive alternative supplies, such as those derived from surface water.

19. One way in which surface and groundwater may be used conjunctively, is by using surface-water resources in wet periods and groundwater resources in dry periods. In this way groundwater can fulfil a buffer role as well as provide an emergency back-up system.

20. In areas where groundwater is just beginning to be developed at widely separated localities, there is no immediate need for resource conservation, but protection against pollution in the immediate vicinity of the source is essential and should be incorporated in project design. Attention should also be given to the disposal of waste so as to avoid pollution.

21. The cost associated with observation well networks and other conservation measures usually represents a small portion of the cost of a groundwater development scheme. This cost can be allocated as a percentage of the value of the groundwater supplied or as a percentage of the total capital cost of the scheme.

22. The general public will only be concerned about groundwater when a serious problem exists such as when a pollution incident directly affects a water supply. That is when protection has failed. The public

is not generally willing to pay higher charges for conservation and protection measures unless the benefit is obvious; hence implementation requires a legal basis, enabling costs to be transferred to the water user or to the individual or organization causing pollution.

23. Externalities stemming from physical interdependence among different individual users lead to inefficient allocations of water. The related costs perceived by the individual user are different from the social cost involved in the development and distribution of regional groundwater resources. Therefore user associations should be encouraged to increase the efficient management of groundwater.

B. Group B: Microeconomics

1. The Workshop concluded that groundwater development has expanded rapidly over the last 20 years given the possibility of expanding systems with relatively small investments and the ubiquitous nature of the resource and its proximity to the points of use. This notwithstanding, there are still two billion people in the world who do not have access to a safe source of potable water; this must therefore be a priority issue for many countries.

2. The initial stage in the conservation and protection of groundwater resources is the creation of a government organization responsible for the establishment and implementation of a strategy and policy leading to progressive legislation that regulates and controls groundwater development based on sound scientific principles.

3. In groundwater development, the role of government should be viewed as that of promoting the development of the resource and regulating the pattern and rates of exploitation, with a view to conserving and safeguarding the resource.

4. In order to carry out its promotional function, government should in the first instance acquire the basic technical skills in data gathering and organization, and establish a data base to incorporate the basic practical knowledge on the availability of groundwater resources, with priority attention given to areas where water supply needs and development potential are greater. In order to minimize the cost of this information-gathering-and-storage function, government agencies should make maximum use of co-operative programmes with scientific and technical institutions from other countries, with a view to focusing the attention of the latter on the priority areas selected for data gathering. Maximum use should also be made of data made available by ongoing groundwater development projects so as to minimize data collection costs for governments.

5. As another aspect of the promotional function, governments should clarify their water resources development policies with a view to separating activities related strictly to humanitarian, social and emergency functions, where no cost recovery may be expected (refugee

camps, drought emergency, etc.) from rural water supply activities, where some cost recovery policy may be expected so as to cover at least operation and maintenance charges; urban water supplies where cost recovery may be expected in full; and finally water use for economic activities (including industry, irrigation and mines), where an economic cash crop return may be expected over and above cost recovery.

6. In countries which are largely agricultural without major incomes from mineral, raw material or industrial exports, governments should consider whether and to what extent water for agricultural use should be subsidised. In this respect agencies should encourage small-scale development of groundwater resources through private initiative and provide assistance in this regard through loans, tax abatement, or other incentives.

7. In order to ensure that water resources maintain their economic value, it is necessary to ensure their protection through conservation and quality control. Monitoring networks, which generally represent a small fraction of the cost of groundwater development, should be established to measure the fluctuation of water levels, water quality and groundwater abstraction. There are economic limits to pumping wells for different types of uses of groundwater in different regions, and the levels of exploitation should recognise these in establishing well spacing. This should provide guidelines for optimal designs of well-fields, especially as regards irrigated agriculture.

8. National water legislation should incorporate aspects which directly relate to the economic value of water as a factor in the production process. This implies that such legislation should regulate quantitative and qualitative aspects of development so as to prevent a waste both of financial and natural resources. Government agencies may set conditions for efficient use and standards for quality control.

9. Due to the high cost of aquifer rehabilitaton from pollution, aquifer protection policies are necessary and should be based on the degree of vulnerability of individual aquifers to different pollutants and their relative importance taking into account delayed effects.

10. In the plans to develop groundwater for specific large-scale projects, it is essential to make long-term forecasts of the evolution of groundwater resource use and of its probable future cost. Moreover, such developments should include restitution for any detriment to existing water users.

11. In order to ensure maximum economic efficiency in groundwater development programmes, and to avoid duplication, waste and policy contradictions, it is essential to secure close co-operation between national, regional and local groups on the one hand, and between sectorial interests on the other, so as to achieve an integrated approach in programme implementation.

12. At the local level, especially in rural and peri-urban areas, cost recovery should be secured at a level which takes into account both economic and social factors. It is essential that local communities participate actively in the efficient operation and maintenance of water supply systems (in particular hand pumps and motorised pumping stations for the watering of cattle, where applicable). However symbolic it may be, the financial participation of the population should be assured, for spare parts, fuel, services of a mechanic, etc.

13. In many developing countries women are the traditional water carriers and also represent the bulk of the working population in the countryside in view of the emigration of much of the male working population to the cities. Under these conditions, it is important to minimize the time spent by women in conveying water from the wells to the house through introduction of appropriate technologies, allowing the transportation of relatively large quantities of water with minimum effort.

14. External assistance in terms of technical co-operation should be geared primarily to delivering services, training, and technology which are directly applicable to groundwater resources development activities, within the context of development plans, and which a country has the capacity to absorb and use over the long term. With respect to project-related decisions, equal weight should be given to the development of surface water, groundwater or conjunctive-use options, even if this includes the need for conducting hydrogeological surveys to expand the existing data base, as much as is practical.

15. External assistance in terms of investment should generally be preceded by preparatory pre-appraisal investigations which will require the disbursement of funds to ensure the long-term availability of groundwater resources, alone or in conjuction with surface water.

16. It may be expected that assistance through loans in the foreseeable future will focus largely on the expansion of projects for urban-rural water supply on the one hand, and of irrigation on the other. The relatively low risk involved in groundwater-based projects, as a result of the gradual investments required to meet increased demand, may in many cases provide the most economic option for newly developed projects.

Annex I

LIST OF PARTICIPANTS

1. Participants from developing countries whose attendance was sponsored by the United Nations:

ANGOLA:	A. Germando Araujo, Director of Department of Geology and Mines, Luanda.
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	R. Herbert, Geological Survey	Wallingford
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	S. Gorelich, USGS (California)	Menlo Park
	W. Martin, University of Arizona	Tucson

4. Participants from international organizations:

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R. Dijon, Interregional Adviser (Groundwater)
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WORLD BANK (Washington, D.C.):

S. Arlosoroff, Infrastructure Strategy, Management and Assessment Division

FOOD AND AGRICULTURE ORGANIZATION (FAO - Rome):

R. Thomas, Land and Water Division

PANAMERICAN HEALTH ORGANIZATION - CEPIS
PAN AMERICAN CENTER FOR SANITATION ENGINEERING AND ENVIRONMENTAL SCIENCES (Lima, Peru):

S. Foster, Groundwater Adviser

ORGANIZATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT (OECD) (Paris):

G. Dorin, Environment Directorate

Annex II

PROGRAMME OF THE SYMPOSIUM-WORKSHOP

Monday, 19 October 1987

Opening Session

Introductory remarks by:

A. Millet, Savings Bank of Barcelona

R. Llamas, President, International Association of Hydrogeologists and member of Organizing Committee of the Symposium

L. Garcia-Cerezo, Dirección General de Cooperación Técnica Internacional, Ministerio de Relaciones Exteriores

E. Fano, United Nations: Department of Technical Co-operation for Development

J. M. Fons Boronat, Polytechnic University, Barcelona

S. Arlosoroff, World Bank, Washington, D.C.

J. Tosas, Department of Public Works, Autonomous Government of Catalonia

Topic I: Economic Aspects of Groundwater Exploration and Assessment

- Key paper: S. S. D. Foster: Economic considerations in groundwater resources evaluation.
- Rapporteur's report: J. Schwartz
- Discussion
- Presentation of selected papers:
  - A. Cimino: The intervention of hydrogeophysics to the economics of groundwater exploitation and management in Sicily.
  - F. Attia: Economic aspects of groundwater development for irrigation and drainage in the Nile valley of Egypt.
  - A. Vernier: Water supply for emergency -- Ethiopia, 1984-86.
- Discussion

- Presentation of papers by United Nations representatives:

  . E. Fano and M. Brewster: Issues in groundwater economics.

  . R. Dijon: Some economic aspects of groundwater projects executed by the United Nations in developing countries.

<u>Tuesday, 20 October</u>

<u>Topic II-A: Economic Aspects of Groundwater Exploitation</u>

- Key paper: A. Navarro: The economics of groundwater works.

- Rapporteur's report: S. Niñerola

- Presentation of selected papers:

  . S. Arlosoroff, D. Grey and D. Roche: Economic considerations of low-cost groundwater-based rural water supply.

  . F. M. Spaziani, M. Vurro, M. Troisi: Evaluation methodology for withdrawal costs obtained from studies on some groundwater aquifers.

  . A. Benton-Cuellar: Aprovechamiento económico del agua subterránea mediante el conocimiento detallado de los acuíferos atravesados por una captación.

- Discussion

<u>Topic II-B: Economic Aspects of Groundwater Development and Use</u>

- Key paper: R. C. Cummings: Economic aspects of groundwater development and use.

- Rapporteur's report: M. A. Karim

- Presentation of selected papers:

  . A. Hoyos-Limón, J. Braojos and L. Puga Miguel: Methods of optimization in the design of well-fields in coastal aquifers.

  . N. Columbus, M. Fink: Economic comparisons between the use of groundwater and surface water for irrigation in Northwestern Uruguay.

  . S. Moreno-Mejía: Evaluación técnico-económica de diferentes fuentes subterráneas y superficiales de suministro.

- Discussion

Topic III: Economic Aspects of Groundwater Conservation

- Key paper: J. Vrba: Economic aspects of groundwater conservation

- Rapporteur's report: R. A. Downing

- Discussion

- Presentation of a film (J. Vrba)

Wednesday, 21 October

Topic III (continuation)

- Presentation of selected papers:

  . E. Spiteri Staines: Aspects of water problems in the Maltese islands.

  . A. Navarro, M. A. Soler and T. Martin: Evaluación económica de un estudio piloto de recuperación del acuífero fluvial de la cuveta de la Llagosta.

Topic IV: Economic Aspects of Combined Use of Surface Water and Groundwater

- Key paper: N. Buras: Economic aspects of the combined use of surface and groundwater.

- Rapporteur's report: A. Satuquillo

- Presentation of selected papers:

  . Y. Tsur and A. Issar: The buffer role of groundwater when supply of surface water is uncertain.

  . E. B. Kaminsky: Economic considerations of combined use of ground- and surface water.

  . J. Marcé i Miracle: Sobre costo del tratamiento de aguas subterráneas salinizadas: Caso del Delta del Río Llobregat.

- Discussion

Topic V: Economic Assessment of the Consequences of Groundwater Use

- Key paper: J. Tinajero: Aspectos asociados a la explotación del agua subterránea.

- Rapporteur's report: A. Sánchez

- Discussion

- Presentation of selected papers:

  - S. Farid: An optimization approach for selecting feasible groundwater policies in the Nile delta.

  - L. Villenas: On groundwater situations in metropolitan Manila: Problems and conservation measures.

  - C. M. de la Cruz: Public water supply: Economic loss due to salt-water intrusion.

- Presentation of a paper by: R. Thomas, United Nations, Food and Agriculture Organization (FAO), Rome.

Annex III

PAPERS PRESENTED BY UNDTCD

A. Opening Remarks by the Representative of DTCD (E. Fano)

It gives me great pleasure to bring to this meeting the greeting and best wishes of the United Nations Under-Secretary-General for Technical Co-operation, Mr. Xie Qimei, who hopes that this will be a fruitful and successful week.

It is not coincidental that this meeting on groundwater economics, so effectively organized by the Government of Spain through the Curso Internacional de Hidrología Subterránea, the International Association of Hydrogeologists, and several other organizations, in co-operation with the Department of Technical Co-operation for Development, is being held in 1987 in this beautiful city of Barcelona, ten years after the United Nations Water Conference. As you will recall, this Conference was held in Argentina, and gave rise to the Mar del Plata Action Plan. The organization of such a meeting ten years after this major event underscores the fact that groundwater has become one of the primary sources of supply, especially in the rural areas. Given that the main purpose of the Conference had been to promote a level of preparedness, nationally, regionally and internationally, which would help the world avoid a water crisis of global dimensions by the end of the present century, this meeting comes at a most appropriate time. It is in fact taking place roughly at the mid-point of the International Drinking Water Supply and Sanitation Decade, which has been the major international effort to launch a programme of intensified water supply and sanitation activity for the most disinherited populations of the world, namely the poor in the rural areas of the developing countries.

Why is the issue of groundwater economics a particularly relevant one, and why is it that it has not been made the main focus of an international meeting until today?

First, we should be aware that if investments in the water sector have to reflect national priorities, it is essential that there should be a national water development plan with short-, medium- and long-term objectives, with clearly defined financing requirements and priorities in use for the various sectors of the economy. It would be desirable that external donors contribute to such a plan in a co-ordinated manner, and one of the premises in this regard is that there should be a clear understanding of needs, in terms of technology, human resources and, above all, financing.

Second, in the case of groundwater, the use of which is multisectoral in scope, cost recovery becomes an important issue, since it may be assumed that governments should be able to reclaim at least part of their investment, and that water should not be provided totally free of charge. This does not exclude the possibility of reducing the basic cost of water through user participation in the establishment of systems and in their operation and maintenance.

This question of maintenance is an all-important one, especially in developing countries, since newly established systems are frequently found to have broken down a short time after installation because no provision has been made to maintain them in an adequate manner. Thus, in reviewing the factors affecting groundwater economics, costs of operation and maintenance are crucial, as are the criteria for allocation of costs between consumer groups, and the avoidance of oversizing systems and equipment.

In January 1987, in order to review some of the major issues stemming from the United Nations Water Conference, the United Nations organized a Symposium on Improved Efficiency in the Management of Water Resources. Among the small number of selected issues dealt with, the first related to the availability of financial resources. One of the major issues which emerged in this regard was that governments would have to grapple with the fact that the existing level of funding was but a small fraction of the estimated requirements for all water-related uses, and that developing countries would have to make significantly increased allocations of financial resources for water resources development, especially from national sources of revenue. Once again, the critical issue to emerge was that of cost recovery, in addition to the need for institutional efficiency and active participation from the outset in construction, operation, and maintenance, by the local communities. It is interesting to note that an increased role for private sector and autonomous entities was also envisaged as a way of mobilizing additional resources, improving efficiency, and providing flexibility in responding to local needs.

The need for a cost-recovery policy, which we may presume will be one of the major issues discussed at this meeting, relates to the imposition of reasonable charges upon the beneficiaries according to ability to pay, not only as a means of ensuring long-term sustainability of projects, but also as a way of ensuring their interest and support. We may assume that the meeting will also concern itself with criteria for the sound evaluation of costs and benefits, based not only on expenses and revenue, but also on such related issues as the cost of data collection and analysis; training and administration; operation and maintenance; and criteria for the retirement of the initial investment. The issue of cross-subsidization of non-revenue-producing uses by revenue-producing ones, such as from the sale of electricity, is another issue that could be of relevance to the discussion here this week.

Our meeting may also wish to dwell on the possible use of revolving funds as desirable mechanisms designed to cover recurring costs, such as repairs, spares inventory, data-base updating, inspection, testing and even expansion. In short, this meeting will provide an exciting opportunity to develop some in-depth considerations regarding issues and approaches which are relevant for water-planning purposes. The participation of a significant number of distinguished representatives from the water sector of the developing countries will help us focus on the concerns of some of the water-deficient areas of the world. Let us all work together this week to find meaningful solutions to some continuing crucial issues affecting the future of mankind.

B. Issues in Groundwater Economics

(E. Fano and M. Brewster)*/

Abstract

This paper raises economic issues related to groundwater development for consideration by policy-makers and technical specialists in developing countries. Those issues include factors affecting the costs of groundwater; the economics of conjunctive use and conservation; and, public vs. private development of the resource. Constraints to sustainable groundwater 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.

Introduction

Economic issues related to groundwater have become increasingly important in recent years, with the widespread expansion in groundwater 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 groundwater development. In this regard, it is not sufficient simply to have an excellent source of groundwater. 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 should be 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 groundwater; 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.

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The ubiquity of groundwater in the world

Groundwater is the largest source of fresh water available on the earth. The estimated amount of groundwater to a depth of two miles into the crust of the earth, is about 18 million km^3 (United Nations, 1975). This groundwater constitutes a vast and almost ubiquitous resource for satisfying water requirements of all kinds. Groundwater 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 groundwater has tended to be overlooked. In recent decades, however, as surface-water supplies have been depleted or contaminated, groundwater 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, groundwater 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 groundwater. Effective methods and tools are now available for hydrogeological research and exploitation and, therefore, for the understanding of groundwater. The greatly increased knowledge of the geology and hydrology of the areas investigated, the more detailed understanding of the hydraulics of groundwater flow and recharge, the improved methods of hydrological analysis and the application of computer modelling and remote-sensing to groundwater problems have led to a more accurate quantitative determination of the water resources stored underground and of the nature of their replenishment.

Advantages of groundwater development

Over the past few decades the economic viability of using groundwater 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 groundwater. Any area with a shortage of surface-water sources and precipitation but with good quality aquifers can clearly benefit from groundwater development.

Groundwater 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, groundwater development can be phased with demand, avoiding costly excess capacity in the early stages of development. Groundwater 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 groundwater has been the main means to provide access to clean drinking water for population in rural areas under programmes of the International Drinking Water Supply and Sanitation Decade, 1981-1990. Using low-cost technologies in many areas, groundwater 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 groundwater 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.

Disadvantages of groundwater development

In many areas, groundwater resources are limited in relation to potential agricultural needs. Some groundwater 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).

Groundwater 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 groundwater 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 groundwater 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 groundwater 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.

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 groundwater 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 groundwater exploration and development. Over a period of more than 25 years the United Nations Secretariat has carried out more than 200 projects in the groundwater field in 75 countries, with total expenditures of over $250 million in convertible currency.

Through United Nations projects, governments and population have been made aware of the importance of groundwater 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, 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 is included, the level of external assistance is wholly inadequate to meet the needs of developing countries for water resources development. While the international community may act as a catalyst for groundwater 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.

Economic Issues

Factors affecting the costs of groundwater

The total cost of a given groundwater 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 groundwater 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 of 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 groundwater development will be lower in areas with favourable hydrogeological 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 (recurring costs) are very important components of total groundwater 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, recurring 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 groundwater produced gives us the cost per unit (i.e., $\$US/m^3$). For low cost groundwater 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.

Conjunctive use of groundwater and surface water

The decision on whether to use surface or groundwater 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 groundwater or conjunctive use for water supply may be necessary and indeed desirable, even though more expensive at times.

In the initial stages, tapping of groundwater sources may be a boon to a water-short or depressed area. Since 1960 groundwater 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 groundwater 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 groundwater, especially in those cases where there is a drainage benefit from groundwater pumping. This is the common feature of many projects in the Indo-Gangetic Plain.

Groundwater 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 groundwater at either end of the season or at the peak (Carruthers and Stoner, 1981). The benefits derived from the addition of groundwater in terms of income can be considerably higher than the cost of extracting it.

The wise use of groundwater 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 groundwater 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 groundwater recharge is usually insufficient to keep pace with withdrawals or discharges to rivers. Therefore, it is common for the groundwater table to fall several feet or more over a period of years, particularly where groundwater use is high. Even following severe droughts, however, when rainfall returns to its usual pattern, the groundwater levels return rapidly to normal, generally within six to 12 months (Driscoll, 1986).

In a situation where both surface water and groundwater 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 groundwater, 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 groundwater will benefit from seepage from surface water sources. Such seepage, which can be artifically 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).

Economics of conservation

Mounting pressure on the world's groundwater 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 southwestern United States. Increasingly, widespread groundwater pollution further limits availability of the resources and points up the need to place groundwater use on a sustainable footing.

Even where recharge does occur, groundwater 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 conscious 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 restoring a balance between pumping and recharge. Water pricing measures are discussed below.

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.

Type of ownership

The economics of a groundwater 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 groundwater irrigation, as well as community water supply. For example, public demonstration projects using groundwater for irrigation or water supply can initially be operated by a public water authority. These may stimulate initial interest and widespread development of groundwater 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 groundwater developments and would have a political advantage in negotiating and accepting foreign assistance.

Most important to the future of groundwater development, however, is the involvement of the public sector in integrated management of the water resources of the country. Where groundwater quality has to be maintained for drinking water purposes, or when overexploitation of groundwater 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 groundwater exploitation (Carruthers and Stoner, 1981).

(ii) Private sector development. The tremendous expansion in groundwater 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 over-exploitation 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 groundwater, 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.

Sustaining groundwater development

The key to sustainable groundwater development is to maintain a 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 groundwater resources.

Constraints to sustainable groundwater development

While groundwater 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 groundwater 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 get worse because there are too many separate channels of negotiations between donors and national agencies. By channelling 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 groundwater 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 groundwater 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 groundwater 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 groundwater can quickly become uneconomic. The example of farmers in the western United States pumping their own groundwater 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 groundwater 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.

Recovering the costs of groundwater development

It is important that beneficiaries of a groundwater scheme, be it private or public, understand that water can no longer be treated as a free commodity. 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 groundwater 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 groundwater 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 groundwater 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 plants. 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 groundwater, 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 groundwater for irrigation has become increasingly widespread, as mentioned earlier. 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 groundwater projects involving small farmers may entail simply a nominal fixed charge according to farm size. After basic needs are met, groundwater 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 groundwater 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 and revolving funds. When programmes are self-sustainable, more people can be reached, and the government is not faced with an increased 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 quantities entail higher costs. Water pricing on efficiency grounds can influence both the quantity and quality of groundwater 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 groundwater 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.

Private sector approaches

At the farmer or private sector level, a common response to over-exploitation of groundwater 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.

Government Measures to Promote Sustainable Development

Groundwater 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 groundwater mining may affect a whole region or country. In the United States, for example, 26 billion m^3 of non-renewable groundwater 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 groundwater 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.

Institutional measures

The government through its policies can have a direct impact on the type and intensity of groundwater 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 groundwater 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 groundwater 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 groundwater 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 groundwater 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 groundwater 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.

Pricing policy

The price of water must reflect its true value for highest use if conservation and the wise use of groundwater 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 increase a person's agricultural output and income, but it can also increase the value of his land disproportionately. The lucky farmers benefiting 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 becomes 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 groundwater 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 water and groundwater is intended. Economic efficiency will also be increased if quotas are transferable or exchangeable among users, or if the government 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.

Conclusions

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

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C. Some Economic Aspects of Groundwater Projects Executed by the United Nations in Developing Countries

(Dr. Robert E. Dijon)*/

Introduction

In the course of the last 25 years, the United Nations has been involved in the execution of some 150 projects for groundwater exploration, development and management in about 70 countries around the world. It is now appropriate to draw some conclusions on the economic aspects of these projects for the benefit of the international community. This paper will concentrate on the activities of the last 10 to 15 years.

In 1973, the first "oil-shock" changed considerably the perspectives of groundwater utilization, as the cost of a barrel of oil increased tenfold within two years, thus increasing costs of drilling and pumping. As a result, some countries changed their groundwater development policies, especially regarding large-scale irrigation, which was no longer economically feasible for crops of moderate market value such as cereals. It must be borne in mind that energy costs may constitute as much as 50 per cent or more of the cost of groundwater delivered at the pump, and that the cost of water for irrigation purposes cannot normally exceed one US cent per m^3 in conventional irrigation (flood or furrow type, according to United States, United Kingdom and Commonwealth sources). This was the case in the Philippines, where the idea of developing groundwater resources for rice irrigation was abandoned, while surface-water irrigation projects were given increased attention. Conversely, in the North China Plain, where groundwater is the only water resource available, some 800,000 pumping stations have continued to operate, yielding large amounts of groundwater for the irrigation of wheat and corn. Economic considerations were of little importance there when compared with the vital characteristics of the operation. Moreover, since the stations are primarily equipped with electric pumps, fueled by coal or hydropower, the oil-shock had little impact.

In the India peninsula also, large-scale groundwater irrigation continued for similar reasons. In oil and gas-producing Arab countries groundwater irrigation projects developed, limited by the availability and the quality of the groundwater resource. Since the purpose of these projects was to attain self-sufficiency in cereal production, economic considerations were largely forgotten.

In many developing countries and especially in Africa, the hopes of large-scale groundwater irrigation projects did not really materialize. In this connection, it is well known that agriculture is heavily subsidized in

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industrial countries. To maintain the prices of certain agricultural commodities at a level acceptable for farmers, large amounts of surplus products are purchased by governments, especially in Western Europe and in the United States. In Japan, rice is produced at a cost which is said to be several times that of California. In Saudi Arabia, agriculture is subsidized by the oil industry. The wheat produced near Riyadh, using sophisticated pivot-wheel irrigation technologies, is produced at a cost which is several times higher than current world market prices. On the other hand, in many developing countries agriculture is the main economic activity, and therefore cannot be subsidized. It must be self-supporting and, as a result, irrigation from groundwater sources can hardly be considered. There are, however, some notable exceptions, related to the production of high-value cash crops, including counter-season produce such as green vegetables, salads, green beans, tomatoes and also certain fruits, especially citrus. From this point of view, the areas bordering the Mediterranean basin, parts of California and Florida, and some parts of Central America, enjoy a prosperous groundwater irrigated agriculture. The main problems are the threat of depletion of groundwater reservoirs and the degradation of water quality.

Apart from irrigation, groundwater is mainly used for:

- Industry;
- Municipal water supply, including tourism and recreation; and
- Rural water supply, including cattle watering.

Industry is a major user of groundwater. In industrialized countries uses have emerged such as cooling water related not only to the industrial processes themselves but also to the operation of air-conditioners, and heat pumps. In France, some 30 years ago, the steel industry absorbed enormous quantities of groundwater, amounting to more than 50 per cent of the groundwater developed in the country, which resulted in depletion of the chalk aquifers in the North.

Municipal water supply systems are also major groundwater users, not only in arid countries. For example, the Hamburg metropolitan area, in the Federal Republic of Germany, uses mainly groundwater for municipal supply. Industrial and urban consumers can generally afford to pay a relatively high price for water. In fact, the production of raw water does not cost much if compared with treatment, storage, conveyance and the management of distribution systems. Groundwater which needs minimal treatment if any (mostly chlorination), has proved in many cases more economical than surface water.

Activities of the United Nations Department of Technical Co-operation for Development

As an agency of the United Nations family engaged in development activities in developing countries, the Department of Technical Co-operation for Development (DTCD), with few exceptions, has not been involved in projects dealing specifically with groundwater development for agriculture, industry and municipal water supply, which normally fall within the competence of other United Nations agencies. The Department's activities have been concentrated mainly in the following areas:

- Groundwater resources surveys, exploration, and assessment for multipurpose uses, as aspects of a natural resources inventory;

- Groundwater development for rural water supply, including water points in rangelands, mainly for drought relief operations;

- Maintenance and rehabilitation of wells and pumping stations; and

- Groundwater resources planning and management projects.

All of these activities have included the strengthening of government and other public organizations, the transfer of technologies and the training of personnel. Some economic aspects which emerged from these activities are presented below.

Surveys, exploration and assessment

Most of the groundwater projects which were carried out in the 1960s and the first half of the 1970s concentrated on these activities. Some examples from recent on-going or forthcoming projects are:

(a) Exploration of shallow groundwater: Djibouti, Timbuktu region, Mali, Nepal, Viet Nam;

(b) Exploration of deep groundwaters: Morocco;

(c) Monitoring and control of salinity: Qatar, Pakistan;

(d) Karst aquifers: Turkey;

(e) Water resources assessment and groundwater balance studies and modelling: the Northern China plain; three selected areas in the Republic of Korea; Islands of the Caribbean, of the Atlantic Ocean (Cape Verde), of the Pacific Ocean; Nubian sandstones (Egypt and Sudan) and Bangladesh;

(f) Cartography of groundwater resources: the Yemens, Zanzibar; and

(g) Artificial recharge in India.

The economic aspects of such projects were not overlooked. First, they were or are being carried out at the lowest possible cost; thus, the services of expatriate personnel have been minimized to a few man-months of high-level specialized expertise to advise countries such as Turkey, China and the Republic of Korea. Equipment inputs have been reduced to the minimum compatible with the requirements of the transfer of technology, using as much as possible equipment already available in the country and arranging for its rehabilitation (e.g., drilling equipment in Djibouti).

Second, a socio-economic component has been introduced into such projects in order to determine, after assessment of the water resources, what socio-economic benefits could be expected from groundwater development. For example, in the Timbuktu region, an agropastoral study was carried out in co-operation with FAO, while a similar study is to take place in the Sudan and Egypt within the framework of the "Nubian sandstone aquifer" project. In Morocco a preliminary economic feasibility study will be carried out on the development of deep groundwater resources which will be assessed in project areas.

The economics of water resources development and conservation in smaller islands of the Caribbean and the Pacific will also be closely examined.

Rural water supply

In 1973-74 a major drought struck sub-Saharan Africa. Since then, a number of drought crises varying in amplitude have occurred not only in sub-Saharan Africa, but also in East, Central and Southern Africa. The crisis of 1984, which affected in particular Ethiopia, Somalia and the Sudan, generated a vast solidarity movement around the world.

These crises demonstrated the vulnerability of traditional water supplies in the rural areas of Africa. In times of drought, surface-water supplies, such as natural or artificial ponds or alluvium water which depend directly upon rain, dry up. Traditional wells also dry up if, under normal circumstances, they contain less than one to two metres of water. The need for permanent water points unaffected by droughts therefore emerged as a priority to avoid loss of life and widespread migration to urban areas. The creation of reliable water points would make it possible to maintain populations in rural areas, and so preserve the social fabric of the countries concerned. In support of such policies, the United Nations has developed a number of rural water supply projects in several African countries, especially the sub-Saharan countries of Burkina Faso, Chad, Gambia, Mali, Mauritania, Senegal, Somalia, and the Sudan, as well as Benin, the Central African Republic, Guinea-Bissau, Liberia, Sierra Leone and Togo, and the Cape Verde and Comoros Islands. Many other donors and leading institutions have been involved in such operations in most African countries. New water points have been thus created by the thousands, according to two different concepts, as follows:

(a) The modern open, large diameter concrete-lined dug well, is excavated by machines, or "by hand", but in this case through the use of mechanized derricks, jackhammers and explosives. Such wells hold four metres of water or more and can last for centuries. Water can be extracted by hand. The major drawbacks are their vulnerability to pollution if they remain open, the slowness of construction (at a rate of 0.25 to 0.40 metre per day), and the high cost.

(b) The drilled "tubewell" can be completed in one or two days at depths exceeding that of water static levels of 10 to 20 m or more. The main drawbacks of tubewells are the relative fragility of the pumps, whether mechanical or hand-powered, their vulnerability to corrosion, collapse of the casing, and wear and tear, as well as breakdowns due to mishandling. Indeed, the main problem is to keep the hand pumps, which are now a common feature of the rural landscape of Africa, in working condition. The life expectancy of such pumps is about 10 years at most; repair and replacement of this equipment is in a number of cases beyond the financial means of the local population and governments.

A rural water supply project in Africa is in most cases relatively costly. The lowest investment costs are found in countries such as Rwanda and Burundi, where minor works to improve the yield of small springs amount to a few dollars per capita. Conversely, the cost of an 80-metre tubewell in hard rock expected to supply some 200 people is now in the range of $US 12,000, with annual recurring costs amounting to 10 per cent or more of this amount. In rural areas of the sub-Saharan belt, the average per capita annual income may be in the range of $US 100 or less.

The situation is even more critical in areas where groundwater is to be reached at sizable depths and where mechanically powered pumping installations are needed. In many areas of Somalia, groundwater is not reached at less than 150 to 200 m, and static levels are more than 100 m deep. The cost of a tubewell equipped with a submersible pump and a generator capable of delivering 10 to 20 m^3 per hour is in the range of $US 100,000.

In the execution of rural water supply projects, the United Nations has attempted to reduce the costs through the following:

(a) Africanization of technical personnel: the expatriate expert component has been reduced to a minimum; the professional capability of African technicians has been upgraded through in-service training and fellowships abroad. A school for water-well drillers is being established; and

(b) Savings in equipment costs, through the use of lighter drilling rigs, and pumps manufactured in developing countries, especially in Africa, such as the "India Mark II" pump, which is now manufactured in several countries including Mali, and by means of improvement in the maintenance and repair of equipment, especially the pumps.

Besides the health and social benefits derived from rural water supply development, the evaluation of the economic benefits of such development is another aspect being examined. Particular attention is being given to the economic feasibility of small-scale irrigation projects in the vicinity of village pumps.

Major bilateral and international funding institutions give consideration to small-scale groundwater irrigation projects, which aim to increase food production and improve nutrition, and by raising income may finance in part rural water supply systems, especially in Africa. However, the economic feasibility of such projects depends on a number of conditions, such as groundwater at shallow or moderate depth; acceptable water quality; good soils; adequate climatic conditions; and favourable market conditions for the crops.

Maintenance and rehabilitation of wells and pumping stations

In some of the least developed African countries, the United Nations has provided assistance in the operation, maintenance and rehabilitation of motorized pumping installations. This has involved: the training of pump operators, as in Somalia; the rehabilitation of pumping stations which have been damaged or destroyed, or which had fallen into a state of disrepair, such as in Chad and southern Sudan; and organization of a service for the operation and maintenance of pumping stations in remote areas of Mauritania, including the delivery of fuel. In Malawi, a project team was organized and provided with equipment to clean tubewells clogged with fine sand.

Normally, the maintenance of equipment, including its replacement after amortization, and the supply of spare parts, and its operation, including the supply of fuel, are the responsibility of the countries concerned, at the government or local community level. The few cases in which the United Nations has been involved in such operations were basically emergency or humanitarian in nature and cannot be considered significant in economic terms.

Nonetheless, it appears as if the maintenance, and even the operation of some installations, not to mention the creation of new water points, are beyond the means of certain areas in some countries. Conversely, as far as village hand pumps (or foot pumps, or animal-powered pumps) are concerned, great progress has been made. By and large the population has taken charge. The service of competent mechanics are available in many villages, and the populations are willing and able to buy the necessary spare parts. However, the purchase of replacement pumps after a few years may not be so feasible if resources at the village level do not increase significantly. The cost of a pump may be equivalent to the per capita income of half a dozen people for one year, and its relative importance for the village is even greater in proportion to the effective cash flow.

Groundwater resources planning and management

With the ever-increasing number of water projects in Africa, especially rural water supply projects benefiting from the assistance of many international, bilateral and non-governmental organizations, the need for rational, long-term planning and for co-ordination of activities for on-going projects is imperative. The United Nations has entrusted the Department of Technical Co-operation for Development with the task of formulating and executing projects aimed at the preparation of water policy guidelines and preliminary master plans for water development. Countries in which such projects had been initiated as of 1987 were: Benin, Burkina Faso, Cape Verde, the Central African Republic, Guinea-Bissau, Mauritania, Niger, Mali, and in the Caribbean, Haïti and Jamaica.

In general, the projects are centred around the organization of data banks, including such categories as: potential water resources, water needs (at the level of villages), and existing water points with their hydrological characteristics and priority needs to be met. These listings can be interlinked, thus allowing an identification of future actions needed or desired. The basic elements of future projects can therefore be identified almost instantly through the computer.

The projects also assist inter alia, in the collection of data, monitoring of groundwater levels, assessment of water resources, and preparation of sectoral reports on water resources, water uses and water technologies; identification of socio-economic aspects of water projects; training of personnel; preparation of water planning exercises; drafting of water legislation; and co-ordination of activities of various water agencies. The final aim of such projects is to improve the efficiency of water programmes by reducing delays in implementation, risks of overlapping, investment and recurring costs, and eventually the cost of water delivered at the pump or well.

All such projects are in their earliest stages of implementation, and no conclusions have been drawn yet regarding the economic aspects, that is, how and to what extent water costs can be reduced.

Conclusions

Considering the nature of the projects in which the United Nations is involved, mainly in the least developed countries, no far-reaching conclusions may be drawn from them in strict economic terms and from a global perspective. However, two major observations emerge.

First, the supply of water to communities on the edge of survival and settled on the fringes of deserts cannot be weighed only in economic terms. A parallel situation exists for education and health for which a benefit/cost ratio cannot be established through orthodox economics. If the provision of basic water supplies helps to maintain the population in its ancestral lands, where some local resources such as arable soil and rangeland are still available, then a massive exodus, uprooting and destitution under subwelfare conditions can be avoided or at least slowed down: large tracts of land will not be abandoned. Eventually, some economic benefits will result, and major losses will be avoided.

Second, while the benefit/cost ratio cannot really be ascertained, it can be substantially reduced if costs are reduced. In this respect, investigations have to be kept to a minimum while a high degree of efficiency is acquired through the use of adequate technology and methodology; local human and physical resources must be utilized to the fullest extent possible. The same considerations need to be applied to well construction equipment and methods, and to groundwater extraction devices. Considerable success has been achieved along these lines in Africa in recent years, especially in United Nations-assisted projects. Also, it is most important to keep equipment in good operating and working condition, and to have adequately planned projects which fit into a rational master plan for water resources development, if a satisfactory level of economic development is to be attained and maintained.

In the United Nations family of agencies, it is the Department of Technical Co-operation for Development (DTCD) which carries out most of the activities related to economic planning and groundwater exploration and development.

It was therefore appropriate for DTCD to help in the organization of this Symposium and to try to go beyond the limited scope of its operational activities consisting of groundwater projects fielded mainly in the least developed countries. Through the action of the Organizing Committee and the contributions of Spanish professionals in this venture, the co-operation of the Government of Spain -- a country in which groundwater development has for centuries been given much attention -- has proved extremely helpful.

Annex IV

SUMMARY OF PAPERS PRESENTED BY PARTICIPANTS FROM DEVELOPING COUNTRIES

ANGOLA:

Groundwater situation in Angola (A. G. de Araujo)

In Angola there is a definite need to prepare a national plan for groundwater development. In the arid southwest it is essential to identify priorities due to the insufficient capacity of Government services for groundwater development. There is a lack of qualified personnel. Thus far, rural water supply operations have been carried out on a humanitarian basis, irrespective of costs. A "groundwater brigade" was first constituted in the late 1940s and wells were delivered as a free service. It is therefore difficult nowadays to convince the villagers that they have to support at least part of the costs of the wells and pumps provided by the Government (National Groundwater Company, "Hydromina"), while these costs are steadily increasing.

The influx of refugees from Namibia and the increasing number of displaced nationals fleeing the areas affected by the civil war have resulted in the multiplication and swelling of refugee camps where water is to be supplied on an emergency basis, mainly from groundwater sources. This situation has developed on the fringe of the Kalahari Desert and has contributed to the degradation of fragile ecosystems -- forest, rangeland, soils -- as a result of the drought of the last five years.

Groundwater exploitation brigades operate mainly in the three districts located in the southwest. A number of water installations have been destroyed as a result of the civil war.

BANGLADESH:

Report on groundwater economics in Bangladesh (A. Karim)

In Bangladesh, groundwater costs are US 5 cents ($0.05) and US 1.6 cents ($0.016) per cubic metre, respectively, for irrigation and rural water supplies. It has been proven that groundwater development for various uses is economically viable, especially for irrigation during the dry season from November to April. Several types of wells are in use, but most are 30 to 60 m deep. There are also 20,000 tubewells reaching down to 100 m and yielding up to 90 litres/second, in addition to the 65,000 shallow motorized tubewells and a great number of manually operated tubewells for irrigation (MOSTI). The average cost of a deep tubewell is $US 20,000. Maintenance and operation costs average $US 3.25 per year (16 per cent), including depreciation, for 1,000 hours of pumping yielding 204,000 m^3.

The cost of a shallow tubewell is in the range of $US 2,000; the cost of a MOSTI is about $US 150. MOSTIs have a lifespan of three to five years. Water cost is in the range of US 1 cent/m^3.

CHINA:

Development and utilization of groundwater in China (Lierong Li)

In China, some 600 billion m^3 of groundwater are extracted every year, mainly in the northern plains. Measures are being taken to optimize groundwater development and lower costs, especially by means of defining well spacing, selecting adequate well sites and depths, and assessing adequate pumping rates. Considerable efforts are exerted for groundwater development, planning and protection.

COSTA RICA:

Plan de desarrollo proyecto piloto Zapandi Guanacasti-Costa Rica (E. Fernández)

This groundwater project covers an area of 500 ha. Irrigation water is supplied by 20 wells 30 to 60-m deep and yielding 15 to 100 l/s, allocated to individual farms and co-operatives which represent a total of 212 beneficiaries. The project is in its first phase of implementation. It was developed by "SENARA" (National Services for Groundwater, Irrigation and Drainage), in its first step of implementation, at a total cost of $US 1 million, of which 40 per cent is expected to be recovered during an amortization period of 20 years.

CUBA:

Prospection and development of coastal karst aquifers; Economic importance of planning groundwater use in Cuba (L. A. Barreras Abella)

In Cuba, considerable efforts have been made in the last 28 years in the field of groundwater exploration and development. It is estimated that 90 per cent of groundwater resources of the country occur in karst formations, especially in coastal areas where they are vulnerable to sea-water intrusions. Karstic water is also exposed to pollution occurring from the surface through the infiltration of domestic and industrial waste water. In Cuba, water management is handled by the Institute of Water Economy of the Ministry of Construction.

Artificial recharge schemes have been successfully implemented in Cuba, although karstic aquifers do not represent the best hydrogeological environment for such operations. Groundwater resources are diversely affected by various natural calamities, such as hurricanes and droughts (since 1987, rainfalls have amounted to 17 per cent less than average).

Co-operation between groundwater specialists and economists has so far been quite limited. To date, groundwater development has occurred mainly under the pressure of social and political imperatives. Be that as it may, it appears that the benefit/cost ratio of past projects is acceptable, if not favourable.

ECUADOR:

Groundwater in Ecuador (F. Larrea Naranjo)

Groundwater conditions are varied in Ecuador, a country of sharp topographical, geological and climatic contrasts.

This paper presents a number of formulas for the calculation of investment costs, amortization, operation costs (on a yearly basis), water pumping for urban water supply, and eventually total costs.

The cost of an alternative source of surface-water supply involving water treatment is not considered as such, since it does not present a sufficient guarantee of permanent supply.

The courses of water supply for the metropolitan area of the capital, Quito, are briefly described.

EGYPT:

Groundwater economics in Egypt (Drs. K. Hefny and S. M. Farid)

Up to 5 billion m^3 of groundwater produced through induced recharge from the Nile waters are available in the Nile valley and its delta. Fossil groundwater is also available in the desert from the Nubian sandstone aquifer, one of the major aquifers of the world.

Groundwater is used for irrigation to supplement surface-water supply in the summer months. Careful water management allows for an improvement of the quality of Nile water in the delta area.

Some 3,000 new tubewells will be constructed in the years 1988-1993. By the year 2000, the development of groundwater will have reached its full potential of 5 billion m^3 (present extraction is about 2.2 billion), through implementation of a management plan now under preparation by the Government.

Policies for groundwater extraction in desert areas are yet to be established. In most areas, it may be hundreds of years before the economic limit of extraction is reached.

Economic studies on groundwater development can be undertaken only if adequate information on groundwater systems is available and if aquifer response to different development methods can be determined in advance.

The approach to the exploitation of well-fields for irrigation is very different from that followed when well-fields are used for drainage and community water supply. Regarding the design of well-fields, the presence of cones of depression is favoured to facilitate drainage, but these are avoided in other cases.

The cost of a well-field (73 wells: diameter, 600 m, discharging 200 to 300 m^3/hour each) in upper Egypt is in the range of $US 600,000. Expected life span of the well is between 20 and 30 years, and 10 years for the pump.

Annual maintenance costs are estimated at one per cent of capital cost for the well, and three per cent for the pump and related equipment.

JORDAN:

Water resources and production in Jordan (Dr. Abdul Aziz Washah)

The occurrence of both surface and groundwater resources is recognized. The Water Authority of Jordan is responsible by law to supply water to the urban and rural community. It is estimated that 99 per cent of the population will benefit from adequate supplies by 1990. The average water production is in the range of 300,000 to 450,000 m^3 per day. Water production for all uses (municipal, irrigation, industry, etc.) amounted to 500 million m^3 per year in 1986. Projections are for 900 million m^3 in 1990, and 1.2 billion m^3 by the year 2000, by which time all available conventional sources of water will have been developed.

Sound management of water resources is needed.

REPUBLIC OF KOREA:

Potential of groundwater in Korea (Dong Woo Lee)

In Korea, groundwater is developed for municipal, industrial and irrigation purposes. Groundwater in storage has been assessed at approximately 400 billion m^3 per year. At the present time, about 1.2 billion m^3 of groundwater is consumed every year.

Surface water consumption is about 14 billion m^3 yearly, of which nearly 70 per cent is used for irrigation.

It has been determined that water pumped for boreholes is less costly than water pumped from large-diameter wells.

MALTA:

Aspects of water problems in the Maltese Islands (E. Spiteri Staines)

Malta is one of the most densely populated countries in the world (1,000 inhabitants per km^2). Water supply is secured by groundwater sources supplemented by desalination. Intensive pumping and drainage through a network of galleries have depleted the aquifers and induced salinization. From 1966 to 1986, groundwater development through drainage galleries, boreholes and springs increased the water supply from about 15.5 million m^3 per year to about 21 million m^3, with the share of borehole water alone increasing from 10 to nearly 30 per cent.

Cost of water production from boreholes is in the range of US 22 to 25 cents per cubic metre. This cost is to be compared with that of reverse osmosis water, which is $0.75, and flash distillation water, which costs $1.17.

Distribution costs amount to $1.23 per cubic metre.

MEXICO:

Evaluación técnico-económica de diferentes fuentes subterráneas y superficiales de suministro (S. Moreno-Mejia)

The city of Mexico is supplied mainly by means of local groundwater, as projects involving the transfer of water from other basins are very costly. At present some 3.8 m^3/s are extracted from 820 wells and 60 springs located to the southwest of the Federal District. In addition, surface waters are taken from Río Cutzamala, outside the basin of "Valle de México". The population of the Federal District at present exceeds 10 million, of which 97 per cent are served by house connections. It is estimated that during the period 1990-2000, some 10 m^3/s of additional resources will have to be mobilized. Meanwhile, water levels will be lowering: about 0.5 m per year to the north and northeast, 0.2 m in the city area, and about 1 m in Xochimilco. In addition, groundwater pollution and subsidence (up to 2.5 m in the last 10 years to the southeast of the city) are occurring.

A number of technical regulatory and legislative measures have been taken to protect the resources. Several plants for the treatment of used water will be constructed, and several projects for the transfer of water from neighbouring basins are being studied.

Analyses of cost effectiveness are prepared on the basis of various criteria, taking into account health and environment, technological, political and social factors.

MOROCCO:

Quelques aspects économiques de l'eau souterraine au Maroc (M. Azili)

In recent years groundwater development has intensified due to an increase in water demand and a succession of dry years. In the meantime, groundwater levels have dropped significantly in many areas (up to 3 m per year). The total number of boreholes drilled per year is in the range of 700 units. Distribution by use is as follows: 65 per cent for rural water supply; 10 per cent for urban water supply; 8 to 10 per cent for irrigation; and about 15 per cent for reconnaissance and studies.

In Morocco, amortization periods considered in economic calculations are 20 to 25 years for wells and boreholes, and 10 years for pumps. Groundwater costs at the well are in the range of:

US 5 cents per cubic metre (year 1985);
US 3 cents for energy costs (60 per cent of cost); and
US 2 cents for maintenance and amortization costs.

Energy costs are higher for yields under 20 litres per second (70 per cent).

From 1980 to 1985, costs have more than doubled. The demand in community water supply for the 95 main urban areas, which amounted to 580 million m^3 in 1982, will now exceed 1.7 billion m^3 by the year 2000. The share of surface water will increase, as groundwater is already overexploited in several areas. As a result, water costs will increase. The cost of municipal water, which is in the range of US 65 cents per cubic metre, may well reach $1.1 as per on-going studies regarding the use of surface water.

The cost of irrigation water (surface water) varies widely from one region to another: about US 10 cents in the north, and US 35 cents per cubic metre in the south.

It is considered that irrigation is no longer economical for various crops if it exceeds the following values:

Cereals	US 14 cents
Citrus	US 17 cents
Vegetables	US 10 cents

MOZAMBIQUE:

Groundwater exploitation in the area of Maputo (E. H. Smidt, I. I. Chutumia, P. Haao, N. M. Egidio)

Water delivered to the supply system of Maputo (population 1 million, as opposed to 400,000 at the time of Independence) amounts to about 3,000 m^3/h of surface water and 1,200 m^3 of groundwater. Salt-water intrusion is a major threat to groundwater resources in the area. A hydrogeological mathematical model has been devised to evaluate the effect of increased pumping rates (25, 50, 100 and 200 per cent). It has been determined that up to 50 per cent, the effect on drawdown and salinity remains moderate, while an increase of 100 per cent would rapidly decrease the availability of fresh groundwater resources in the area.

Several emergency well-fields were drilled near Maputo between 1984 and 1987 to make up for a temporary breakdown of the surface-water supply system. No economic analysis has been made so far. A groundwater irrigation scheme has been developed in the coastal belt 30 km north of Maputo. Groundwater costs per cubic metre vary from US 28 cents per cubic metre to US 50 cents per cubic metre depending on the type of intake (tubewell, dug well, water point).

A study has been made by a consultant to determine the most economic ways to develop additional sources of water, as an additional supply of 5 500 m^3/h will be needed by the year 2000. The cost of water production ranges from US 11 cents per cubic metre (2,200 m^3/h groundwater system Mahotas-Pateque) to US 26 cents, pumping in the Incomati River (Corumane dam).

Additional studies are needed to define groundwater policies in the Maputo area, and to determine the costs of various alternatives for water resources development, both for the city and for the surrounding agricultural areas.

SENEGAL:

Experience gained in Senegal in groundwater benefits (M. Lakh)

In Senegal, several years of drought have resulted in the lowering of the level of groundwater and the progress of sea water inland along the river courses. A Ministry of Water was created in 1981.

Water needs for the Dakar metropolitan area are steadfastly increasing. It is estimated that between 1980 and 2001 average and peak demands will have increased more than fourfold, as water availability has a tendency to decrease in proportion (nowadays, needs are covered up to 71 per cent).

It is unfortunate to note that in the Dakar area water supply system, 28 per cent of the water entering the system is lost. About 30 per cent of the population get water at home and pay water bills. Some 50 per cent obtain water from municipal standposts -- water bills being paid by municipalities. The last 20 per cent take water from wells or from water merchants selling water from carts.

For socio-political reasons, the price of water is maintained largely below cost, which prevents the Water Authority from finding the internal and external financing necessary for the rehabilitation and expansion of the present system.

In rural areas the fact that water is provided free of charge has encouraged the waste of water and resources. A tariff policy will have to be initiated.

TANZANIA:

Groundwater resources development in Tanzania -- Economics in perspective (George M. Kifua)

In Tanzania, inexpensive geophysical surveys, especially resistivity and magnetic surveys, greatly improve the rate of success of water-well drilling in crystalline rocks, thus reducing groundwater costs.

Less costly technologies in well construction are being utilized to the fullest extent possible, particularly in the construction of shallow wells. Cost recovery and community participation are embodied in most projects.

THAILAND:

Expenditures on groundwater development in Thailand (C. Chuamthaisong)

There are more than 20,000 privately owned tubewells in Thailand, mainly for rural water supply and small-scale agricultural use.

In the Bangkok area, about 1.35 million m^3 are pumped every day, including 0.37 for domestic use, 0.72 for industrial, and 0.25 for irrigation purposes, from a total of nearly 10,000 wells.

At present, drilling costs average $US 68 per metre. Ninety per cent of wells drilled by Government agencies in rural areas are fitted with hand pumps costing about $US 150. Operation costs, in the amount of US 4 cents per cubic metre, are paid for by the villagers. Yearly maintenance costs are about $US 60 for hand pumps and $US 75 for small submersible pumps.

It has been observed that groundwater recharge has diminished as a result of deforestation. Pollution by mining residues, and the occurrence of pesticides and fertilizers in the environment are steadily increasing. Operation and maintenance costs in (shallow) groundwater irrigation projects are estimated at $US 80 per hectare (since energy costs are subsidized, they do not exceed US 5 cents per cubic metre pumped).

A "Ground Water Act" went into effect in 1978. The cost of water for individual tubewells is low, as compared with the price charged at the tap by the Water Authority (16 cents per cubic metre, soon to double). The Act, which is now in application in the Bangkok metropolitan area, is expected to be extended to other major cities where heavy pumping is practised.

In rural areas, some 50,000 tubewells have been constructed by the "National Potable Water Project" (NPWP). Yearly requirements for the future are 6,000 tubewells. Maintenance costs are high because of the diversity of pump types.

Costs for fitted and shallow wells are low.