TCD/SEM.83/1

UNITED NATIONS

DEPARTMENT OF TECHNICAL CO-OPERATION FOR DEVELOPMENT

TECHNICAL CO-OPERATION AMONG DEVELOPING COUNTRIES IN GROUNDWATER RESOURCES DEVELOPMENT

Report of a United Nations International Colloquium
convened in co-operation with the Government of Yugoslavia

Zagreb, Yugoslavia
23-28 May 1983

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UNTCD83
ISN 28729

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CONTENTS

Page

INTRODUCTION 1

I. SUMMARY OF PROCEEDINGS 3

II. INTRODUCTORY PAPERS 5

III. THEME A: GROUNDWATER EXPLORATION AND ASSESSMENT TECHNOLOGIES 8

A. Lectures 8

1. Surface Technologies: "Remote Sensing in Groundwater Investigations," by Marinko Oluić (Lecture 1) 8

2. Surface Technologies: "Geophysical Methods in Groundwater Investigations," by Stjepan Kovačević (Lecture 2) 10

3. Subsurface Technologies: "Groundwater Exploration and Assessment Technologies," by Čedomil Plazek and Žejko Zagorac (Lecture 3) 13

B. Working Group Meetings (discussion and proposals).... 15

IV. THEME B: GROUNDWATER EXPLORATION AND ASSESSMENT METHODOLOGIES 19

A. Lectures 19

1. "Reconnaissance Report of Hydrogeological Investigations," by Božidar Biondić (Lecture 4) 19

2. "Detailed Groundwater Investigations," by Darko Mayer and Pavao Miletić (Lecture 5)........ 20

B. Working Group Meetings (discussion and proposals).... 21

V. THEME C: GROUNDWATER DEVELOPMENT 24

A. Lectures 24

1. "Well and Pump Technologies," by Robert G. Thomas (Lecture 6) 24

2. "Groundwater Project Concept and Design," by Boris Švel (Lecture 7) 25

CONTENTS (continued)

Page

3. "Children, Mothers, and Others: the Social Aspects of Groundwater Use," by Martin G. Beyer (Lecture 8) 27

4. "Participation of Women in the Development and Use of Water," by Vida Tomšič (Lecture 9) 28

B. Working Group Meetings (discussion and proposals) .. 29

VI. THEME D: GROUNDWATER MANAGEMENT 35

A. Lectures 35

1. "Protection and Conservation of Groundwater Resources," by Robert G. Thomas (Lecture 10).... 35

2. "Institution Building and Training in Groundwater Exploration and Development," by Robert Dijon (Lecture 11) 37

3. "Operation and Management of Groundwater Schemes," by Martin G. Beyer (Lecture 12) 40

4. "National Water Policy and Groundwater Management: the Institutional Dimension," by Enzo Fano (Lecture 13) 41

5. "Legal Aspects of the Protection of Groundwater Resources in Yugoslavia," by B. Petrik (Lecture 14) 43

6. Statement by Ricardo Acosta 44

B. Working Group Meetings (discussion and proposals).. 45

VII. ROUND TABLE MEETINGS: RECOMMENDATIONS AND PROPOSALS... 51

Annexes

I. LIST OF PARTICIPANTS 55

II. PROGRAMME OF THE COLLOQUIUM 77

III. SUMMARIES OF COUNTRY PAPERS 81

A. Bangladesh 82

B. Bermuda 84

CONTENTS (continued)

Page

III. SUMMARIES OF COUNTRY PAPERS (continued)

C. China 87

D. Cyprus 89

E. Egypt 91

F. Fiji 94

G. Ghana 95

H. India 98

I. Indonesia 102

J. Iraq 103

K. Jamaica 104

L. Korea (Republic of) 106

M. Libya 107

N. Mali 109

O. Mexico 111

P. Pakistan 112

Q. Thailand 115

R. Tunisia 118

S. Turkey 119

T. Venezuela 121

U. Yemen Arab Republic 123

V. Yugoslavia 124

W. Zambia 127

Table

1. Annual Groundwater Extraction and Potential in Egypt, to the Year 2000 (Preliminary Figures) 93

INTRODUCTION

The International Colloquium on Technical Co-operation among Developing Countries in Groundwater Resources Development, 23-28 May 1983, Zagreb, Yugoslavia, represented a contribution to the International Drinking Water Supply and Sanitation Decade, 1981-1990 (JDWSSD) and to the United Nations Programme for Technical Co-operation among Developing Countries (TCDC). 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, and the Secretary-General of the United Nations and Directors General of the United Nations organizations most directly affected.

The purpose of the Colloquium was to bring together the expertise available in developing countries with a view mainly to furthering technical co-operation among the developing countries in the development of groundwater resources to provide drinking water in rural areas. The goal of the Decade is to promote action by governments which will ensure that the world's population has access to adequate sources of water and adequate sanitation by the year 1990. The urgency of providing drinking water is underscored by the estimate that 78 per cent of the world's rural population in developing countries does not have access to adequate drinking water resources.

It was the vital importance of this subject that led to the sponsorship by the Government of Yugoslavia, through the Centar za Vode (Centre for Water), and by the United Nations Department of Technical Co-operation for Development, of the International Colloquium held in Zagreb, Yugoslavia, from 23 to 28 May 1983, with participation by representatives from developing countries as well as developed countries, United Nations specialized agencies, and Yugoslavia itself.

Focusing attention upon the primary challenges in the development of groundwater resources which TCDC can help to meet, the Colloquium dealt with four major themes and was concluded with a round table discussion. While the participants reached a number of conclusions regarding TCDC's role in the development of groundwater resources, as detailed in this report, particular emphasis was given to the collecting and dissemination of information. The participants unanimously agreed that the establishment of national, subregional, regional, and international information networks on groundwater resources development represents an obligatory first step for any future co-operation involving such activities as research, training, consultant services, standardization of services and equipment, planning, and management.

The majority of participants agreed that the existing Centar za Vode could become an international institution for collecting and transmitting selected information. The Economic and Social Council in its Resolution 1983/57 welcomed the conclusion of the colloquium at the Centre for Water in Zagreb on support for establishment within this Centre of a small international technical unit dealing with technical co-operation among developing countries in the water resources sector.

The United Nations expresses its deep appreciation to the Government of Yugoslavia and the Centar za Vode for their administrative, substantive, and financial support to the Colloqium, and for the gracious hospitality provided.

I. SUMMARY OF PROCEEDINGS

This report summarizes the activities of the International Colloquium on Technical Co-operation among Developing Countries in groundwater Resources Development, 23-28 May 1983.

The opening session was addressed by Dr. Ivo Margan, Vice-President of the Federal Executive Council, Federal Socialist Republic of Yugoslavia; Mr. Marijan Cuculić, President of the Committee for Foreign Affairs of the Socialist Republic of Croatia, Chairman of the Council of the Associated Organization of the Centar za Vode; Mr. Aleksandar Varga, President of the Zagreb City Assembly; Mr. Khalil Othman, UNDP Resident Representative in Yugoslavia, Belgrade; and, Mr. Vladimir Baum, Director, Natural Resources and Energy Division, Department of Technical Co-operation for Development, United Nations.

The co-directors of the Colloquium were Mr. Vjekoslav Makovac-Dijak, Centar za Vode; and Mr. Enzo Fano, Deputy Director, Water Resources Branch, Natural Resources and Energy Division, Department of Technical Co-operation for Development, United Nations.

Mr. Robert Dijon, Interregional Adviser (Groundwater), Department of Technical Co-operation for Development, United Nations, acted as Rapporteur of the Colloquium and Mr. Ante Ferencić, Advisor, Chamber of Economy of the Socialist Republic of Croatia, acted as General Secretary of the Colloquium.

The Colloquium dealt with four main themes:

Theme A: Groundwater Exploration and Assessment Technologies (surface and subsurface technologies)

Theme B: Groundwater Exploration and Assessment Methodologies (reconnaissance investigations; detailed investigations)

Theme C: Groundwater Development (well and pump technologies; project concept and design), requirements and participation of populations, particularly women and children)

Theme D: Groundwater Management (protection and conservation of groundwater resources; institution building and training; operation and management of groundwater schemes; national water policy and groundwater management)

Activities during the Colloquium included:

(a) the presentation of papers by rapporteurs from the Centar za Vode, United Nations organizations, and other organizations on the four main themes, the presentation on each theme being followed by discussions held in working groups;

(b) the presentation of country papers by participants from various countries;

(c) a round table on mutual co-operation among developing countries, including bilateral and multilateral arrangements institutional and organizational forms; binational or multinational enterprises (joint consultation in design, co-production); joint purchase of equipment; standardization of equipment, maintenance, services; guidelines for water policy and planning; and financing of joint activities.

In addition to the technical sessions, other activities organized in the course of the Colloquium included visits to the various organizations that are members of the Centar za Vode; the presentation of films; and a one-day study tour to the Plitvice National Park and the adjacent Adriatic karstic area.

Summaries of the papers presented during the Colloquium, of the discussions during working group sessions, and of the round table meetings that concluded the Colloquium, are given below. The participants in the Colloquium are listed in Annex I; the Programme is given in Annex II; and the country papers are summarised in Annex III.

II. INTRODUCTORY PAPERS

1. "The Role of TCDC in Groundwater Management," by Dr. Slavko Komar

In his opening remarks, Dr. Komar, Member of the Council of the Federation of the Socialist Federal Republic of Yugoslavia and President of the Scientific Council of the Institute for Developing Countries, stressed the importance of groundwater development in the world and the need for developing countries to achieve a certain level of collective self-reliance in this field through technical co-operation.

The development and management of groundwater resources is a most appropriate field for the activities of the United Nations Programme for Technical Co-operation among Developing Countries (TCDC), he said, groundwater resources play a steadily increasing role in economic and social development, as a result of urbanization, industrialization, and expanded use of irrigation in developing countries.

The TCDC programme is intended to create a framework for co-operation among developing countries, in an open-ended and flexible system. It represents the exchange of experience and skills between two or more developing countries with the support of developed countries and international organizations.

The expression "technical co-operation among developing countries" was officially referred to for the first time in Resolution 2974, of 14 December 1972 during the 27th General Assembly. In May 1974 a working group of 19 nations offered a concept and objectives for TCDC; its report was embodied in Resolution 3251, of the General Assembly 13 December 1974, which decided further in December 1976 that a United Nations conference on TCDC would be convened in Buenos Aires, Argentina.

The Conference adopted a plan of action which stressed that TCDC activities should be supported by developed and industrialized countries, because of their interdependence with developing countries.

The main purposes of TCDC are (a) to further collective self-reliance; and (b) to increase and improve communication among developing countries, leading to a greater awareness of their common problems.

TCDC projects are to be implemented through the sharing of experience, the exchange of know-how, and the transfer of resources, knowledge, and/or technology.

In the field of groundwater resources development and management, TCDC is concerned not only with technical matters but also with a wide range of social issues, such as community participation in the use and management of groundwater, through the mobilization of human resources and through training programmes.

Adequate results may often be achieved through relatively simple technological means, requiring relatively low investment, and through labour-intensive projects.

In conclusion Dr. Komar expressed his conviction that the Colloquium represents a useful contribution to close co-operation among developing countries, not only in the development and management of water resources, but also in the realization of wider goals of social and economic development.

2. "Introduction to TCDC in the Groundwater Sector," by Enzo Fano

In his introductory remarks, Mr. Fano, Deputy Director, Water Resources Branch, Natural Resources and Energy Division, Department of Technical Co-operation for Development, United Nations, New York, defined the role of the United Nations in TCDC.

He recalled that the concept of TCDC went beyond the sharing of skills and information among the developing countries; also embodied the transfer of expertise from developed countries to developing countries according to the requirements of the recipient states, and the transfer of financial resources from international financial organizations and other donors for activities leading to the most efficient applications of this expertise given the financial, economic, and institutional conditions existing in the recipient states. The United Nations, through its Department of Technical Co-operation for Development, can be a facilitator of the exchange of information, bringing together countries which have experiences to share, making available data on the effectiveness of various technologies, and pointing out the relative advantages of one or another type of management structure. Moreover, it can serve as a guide in establishing training programmes, or undertake training programmes itself, as required.

In short, the United Nations can be viewed not only as a provider of technical co-operation from multilateral sources, but as an actual partner in the TCDC process, willing to share its 25 years experience in water resources management in developing countries. The United Nations is also able to work with donors in channeling their special skills, expertise, and technologies to specific groundwater programmes in the developing world; to utilize effectively the funds entrusted to it for water resources activities; and to work with or on behalf of financing organizations to identify the speediest and most productive solutions to the problems of the International Drinking Water Supply and Sanitation Decade.

III. THEME A: GROUNDWATER EXPLORATION AND ASSESSMENT TECHNOLOGIES

A. Lectures

1. Surface Technologies: "Remote Sensing in Groundwater Investigations," by Marinko Oluić (Lecture 1)

In his lecture, Mr. Oluić stressed that remote sensing is achieved by means of cameras, scanners, or radar, which may be mounted on aircraft or satellites and which record electromagnetic radiation. (This excludes the electromagnetic and gravity surveys that measure "force fields," as used in geophysical surveys.) Remote-sensing sensors can be classified as "passive" that is, those that measure the electromagnetic waves emitted by the objects observed, as cameras and scanners do, and "active" --systems that emit waves which rebound from their object and are received back at the source. Radar is an example of the "active" type of sensor.

Remote-sensing techniques have been successfully used in hydrological studies: outlining the extent of surface water; tracing geologic structures and lithological and geomorphic features that would indicate possible sources of groundwater; and measuring the temperature of surface water. Through the use of such methods, large areas can be examined in a short period of time.

Remote sensing should be the first technique used in the investigation process, although it can also be applied later in combination with other methods. It must be remembered, however, that remote sensing is only one useful tool, and there are others; other investigative methods should not be excluded.

In practice, satellite images--particularly those of the Landsat series--are analyzed in the reconnaissance phase in order to obtain a preliminary assessment of groundwater resources. This analysis can show geologic, geomorphologic, structural, hydrogeological, and geobotanical features that might indicate the presence of water, such as sedimentary basins, folds and faults, and geomorphologic units. By identifying and interpreting such features, basic information on the occurrence of groundwater can be obtained. In interpreting satellite images, many hydrogeological relationships can be found which would be difficult--or at times impossible--to identify using ordinary methods of data gathering.

Although much of the imagery can be interpreted by visual examination, additional interpretation is possible using a computer.

While the use of satellite images permits the analysis of broad-scale regional data, aerial photographs should be used to study local structures in greater detail. Medium- and large-scale aerial photographs assist in detecting occurrences of groundwater in relation to morphological features such as hydrographic networks.

Photo-analysis of geological units and tectonic structures, revealing morphology, climatic conditions, vegetation, and other factors, may also disclose such hydrogeologic factors as the recharge zones of water-bearing horizons and the direction of ground-water flow. Other geologic and geomorphologic features related to groundwater occurrence can also be detected, such as systems of fractures and faults, variations in slope, and hydrographic patterns.

There is practically no region where remote-sensing techniques cannot be applied in hydrogeologic research. The amount of data obtained varies depending on the method applied, on the terrain, on the geological structure and composition of rocks, and on climatic and other conditions.

In arid areas, which are mostly without cover vegetation (North Africa, Arabian peninsula), aerial and satellite images show almost all of the data relevant for detection of underground aquifers.

In humid areas which are mostly covered by vegetation, there is a surplus of water in the soil which can be identified by using infrared aerial photographs (or radar, if available).

Investigations for groundwater in karst regions require special techniques. Analyses of satellite images and aerial photographs make it possible to identify lithologic units and networks of faults and fissures, indicating possible groundwater movements, and to choose locations suitable for geophysical measurements and tracer studies. Positive results from such investigations have been obtained in the karst of the Dinaric Alps of Yugoslavia.

Infrared thermal images are particularly suitable for hydrogeologic investigations in coastal regions where groundwater flows discharge into the sea. Because of the temperature differences between the cold groundwater and the warm seawater, freshwater coastal springs can be identified by the sharp contrast between the colour of the seawater and that of the flow of the submarine springs discharging into it (Adriatic coast, Hawaiian Islands, etc.).

The use of remote-sensing techniques in groundwater surveys has proved beneficial in reducing the time and the cost involved in surveys, and in collecting accurate and reliable data.

2. <u>Surface Technologies: "Geophysical Methods in Groundwater Investigations</u>," by Stjepan Kovačević (Lecture 2)

Mr. Kovačević stressed that while the use of geophysics is not always indispensable when one wishes to drill a well, in many cases geophysical investigations are really needed to avoid failures. For instance, this may be the case where the thickness and composition of aquifers vary over an area, or in hard-rock areas where water in quantity is to be found only in rocks of certain types or in certain zones (fractured, karstic, fault zones).

Geophysical techniques are used in two principal ways--in regional surveys and in detailed investigations:

a) <u>Regional surveys</u>

A regional survey aims at obtaining preliminary data on hydrogeological conditions (extent of aquifers, thickness of sediments, main tectonic characteristics, etc.).

i. <u>Airborne surveys</u>

Airborne geophysical surveys are performed mainly for ore and oil exploration, but also for groundwater investigation. In such cases they may include:

-- <u>Magnetic surveys</u>: to locate magnetic masses at various depths, especially in the basement (in order to determine depth to the basement).

-- Electromagnetic surveys: to distinguish rocks on the basis of their conductivity and to locate large conductive zones (lineaments, fractured, karstic, fault zones, saltwater lenses, etc.).

Existing geophysical data collected by air for ore or oil exploration purposes may be utilized for hydrogeological studies.

ii. Ground Surveys

-- Gravity surveys are applied mainly in sedimentary basins, to obtain qualitative data on structure and tectonics. The resulting gravity maps may be interpreted using quantitative data on depth. Such data may also be obtained by deep resistivity sounding and seismic refraction.

-- Deep resistivity sounding yields quantitative data on the sequence of layers and the depth of the basement. It is applied jointly with the gravity method; it can also be the only regional geophysical method used, in which case a higher density of profiles is required.

-- Seismic refraction gives depth boundaries between media characterized by different velocities of elastic waves. Seismic refraction is more costly than the resistivity method and is applied when the former is hindered by unfavourable resistivity contrasts.

-- Magnetic survey is carried out simultaneously with gravity survey if magnetic rocks are expected at various depths or in the basement. The additional data thus obtained help to obtain more definite interpretation.

-- Seismic reflection method may be applied for large and deep sedimentary basins to obtain an accurate image of structure and tectonics. Because of its high cost, seismic reflection will rarely be included in groundwater projects. Existing seismic reflection data from oil exploration may be utilized for hydrogeological studies.

Regional geophysical surveys serve to select areas for further, more detailed investigations. However, some exploratory drilling may be done on the basis of the regional surveys.

(b) Detailed Geophysical Investigations

Detailed investigations concentrate on smaller areas or on particular problems, and employ a higher density of measuring stations. They provide data for planning exploratory drilling and for obtaining more complete image of hydrogeological conditions in the areas concerned.

i) Geoelectrical Method

The geoelectrical method is the geophysical method most frequently used in groundwater investigations. It comprises several types of measure-measurements:

-- Resistivity soundings determine the thickness and resistivities of layers in the subsurface. Resistivity values reflect lithology or, in some instances, groundwater salinity. Potential aquifers are separated from the impervious media. Interpretation results are presented in cross sections or on maps showing the interpretation of various data.

-- Induced polarization soundings, if used simultaneously with resistivity soundings, provide another parameter (polarizibility) which is an aid in interpreting depth sections with complicated resistivity. They help to eliminate aquifer areas with a high clay content, giving more accurate results than resistivity soundings alone.

-- Resistivity or electromagnetic profiling is used to explore lateral changes in the subsurface--to locate contacts and fractured or karstic or fault zones. In many instances electromagnetic profiling is desirable for detecting conductive masses or zones. Such lateral investigations are useful in hardrock areas, where they enable selection of potential water-bearing zones.

ii. Seismic Refraction Methods

The seismic refraction method is used for lateral investigations, mainly to locate depressions filled with unconsolidated sediments or to detect more highly fractured or karstic zones. They are often used jointly with geoelectrical methods.

iii. Magnetic Method

The magnetic method is used mainly in crystalline rock areas with volcanic extrusions and intrusions, to locate magnetic masses, dykes, lava flows, etc.

iv. Gravity Method

The gravity method is used less often but also to detect depressions filled with unconsolidated sediments, in order to locate cavities and other lateral changes in density. A higher precision in measurements is needed.

Whenever feasible it is desirable to apply more than just one geophysical method, since the methods mentioned above complement each other.

Geoelectrical methods can also be used in (a) study of groundwater flow direction, or even the velocity of the flow (by a combination of borehole-surface measurements); (b) evaluation of aquifer properties from measurements of surface resistivity; (c) monitoring of groundwater pollution by repeated surface or borehole measurements; and (d) exploration of sites for artificial recharge.

The application of geophysical methods has long proved economical. In spite of this, there are many groundwater projects--even in the drilling of wells--which do not use geophysics in exploration. There is a need for a closer contact between hydrogeologists and geophysicists.

3. Subsurface Technologies: "Groundwater Exploration and Assessment Technologies," by Čedomil Plazek and Željko Zagorac (Lecture 3)

Messrs. Plazek and Zagorac noted that their paper covers exploratory drilling methods, borehole logging, geophysical logging, and borehole sampling.

Under the heading "exploratory drilling methods," various drilling techniques were described.

Historically, man-operated hand drilling was the earliest method of drilling but now this is almost abandoned and is being replaced by up-to-date engine-powered, hydraulic drilling systems. Modern methods include:

(a) Percussion drilling, using cable tools and a hydraulic percussion system, for "driven" wells;

(b) Hydraulic rotary systems, with conventional and reverse circulation, using air rotary, rotary bucket, and spiral auger, plus various flushing media: water, bentonite mud, foam, air, and revert mud;

(c) Combined feature methods, such as jet percussion drilling, washed-down jetting, and down-the-hole drilling.

Altogether, a review of eleven exploratory drilling methods was presented, showing their principles of operation and the uses for them recommended by the rapporteurs, including limits to their use. Comments were offered on the selection of the most suitable drilling methods for various hydrogeological conditions.

The section on "borehole logging" described different methods to collect and store information, such as the driller's log, the daily drilling report, the penetration rate log, and the interpreted hydrogeological log.

Under the heading "geophysical logging" the following logging methods were presented: resistivity, spontaneous potential, natural gamma, density (gamma-gamma), neutron, acoustical (sonic), caliper, and temperature logging. The methods of fluid-movement logging and radioactive and chemical tracing, were shown, as well as photographic and TV logging.

The basic methods of borehole sampling were descibed as related to various drilling systems: the sample-interval and continuous method of sampling; and core recovery methods, such as the single and double core barrel system as well as the wire-line double-core barrel system. Bailer methods of sampling, the split-spoon method, and the side-hole core method were also presented.

Methods of collecting water samples for water quality analyses were shown.

B. Working Group Meetings

Working group meetings dealing with Theme A discussed the topics of Lectures 1, 2, and 3 under the headings "Surface Technologies (geophysical surveys)" and "Subsurface Technologies," as follows:

1. Surface Technologies (geophysical surveys)

(a) Discussion

Operations of two types were considered: regional surveys directed at the assessment of aquifer size, depth, and characteristics; and local surveys to select well sites for rural water supply.

It was generally accepted by the group that the use of geophysical methods is definitely recommended for the first type of operation but not always justified for the second.

The discussion focussed upon local surveys, and centered on such questions as these: Is geophysical investigation justified for locating promising well sites in rural areas? Which geophysical method is best for this purpose?

As to the first question, the following concerns were expressed:

i. Costs

Costs may reach $US 1,000 to $US 2,000 per village, a rate that is about 25 per cent of total project costs. However some participants indicated that in most cases simple and inexpensive equipment and methods such as light resistivity or magnetometry apparatus could be used. The experience gained by UNICEF in India in Pre-Cambrian formations and by the United Nations in Mali has shown that the use of geophysics in locating well sites saves money, time, and effort. In some sedimentary formations (as in Libya) the siting of wells can be based entirely upon geological features.

ii. Reliability and Effectiveness

Most participants recognized that the use of geophysics is most useful in locating promising well sites. A 20-year experience in hard-rock areas of Tanzania shows that the use of geophysics allows for a 90 per cent success ratio with an incremental cost of 10 per cent for geophysical prospecting. In Iraq the ratio is 90 per cent, with a 50 per cent incremental cost. In Bermuda the use of geophysics is essential in the monitoring of seawater in coastal areas. It was emphasized, however, that geophysical equipment is very sensitive to mishandling, especially during transport, which may lead to erratic, misleading, or meaningless results.

It was pointed out that in many developing countries there is a lack of qualified personnel to conduct surveys and interpret their results.

Certain types of sophisticated equipment, such as digital VLF radio-wave equipment, are easy to handle. Computerization of the results greatly facilitates interpretation. However, the computer should not be considered a substitute for the geologist or the geophysicist.

With respect to constraints, it was noted that geophysical surveys may be influenced by a variety of factors such as difficult terrain or access; use of irrigation in the area of the survey; and need to locate wells in the vicinity of a village which is not situated in the best hydrogeological location.

One of the participants emphasized that geophysical surveys should not be considered as the one and only tool in groundwater investigation, although they are an essential component for hydrogeological surveys. Basic hydrogeological/water-resources mapping is a prerequisite for the planning of geological surveys.

(b) Proposals

In conclusion the following activities were proposed within the framework of TCDC:

i. Facilitation of the training of geophysicists and operators in hydrogeology, and of hydrogeologists in geophysics;

ii. Exchange of information, (possibly through roving teams) between contries having similar hydrogeological problems, such as the crystalline basement areas in Africa and India;

iii. The establishment of an information center regarding the suitability and economy of various geophysical methods in meeting specific hydrogeological problems and socioeconomic targets.

2. Subsurface Technologies

(a) Discussion

The working group discussion concentrated upon drilling technologies.

It was emphasized that in smaller countries, where one or two rigs at most are to be utilized for groundwater exploration, there is not much choice in selecting equipment. In other countries, however, drilling equipment of a broad variety, is used in various technical co-operation projects. The variety can create difficulties for the drilling personnel, who must be able to handle machines of several different kinds, and also maintain and repair them.

The need for water sampling and detailed drilling reports was emphasized.

It was noted that mud rotary drilling, which is widely utilized, is not the most suitable method for water exploration drilling. It leads to the clogging of aquifers and requires the use of water, which is quite costly and not easily available in arid countries. Light down-the-hole hammers operated by air are more suitable in many cases.

Many rigs are underutilized, as government rules do not allow for more than one shift per day--10 hours at most.

The need for training of water-well drillers was emphasized; and the training center at Wad El Maghboud in Sudan, assisted by the United Nations, was mentioned as an example to be followed in other regions. The need in some parts of the world to develop repair and maintenance facilities on a regional basis, and to train the necessary personnel for this, was emphasized. An effort should be made by certain countries to start training facilities that may eventually act as host to trainees from other countries.

(b) Proposals

In conclusion the working group proposed that the following TCDC actions be considered:

i. Collection and dissemination of information regarding groundwater exploration technologies, including exploration drilling, well logging, and pumping tests, so as to make the best use of this expensive component of groundwater investigations. This may be done with the assistance of the United Nations system, including DTCD.

ii) Organization of intercountry training programmes for drilling and maintenance personnel.

IV. THEME B: GROUNDWATER EXPLORATION AND ASSESSMENT METHODOLOGIES

A. Lectures

1. "Reconnaissance Report of Hydrogeological Investigations," by Božidar Biondić (Lecture 4)

Mr. Biondic said that reconnaissance investigations are the first step in the investigation and exploitation of ground and surface water resources. The need for such investigations is especially great in developing countries because they provide easier and better planning for detailed investigations and assist in the selection of the most suitable technologies for tapping water-bearing structures.

Reliable hydrogeological investigations, which also include reconnaissance, may increase the rate of success of water-well drilling operations considerably, especially in hydrogeologically difficult areas such as, for example, hard-rock regions.

The first operational phase may include remote-sensing surveys made from airplanes and satellites, and airborne geophysical surveys. These methods are widely used in developed countries and are very useful in hydrogeological investigations of extensive aquifers. Their application is strongly recommended: they have become cost-effective since the development of satellite photography.

New investigations should be conducted as a direct follow-up of the previous ones: considerable attention should be devoted to the review of scientific publications and technical reports in hydrogeology and related fields.

Photogeological interpretation has considerable significance in areas lacking adequate geological maps and having a scarcity of geological and groundwater data. Such interpretation can detect (a) geological macrostructures and major variations in lithology, (b) zones of major tectonic deformations, (c) sites of visible water occurrences, and (d) areas suitable for field investigations.

Geological forms with large structures have a direct effect on water occurrences and on the flow of ground and surface water. It is necessary to separate areas composed of igneous, metamorphic, and sedimentary rocks. The zones of major tectonic deformations are mainly related to the bordering areas of macrostructural forms, and they may also intersect them. Networks of faults need to be identified in order to determine major drainage zones, especially in hard-rock regions.

Fieldwork consists of verifying data obtained through previous interpretations of aerial photographs. Field observations should apply to macrostructural forms, variations in lithology, and water occurrences: streams, springs, water wells, drains, etc.; and also to water quality and to the impact of weather on morphology and water resources.

Great attention should be given to analysis of the data gathered through groundwater reconnaissance investigations. This analysis is essential to the success of the second stage of field exploration: geophysical exploration and exploratory drilling.

Hydrogeological reconnaissance may involve ground geophysical surveys, the drilling of small-diameter exploratory boreholes, and pumping tests.

The most important stage of hydrogeological reconnaissance investigation is the final analysis and interpretation of data. The data should be transferred onto topographic maps at appropriate scales. Water resources maps or hydrogeological maps are intended to identify the types and boundaries of aquifers, with all their features. These maps will be most useful if they contain data such as groundwater depth, piezometric contours, transmissivity co-efficients, and specific well capacities. The availability of such maps will facilitate the planning of exploratory wells.

2. "Detailed Groundwater Investigations," by Darko Mayer and Pavao Miletič (Lecture 5)

Messrs. Mayer and Miletič pointed out that there are only a few countries nowadays where at least a modest number of geographical, geophysical, meteorological, geological, hydrological, hydrometric, hydrogeological, and similar investigations have not been carried out. Such exploration has been undertaken to discover mineral and oil deposits, and also for irrigation, water supply, and the construction of energy systems.

However, there are also a few countries where the characteristics of the main water-bearing areas are as yet unknown. In these countries, it is necessary to collect such data by detailed hydrogeological exploration, and submit it to multidisciplinary analysis.

Such an analysis would result, first, in specific information about water-bearing regions, water-bearing systems, and main aquifers. Relating this information on aquifers to the development plans for the country, an idea of the need for further exploration work will be obtained. This will help to minimise unnecessary investment for additional exploration.

Simultaneously, mathematical models should be constructed for isolated water-bearing systems that are compatible with the particular features of these systems and with general knowledge of similar systems. By applying such models, it is possible to perform certain tasks such as water balancing, parameter distribution, and interpretation and extrapolation of data.

The next basic step is to design and organise the monitoring of hydrological and hydrogeological co-efficients and indicators of groundwater quality. This step should be repeated regularly.

This system of detailed hydrogeological exploration should make it possible to establish projects that are acceptable both technically and financially.

The personnel and the financial resources needed to carry out such detailed hydrogeological explorations depend on the size of country, its needs, and the amount of data available.

B. Working Group Meetings

The participants discussed as one both papers presented under the general heading of Theme B, "Methodologies": "Reconnaissance" (Lecture 4), and "Detailed Investigations" (Lecture 5).

(a) Discussion

Throughout the general discussion it was recognized that the matters covered by the rapporteurs in their reports should be supplemented by consideration of the assessment and monitoring of groundwater resources. The need to develop groundwater studies to achieve greater success in water drilling was emphasized.

The need to organize joint surveys of large-scale aquifers that are shared by several countries was also recognized. Such surveys should be carried out notwithstanding political difficulties. The UNESCO-assisted project between Algeria and Tunisia, the FAO-assisted project for the Chad basin, DTCD-assisted projects for the Nubian sandstone in northeast Africa, and the mapping of the two Yemens were mentioned. A UNDP project in North Afica (Algeria, Tunisia, and Morocco) is focussing on the joint study of specific water problems.

It was noted that development banks which finance large-scale groundwater development projects request that a substantial fraction of the funding be utilised for investigation and assessment: the banks are not likely to provide financing for the development of groundwater resources that may be exhausted within 5 to 10 years. There is a constant need for groundwater surveys, as the situation of water resources is a changing one. On the other hand a preliminary knowledge of groundwater occurrences can be acquired on the basis of data on a particular area or on similar areas available through computerized data banks, as is the case with geological data covering mineral deposits.

As an example of regional co-operation for groundwater studies including hydrogeological mapping, the case of Venezuela and its neighbouring countries (Guyana and the Netherlands Antilles) was mentioned. Venezuela has acquired broad experience in groundwater drilling which can be shared with other countries in Central America and the Caribbean.

It was pointed out that reconnaissance studies may utilize methods such as the evaluation of losses of surface water to the underground, to identify groundwater-bearing areas.

In small countries (Bermuda), groundwater resources assessment development and monitoring cannot be dissociated from each other. In Tunisia the preparation of small-scale water resources map (1:200,000) is of invaluable assistance in water-planning exercises.

Some countries like Venezuela are ahead of others in hydrogeological studies. Theii experience may inspire other countries.

(b) Proposals

The following activities were proposed within the framework of TCDC:

i. The organization by DTCD of a working group and a seminar/ workshop on the subject of groundwater resources assessment and monitoring, followed by a publication.

ii. The development of intercountry co-operation in the study of shared aquifers, with the support of organizations of the United Nations system.

iii. The development of intercountry co-operation for ground-water problems of common interest, within the framework of projects such as the UNDP project for North African countries, to study artificial recharge, sedimentation in reservoirs, and recycling of used water; or organizations such as the Inter-African Committee for Hydraulic studies, which involves a dozen African countries.

V. THEME C: GROUNDWATER DEVELOPMENT

A. Lectures

1. "Well and Pump Technologies," by Robert G. Thomas (Lecture 6)

Mr. Thomas, Senior Officer, Water Resources, FAO, stressed that within each country a wide range of technologies is required for well construction. Even in the least-developed countries, modern wells and pumps are required for city water supplies, industries, and large farms, while in the same countries wells sunk by labour-intensive methods are used by villages and farms to obtain groundwater.

(a) Well Technologies

There are many treatises on modern well design and construction; and while in some countries there is a need to improve these technologies, there may be a greater need to make labour-intensive methods available to large numbers of people. Labour-intensive drilling methods and well design are generally widely known. There are, however, some well designs such as the "sludger" or hydraulic-valve well (Bangladesh and India) and the "cavity" well (India and Nepal) which are appropriate for high water-table and sand aquifers and which are quickly installed and relatively inexpensive. Large dug wells with small centrifugal pumps in hard-rock areas provide the necessary storage capacity that would otherwise require surface reservoirs for the irrigation of relatively small areas.

There is a real need to provide information on these diverse technologies to the countries where physical and other conditions may make them useful. Such information should include not only the principles of design and construction but also the specific hydrogeological conditions in the areas where these wells have been successfully used.

Wells should be so designed as to be compatible with prevailing hydrogeological conditions and to meet the needs of water users. Range of discharge should be considered and also all well construction technologies which are appropriate and feasible. Clearly, where the depth to the aquifer is great and/or the water table is deep, low-discharge, labour-intensive met' is will not be used. On the other hand, installing large-discharge wells in areas where there are many shallow, low-discharge wells may mean that the shallow wells will no longer be reliable and replacing them may be costly, adding to the real cost of the deep wells.

(b) Pump Technologies

FAO has issued publications on human- and animal-powered water-lifting devices which have been used for irrigation. However, a considerable amount of research on design and construction of human-powered pumps for drinking water has been completed under World Bank auspices and reports are being prepared. This has already led to draft specifications for rugged and practical man-powered pumps.

Where large wells with high discharge and/or high pump-lift are required it is clear that more sophisticated pumps and motors are appropriate.

Pumps, motors, and engines of various types are being manufactured in developing countries; and UNICEF keeps a record of their manufacturers. Besides this, it would be useful to have a place where both manufacturers and potential buyers could obtain information.

Co-operation between countries to set up new manufacturing centres in less-developed countries might also be useful.

Another idea that has been discussed but which has not materialised is to collect early pump and engine designs from the more-developed countries which may be appropriate to the foundries and machine shops of the less-developed countries.

2. "Groundwater Project Concept and Design," by Boris Švel (Lecture 7)

Mr. Švel stressed that to plan a groundwater development project some prior knowledge of the hydrogeological conditions of the project area is needed. The design engineer should co-operate closely with the geologists and other experts, especially in the preparation of an investigation programme.

A project can be either: a separate groundwater intake project, a project within multiple purpose water-development schemes, or a project which is an integral part of a project which is non water-related.

Since groundwater reserves in nature are limited, especially those of good quality, it is necessary to use them rationally. For this reason, special engineering disciplines and legal regulations on groundwater use and management have been developed.

Design approaches are generally known; however, it is important to point out the sequence in which a problem is solved, step by step.

The hydrogeological basis required for groundwater studies and designs, includes (a) data on the natural hydrogeological groundwater conditions; (b) data on groundwater resources and a safe-yield estimation; (c) results obtained from hydrogeological models (both physical and mathematical); and (d) results of special studies, such as monitoring seawater intrusion into coastal areas, artificial recharge of groundwater reserves, and optimization of the mining of nonrenewable groundwater resources.

Balancing of resources should be based on an analysis of all elements of water inflow and outflow. It should include income and cost elements within a particular area during a selected time period. Normally, inflow and outflow values should be determined through a long-term water-balance calculation leading to a basic groundwater balance equation.

A groundwater balance yields information necessary for estimating elements of the hydrological cycle within a particular area, such as seepage of rainfall and surface water, groundwater recharge, evapotranspiration, groundwater inflow and outflow, and the determination of interrelationships between rainfall, surface water, and groundwater. Familiarity with the hydrological cycle mechanism, including all water-balance elements, offers the design engineer a reliable basis for basic calculations and design preparation.

The most important aspect of the design of a groundwater project is the careful preparation of the investigation programme, including a time schedule covering the work. An inadequate programme will lead to inefficient use of time and money. A time schedule in the form of a flow chart should provide accurate information predicting the completion of the project. When preparing such a time schedule one should take into account the fact that certain stages of a project cannot be shortened, such as observation of groundwater levels and hydrogeological measurements.

Savings in project construction costs are achieved on the basis of studies leading to technical and economic optimization.

3. "Children, Mothers, and Others: The Social Aspects of Groundwater Use," by Martin G. Beyer (Lecture 8)

Mr. Beyer, UNICEF, New York, said that until recently the approaches to provide water to communities from groundwater sources have been purely technological. As a result many groundwater projects have failed to meet the needs of those who use the water. The ultimate objective of groundwater projects (especially for community water supplies) is to improve the quality of life of the users of groundwater by supplying them water at low cost, of acceptable quality, and in adequate quantities (desirable minimum: 40 litres per person per day).

At the same time the protection of the groundwater is important: measures for environmental sanitation (including disposal of excreta) must be undertaken.

Particular consideration needs to be given to the most vulnerable and exposed target groups, who at the same time are the main drawers of water: women and children. The design of water supply and sanitation systems must be adapted to their special needs; and they also have a role in the construction, operation, and maintenance of the installations. Public awareness and community participation in water projects is important at all stages, from planning onward; participation in operation and maintenance is particularly important, including the training of women as village technicians. It should be noted not only that direct benefits to health are involved, but also that women cannot advance in society and have a chance to develop their own lives if they do not have access to water close to their homes.

It is therefore essential that project planners and designers acquire a good knowledge of the attitudes, beliefs, and behaviours of the people whose needs they are serving.

Support from governments and other national bodies, including non-governmental organizations, is essential in this educational effort. The backing of such activities by international organizations, particularly through the United Nations Steering Committee for the International Drinking Water Supply and Sanitation Decade IDWSSD, has been reinforced by the establishment of its Task Force on Women, convened by UNICEF and the United Nations International Research and Training Institute for the Advancement of Women (INSTRAW). The social science aspects of groundwater use and management should be part of any knowledge network on water resources and water supply. Such a network may eventually include a "groundwater centre."

4. "Participation of Women in the Development and Use of Water," by Vida Tomšič (Lecture 9)

Mrs. Tomšič, United Nations International Research and Training Institute for the Advancement of Women (INSTRAW), stressed that in technical co-operation used as a tool for developing the self-reliance of countries, special attention to the role of women is needed. In water supply and sanitation projects, there is a strong need to consider issues relevant to women, not only because of the obvious benefits of such projects to their health and well-being but because of the vital ways in which women can participate in planning and implementation of the projects.

Water supply and sanitation are not only objectives in themselves but also a prerequisite for the fulfillment of development goals. About 60 per cent of agricultural production is the product of women's labour --but this includes the hardest labour with the least productive results, accompanied by malnutrition, hunger, and illness.

Therefore, changes in water-supply projects to make them sensitive to women's needs must be considered. Water supplies need to be developed not only for homes but for agricultural plots; and increased quantities of water are necessary for improving the health of women and alleviating the conditions under which they live.

Women can perform various functions in water programmes: as water managers, drawers, maintenance of installations, family health educators, motivators, and agents of change. They should be involved in all stages of project development.

Any system of co-operation among developing countries in developing and managing groundwater resources should include the participation of women. The support of national governments and international organisations should be secured, with firm commitments to the recognition and enhancement of the role of women.

A number of activities have already been initiated by the United Nations system with regard to women and water. One is the Steering Committee for Co-operative Action of the International Drinking Water Supply and Sanitation Decade (IDWSSD), which has established a Task Force on Women to assist in developing strategies; act as a support mechanism; and monitor, evaluate, and report on progress. INSTRAW serves jointly with UNICEF as the secretariat for this Task Force.

INSTRAW is prepared to assist any national, regional, or international institution to promote the full participation of women in water- and sanitation-related programmes and activities.

B. Working group meetings

The topics of Lectures 6, 7, 8, and 9 (Theme C) were discussed during working group meetings, as noted below. Lectures 8 and 9, having been the subject of a special session of the Colloquium on social issues, 25 May 1983, were discussed together in the working group.

1. Well and Pump Technologies (Lecture 6)

(a) Discussion

The matters brought up by participants during the discussion mainly related to (i) various simple methods for digging wells or drilling boreholes, as used in various developing countries; (ii) problems with defective wells, which allow sand to enter and destroy the pumps; (iii) the selection of suitable pumps and the need to advise farmers on their selection; also the need for co-operation between project engineer and hydrogeologist on pump selection; (iv) the life expectancy of pumps, and the need for regular inspection and servicing.

It was pointed out in the discussion that simple and inexpensive technologies are commonly utilised in a number of developing countries for digging wells or drilling boreholes, especially in Asia. However, these technologies are not well known in certain other developing countries where similar natural conditions--especially geological conditions--are encountered.

It was also pointed out that certain developing countries manufacture equipment and supplies for groundwater exploration and development, and related fields, which could usefully be supplied to other developing countries. A good example is the Mark II hand pumps, used in India.

(b) Proposals

The working group proposed the following TCDC actions:

i. The preparation of a compendium of simple and inexpensive technologies, both traditional and modern, utilised in various developing countries for digging wells or drilling boreholes, including well and borehole rehabilitation.

ii. The creation of a technological centre to provide advice on equipment and products manufactured in developing countries which have to do with pumping, drilling, and related matters.

2. Groundwater Project Concept and Design (Lecture 7)

(a) Discussion

During the discussion of the study group the following points were stressed:

1. Groundwater development projects should be designed so that they can be implemented in steps, starting with an exploration phase followed by a water resource assessment, and ending with final design, construction, and implementation, including monitoring during and after

construction. Certain steps may be skipped in case of emergency, when there is no time for long-term exploration, programming, and evaluation.

2. To decide on the basic concepts for a groundwater project, considering all possible alternatives, a programme of investigations should be instituted. The design of such a project is a multidisciplinary task, with specialists from various fields working in cooperation. A hydrogeologist should head the investigation and resource assessment teams. The design of a groundwater project should take into account the results of these investigations, with hydrogeologists playing a leading role.

3. When designing a project in groundwater exploration and development, the following criteria need to be considered: (i) the development objectives of the project and the needs to be served over the medium and long terms; (ii) available data and information, including preliminary evaluations of groundwater availability, quantity, and quality; (iii) project costs, including the cost of alternative plans; (iv) resources, expertise, equipment, and financing available indiginously; and imports needed; (v) duration of project; schedule of work; (vi) sociological and political considerations; (vii) choice of appropriate technologies; (viii) environmental considerations; (ix) economic and social benefits of the project; and (x) infrastructure for operations and maintenance.

(b) Proposals

A useful TCDC activity would be an international centre to be created under United Nations auspices, geographically acceptable to most of the developing countries, which would act as a clearing house for the exchange of information, and as a place where reports, case histories, and project results would be stored and made available for consultation. The centre would keep an up-to-date roster of groundwater experts and consultants from developing countries who are available to provide services to developing countries upon request (under conditions to be specified).

3. Children, Mothers, and Others: the Social Aspects of Groundwater Use (Lecture 8) and Participation of Women in the Development and Use of Water (Lecture 9)

(a) Discussion and Proposals

The papers presented by Mr. M. Beyer and Mrs. V. Tomic were discussed at length by the participants, expecially by the participants from Bermuda, Libya, Iraq, India, and Mexico.

Among the general questions raised, the following may be noted:

i. What can be done to increase public awareness of groundwater and its potential?

It was suggested that the public should be made aware--through local newspapers, radio, TV, videotapes, and other means--of the various technologies involved in groundwater development; and also of how and where groundwater occurs and the limits to its extraction. Also of the limited availability of groundwater; its possible pollution by chemicals or organic compounds, and its possible contamination by the intrusion of saltwater or seawater. Explanations should be provided as to how and why a well goes dry.

Such information can be provided through schools, community groups, health centres, religious organizations, political parties, and others.

In arid areas and other water-short areas, such as small islands, the proper use and conservation of water should be emphasized through teaching aids, such as brochures and films intended for children, which may be prepared and disseminated with WHO, UNICEF, and UNESCO assistance.

ii. What can be done to secure the active cooperation of communities in the protection of groundwater?

In this case an information campaign such as that mentioned above should be complemented by appropriate legislative actions. The protection of groundwater is primarily the responsibility of the hygiene services and the sanitary engineers of public health departments, with community co-operation. It is essential also to control the use of chemical products, especially in agriculture (pesticides, fertilizers) and in the household (detergents). Use of products which are likely to create major health hazards through the contamination of groundwater should not be authorized, and farmers and other users should be made aware of their responsibilities as regards such products.

iii) How can one encourage the involvement of communities, and particularly of women, in developing and managing groundwater resources?

This can be done through an official transfer of the village water-supply installations, such as wells and pumps, from state authorities to the village communities, through contractual arrangements whereby the community takes responsibility for the operation and maintenance of installations up to a certain level, including the purchase of spare parts. In countries where women are water-carriers, they should be trained in the proper operation and maintenance of pumps and the need to keep water utensils clean and protected from pollution from the time it is extracted at the pump until it is used in the home.

iv) What can be done as an immediate follow-up to the current Zagreb Colloquium?

The answer from various participants was that some clear-cut conclusions and concrete TCDC proposals should be drafted by the relevant organizations of the countries concerned, with the assistance of the United Nations organizations.

v) How can a better international understanding be attained leading to an integrated approach in the assessment and development of groundwater resources?

This goal requires that international, multidisciplinary training programmes be established; considerable benefits in water resources management can be expected from programmes involving specialists from several countries, through programmes aimed at promoting TCDC Co-ordination of activities between various organizations dealing with water resources within a country should be pursued, and if possible, all water services in a country should be amalgamated under a single ministry or organization, such as a water authority.

Proper water legislation should be enacted within each country. This has already been done by several developing countries; and their experience may be instructive to others through information programmes undertaken with the assistance of United Nations organizations.

On the specific subject of the impact of water supply schemes on the welfare and social position of women, the case of Mali was referred to in particular. In Mali, through various projects including a major UNDP/DTCD large-scale rural water supply project in Bamako, campaigns of basic education for women were developed in the subjects of proper operation and maintenance of hand pumps, basic hygiene, and conservation of water quality from the time water is drawn until it is used.

In addition to the usual social benefits of a hand-pump water supply (such as cleanliness) economic benefits may accrue as a result of the use of water for small-scale irrigation of crops (several hundred m^3 can be irrigated per hand pump); manufacture of bricks for improved housing; coloring of fabrics; cattle watering; and other uses.

These benefits can compensate for the cost of spare parts and (in some cases) of the hand pumps themselves.

As the male working force is, in large part, employed outside the villages, women constitute the bulk of the working population in the villages, especially as regards farming and construction (in addition to their family tasks). They are the first and major beneficiaries of any improvement in water supply.

VI. THEME D: GROUNDWATER MANAGEMENT

A. Lectures and Statement

1. "Protection and Conservation of Groundwater Resources," by Robert G. Thomas (Lecture 10)

Mr. Thomas, Senior Officer, Water Resources, FAO, discussed the conservation of water resources and their protection against contamination.

(a) Water Conservation

At times during critical periods when water resources are being tapped to their limit, available water resources may be increased either by engineering measures (increasing the recharge, preventing leakage in pipes, etc.) or by using water more carefully, to reduce waste. Waste may be due to flow out of the area or into swamps, to large but short-term floods which do not allow recharge, or to water use by nonbeneficial plant life.

In city water systems the losses in distribution systems may exceed permissible limits. Resolution of distribution loss problems lies in planning, engineering design, and in adequate operation and maintenance.

Conservation by users of water is a more complex matter. When much labour or cost is involved in water use, people automatically use it as sparingly as possible; whenever the user does not perceive that there is a water shortage, problems occur.

Education of water users may limit the waste of water somewhat, but in general economic pressure may also be required. Legal restraints and regulatory institutions will be needed at some stage in order to carry out effective conservation programmes.

In irrigation, FAO has a programme for training of teachers to help farmers increase their production through better use of available water.

(b) Protection of Groundwater Against Contamination

Conservation measures may also be needed to conserve water quality, for instance, to prevent movement of saline water into freshwater. Protection of groundwater from pollutants is also extremely important because of the long time it takes for pollution to become apparent and the time and cost of repairing the damage.

Pollution may occur either at point sources (landfills, rubbish dumps, untreated sewage outfalls, industrial waste outfalls, etc.) or from non-point sources (such as fertilizers, pesticides, herbicides, domestic sewage systems, and leaks in sewer lines).

Safe disposal of toxic chemicals may be very difficult. It has been found that even the seemingly least permeable rocks eventually allow some seepage to develop. Furthermore, there are reportedly 15,000 new organic chemicals invented every year by the chemical industry, some of which are widely distributed. Most of these are not tested for their stability or deterioration in groundwater or in the soil, and are dumped with other chemical wastes. In recent years it has been found that certain water-treatment materials previously used can form highly carcinogenic molecules when reacting with other materials in sewage treatment plants. Expensive specialized equipment is needed to detect these molecules at levels possibly injurious to health.

Such facts as these indicate that the less-developed countries should, as early as possible, develop staff who can be aware of such dangers and prevent their occurrence.

The control of point sources of pollution is easy to understand but may not be easy to accomplish. Control of non-point sources is best done by controlling the manufacture and distribution of possibly dangerous materials. In either case some kind of monitoring is needed as early as reasonably possible.

Education of engineers and the public to these dangers is obviously necessary, but a legal and institutional framework is also needed for adequate protection of groundwater resources. The recent example of dioxin contamination in Europe shows that education is sometimes not enough.

The World Health Organization has a major programme to combat water pollution and the International Research Centre in the Hague includes this in its activities. Other United Nations agencies are involved in various aspects of pollution control, such as UNESCO, which in 1980 published the report "Aquifer Contamination and Protection" within the framework of a project of the International Hydrological Programme.

2. "Institution Building and Training in Groundwater Exploration and Development," by Robert Dijon (Lecture 11)

In his lecture, Mr. Dijon, DTCD, United Nations, stressed the institutional aspects of groundwater management, as follows:

(a) Institution Building

Groundwater services are presently attached to ministries or agencies of three kinds:

-- Geological and mining services. These bureaus consider groundwater as a phenomenon to be studied for the furtherance of general scientific knowledge as well as for its value as a natural resource.

-- Specialized agencies for water resources. Groundwater is considered by these agencies as an element of the hydrologic cycle and an essential component of the overall water resource.

-- Public works departments, agricultural services, and other technical departments. Groundwater activities may have been entrusted to such departments for reasons of convenience or policy, or as a result of the priority given to specific development objectives.

A survey of the functions of services dealing with groundwater shows that in somewhat less than 50 per cent of the countries surveyed, groundwater investigation is considered an activity related to geology or to mineral exploration. For more than one-third it is considered a component in the integrated utilization of water resources. For less than one-third, groundwater investigation is related to a specific development sector, such as agriculture, or public works.

In most cases, hydrogeological problems related to well drilling and well digging programmes do not appear to be extremely complex, expecially in rural areas and in humid tropical areas. In such areas, hydrogeological studies can be reduced to a minimum and undertaken on an ad hoc basis, rather than systematically and countrywide. They can be handled by ministries of public works, hydraulics, or agriculture; and also by development corporations.

However, the need to organize specialized units for the rational and systematic study of groundwater resources on a broad basis has been increasingly felt, for example, in Central America, where several such units have been created with United Nations assistance.

The groundwater specialist will be involved increasingly in public works, drilling, and hydrological/hydraulic activities. The reason is that large groundwater yields are available mainly in the vicinity of riverbeds or other areas where extensive surface water infiltration occurs, calling for an integrated study of surface water and groundwater in an assessment of the overall water balance.

Last but not least, the groundwater specialist is increasingly involved in water resources planning, including implementation of different "scenarios" exploitation.

Because of this variation in function, groundwater activities have a tendency to migrate away from where they originated, that is, from mining and geology services to hydrological services, water supply agencies, development agencies, and economic planning offices. As a result, there may be several groundwater organizations dealing with the same subject matter from different--perhaps antagonistic--viewpoints. To avoid such conflicts, a water policy should be established at a national level and the terms of reference of agencies dealing with water resources should be clearly defined as recommended by the United Nations Water Conference. If water policy can be handled within one single organization or ministry, the task may be facilitated.

(b) Training

As regards training of groundwater professionals, considerable progress has been achieved in the last 20 years. Because of the extensive fellowship programmes sponsored by international and bilateral organizations, professional personnel holding at least one engineering diploma or a university degree are now in service in most, if not all, developing countries, including the least developed.

However, additional training is needed not only at the professional level but also (i) at the subprofessional level (surveyors, assistant geologists, geophysical operators); (ii) in the maintenance and repair of equipment (drillers, mechanics); (iii) in certain highly specialized fields, such as the study of artificial recharge, organization of computerized data banks, and mathematical modelling; (iv) at the managerial, policy, and planning levels; and, (v) at the operator level.

In-service training has been provided by the United Nations in the number of projects for personnel of the first two categories mentioned above. In addition, a project for the training of East African water drillers has been operated successfully for some 12 years near Khartoum/ Sudan. The possibility of organizing such a project in French-speaking Africa is under study. The United Nations International Labour Organisation has carried out a number of projects for the training of mechanics. Training in the specialized fields mentioned in category (iii) above is provided in the form of short-term fellowships--three to six months on study tours--for highly qualified professionals.

Guidance for water managers, category (iv), is provided by specialized United Nations sponsored institutes such as the Centre de Formation Internationale a la Gestion des Ressources en Eau (CEFIGRE), located in Southern France, which hosts training sessions mainly for managers from North Africa, West Africa, and western Asia. Such guidance is also provided by means of study tours and inter-regional meetings and seminars.

In Africa, pump operators, including women, are trained in elementary mechanics and in basic rules of hygiene. This relates to the conservation of water quality within the framework of projects involving UNICEF and the World Health Organization.

3. "Operation and Management of Groundwater Schemes," by Martin G. Beyer (Lecture 12)

Mr. Beyer, UNICEF, New York, stressed that projects involving groundwater operation and management fall into two categories: big schemes, (such as large-scale irrigation and big-city projects) and small schemes (for micro-irrigation, small towns, villages, and single households). In both categories, the governing factors include the milieu or environment, including groundwater resources; human resources; machinery (technology); and capital(funding).

Programme development consists of several phases: monitoring and evaluation, planning, programming, implementation, operation and maintenance, and renewal. Inputs come from four different groups: executive (management), professionals, paraprofessionals, and the community.

The governing factors mentioned above can be broken down further. For example, "human resources" involves personnel who are expert in organization and administration, planning/monitoring/evaluation, and human resources development. "Technology" involves transport; exploration and production (geology, geophysics, drilling, testing, well development); services (protection, cleaning, treatment, recharge); installations (casing, screens, pumps, pipes, fittings, storage); and logistics (spare parts and fuel).

In proper management of groundwater resources, the following considerations are of prime importance:

(a) Planning
- (i) Policies
- (ii) Priorities
- (iii) Linkages

(b) Administration and human resources development
- (i) Budget
- (ii) Personnel: Organisation
Management
Policies (including salaries and wages)
Transport provisions
- (iii) Training, retraining, upgrading (career development)
- (iv) Community education

(c) Materials and equipment (selection and procurement)

  (i) Simple technology, widely available

  (ii) Low cost

  (iii) Standardization

  (iv) Testing and selection

  (v) Procurement procedures

  (vi) International/national manufacture and procurement

  (vii) Evaluation

  (viii) Feedback to manufacturers, and collaboration with them in development

(d) Maintenance systems

  (i) Organization

  (ii) Funding

(e) Water resources control

Discussions of the operation and management of groundwater schemes might center on the following questions:

-- What are the experiences, problems, and requirements of various countries?

-- What improvements can be made in technologies and equipment, and how can manufacturers' services be secured at acceptable costs?

-- How can different systems be improved and adapted for operations, maintenance, and management of groundwater resources?

-- How can the UN system serve various countries most effectively?

-- How can an exchange of information and experience best be accomplished?

4. "National Water Policy and Groundwater Management: the Institutional Dimension," by Enzo Fano (Lecture 13)

Mr. Fano, DTCD, United Nations, stressed that taking into account the availability of other water resources, groundwater often constitutes an asset whose preservation in quality as well as quantity, is of primary importance to the national economy of every country.

Thus, an ever-increasing number of countries have enacted legislation to protect and control groundwater resources. The legislation and the regulatory approaches vary, but essentially have to do with ownership rights and rights of use; with government control over groundwater exploration and exploitation; and with the protection of groundwater quality.

The first question regarding ownership rights over groundwater is whether the water is privately owned or whether it is in the public domain. Traditionally, surface water resources have been regarded as the property of the owners of the land holdings in which they lie; and according to the principle that ownership of the surface implies ownership of the subsoil, the ownership of groundwaters and of wells to extract it accompanies the ownership of the soil. According to this tradition, the owner of a well is the only person entitled to use it for irrigation purposes (though he may be required to share his water for domestic use, depending upon legal precepts in his area); and he is not required to supply water to irrigate other land. However, the right of ownership is increasingly being differentiated from the right of use, and the latter is being subject to ever-increasing legal restrictions in various countries. More and more, the right to use groundwater is assigned by legislation, under public domain or trust status, and the development and use of groundwater is subject to government permit or concession.

Drilling of wells is generally regulated as regards the depth planned and the volume of water to be withdrawn; the maximum depth permitted may vary within a given country according to region. The most complete regulations prescribe that a government permit must be obtained before drilling a well, and that technical information and reports on the progress of the work must be submitted.

Several enactments lay down, in more or less similar form, the principle that groundwater must be protected against all pollution which might render it dangerous to health or unfit for normal use, by causing harmful changes in its properties. Accordingly, restrictions are placed on waste-disposal activities that can degrade the quality of groundwater, such as underground disposal of wastes, underground storage of gas, the installation of sewer systems, the installation and use of septick tanks for disposal of household refuse, and the storage and use of fertilizers.

Experience proves, however, that regulations alone are insufficient to control and protect groundwater resources. With respect to regulations on development and extraction, in particular, it is of critical importance that legislation grant the government authority to enter private holdings and verify the actions being taken by the user and, even more important, the amount of groundwater actually withdrawn. Only an express grant of this authority will enable the government to ensure that regulations are complied with by those who actually drill for and extract groundwater.

Ultimately, the usefulness of groundwater legislation and regulations depends on the existence of adequate administrative machinery for their enforcement and implementation. Legislation, therefore, must identify the government department or agency responsible for conservation, development, and use of groundwater resources, or, in the alternative, specify the form of the co-ordination necessary should groundwater resources fall under the jurisdiction of more than one government department or agency. Whichever approach is taken, it is of critical importance that the government have the capability to administer and enforce the regulations not only at the central level, but equally important, at the local level.

5. "Legal Aspects of Protection of Groundwater Resources in Yugoslavia," by B. Petrik (Lecture 14)

In accordance with the Socialist Federal Republic of Yugoslavia Constitution, waters, watercourses and coastal sea are treated as common property, and as such are specially protected by law. Under the Constitution, the working people and citizens, organizations of associated labor, socio-political communities, local communities and other self-managing organizations have the right and obligation to provide conditions for preservation and development of natural resources, the values created by human labour and the human environment, and to prevent and avert the harmful effects which, resulting from pollution of water, watercourses and seas, endanger these values or even threaten the lives and health of people.

Similar provisions can be found in the Constitution of SR Croatia and in the Constitutions of other socialist republics and socialist autonomous provinces.

By the Act on Elements of Water Regime that is of interest for two or more republics and provinces respectively and by the Act on interstate waters, the basis of the regime of interstate watercourses and waters, as well as the measures for protection of interstate watercourses, international waters and the waters of the coastal part of Yugoslavia, are determined.

By the bilateral agreements reached with the neighbouring countries, conditions for protection and conservation of border-waters have been created.

The question of water protection against pollution, including the underground water resources, has been regulated in details by the Water Act.

The Act on Categorization of Watercourses determines what category the waters of a single watercourse or of one part of the watercourse or the sea along the coast should belong to.

In Yugoslavia special attention is being paid to ground waters. The unique principle of recording and compiling data on ground and mineral-water resources has been established.

For all the works that could, in one way or another, have any impact on the ground-water regime, the investors must provide the water management agreement and the building permit while for the purpose of groundwater exploitation the water management permit must be provided.

6. "Statement," by Ricardo Acosta

Mr. Acosta, of the International Centre for Public Enterprises in Developing Countries, noted that groundwater management is a prerequisite for individual and collective self-reliance and for improvement in the status of rural dwellers--especially women, who confront directly the problems of water scarcity. It is because of the close connection between water supplies and the welfare of the rural sector that the International Center for Public Enterprises in Developing Countries views this Colloquium with great interest. The development of rural enterprises such as agro-industries and agro-based industries very often depends on irrigation and water supply projects. Although the Centre does not currently have a project dealing with groundwater as a specific issue, its programmes do deal with the transfer and development of technology and with rural enterprises as factor in rural development, including the management of food production and distribution.

Within this framework, the Centre recognizes that groundwater resource development and management bear important social implications not only for rural development, but for the development of the economic welfare of a nation.

B. Working Group Meetings

The topics of Lectures 10, 11, 12, and 13 (Theme D) were discussed during the working group meetings, Lectures 12 and 13 being discussed as one topic.

1. "Protection and Conservation of Groundwater Resources" (Lecture 10)

(a) Discussion

The working group first discussed problems of conservation of groundwater supplies from the point of view of limiting losses and waste in distribution systems and in well-point systems.

With regard to irrigation projects, experiences described by several representatives (India, Yemen, and Cyprus) suggested that properly designed and maintained distribution systems using pipes result in a considerable reduction in water losses--up to 50 per cent-- when compared with open-ditch irrigation. It was also suggested that such savings could be encouraged by the provision of free professional advice to farmers on the design and operation of piped irrigation systems; subsidies for the purchase of pipes; and loans for other equipment.

The group also considered the problem of domestic waste of water due to the fact that certain wells and boreholes are equipped with pumps of a delivery capacity considerably in excess of actual demand. Solutions suggested included licensing of domestic supplies (Jamaica) and the careful sizing and specification of pumps at the design stage (Yemen). In any case, adequate information on the range of the pump sizes and types available in an area was felt to be essential.

The problems of conservation that are specific to arid areas were discussed. It was concluded that a promising solution would be to use intermittent surface flows occurring in wadis, conjunctively with groundwater supplies. Experience is limited as regards the use of barriers in wadis to hold back the water of flash floods; but delaying dams, possibly formed of rock gabions, can encourage the infiltration to groundwater and at the same time reduce the sediment load in the streams. In certain cases, where local hydrogeological conditions do not favour direct infiltration to groundwater, the construction of covered-surface storage tanks might be considered. A possible problem associated with infiltration behind dams would be the growth of phreatophytes; these might lead to water losses by transpiration, although the phreatophytes might be controlled by regular cutting.

It was further noted that efforts should be made to improve the water-saving technologies in irrigation, industrial, and domestic use.

The working group considered that the protection of groundwater from contamination can be accomplished only where adequate legislation exists. The desirability of preparing and circulating a model legislation which could be adapted to each country's individual special needs was agreed upon. The close interrelationship between groundwater conservation measures (including appropriate well design and construction) and groundwater protection measures was fully recognized. In addition, it was agreed, there is a need to be aware of the extent to which certain contaminants may occur naturally without the intervention of man; an example was quoted from India, where high pollutant levels had been detected locally.

The complex interactions between the needs for agriculture to increase food production by applying intensive methods of cultivation, including the use of agrochemicals, and the need to prevent pollution of water resources were recognized. The delegates concluded that a specialist workshop to consider these problems should be convened under the auspices of United Nations organizations.

(b) Proposals

Stemming from these discussions, the group put forward four proposals for TCDC action, as follows:

i. It was proposed that model legislation be prepared taking into account United Nations experience in this matter, and circulated among the countries concerned. This model legislation should be studied, adjusted to local conditions, and put forward for consideration by local authorities.

ii. Attention of the participants was called to the studies being carried out in Hungary in the field of pollution of water resources as a result of agricultural activities. It was suggested that a workshop be organized on this subject under the auspices of the United Nations organizations concerned.

iii. It was proposed that a review be undertaken, with FAO assistance, of the most economic and appropriate irrigation systems and pumping systems being utilized in developing countries.

iv. It was proposed that a survey be undertaken of traditional and non-conventional water schemes, including the construction of small dams intended to delay runoff so as to recharge groundwater reservoirs in alluvial fills. All useful information on works which facilitate the conservation of groundwater, including specifications, efficiency, and maintenance, should be collected and disseminated.

2. "Institution Building and Training in Groundwater Exploration and Development (Lecture 11)

(a) Discussion

Several participants in the working groups stressed the need for a better definition of the role of hydrogeologists and of groundwater services within governmental agencies. It was noted that the United Nations Water Conference recognized the need for an integrated approach in the investigation, development, and management of water resources; and that the activities in operational hydrogeology should be located within water development agencies rather than in geological survey organizations. However, the need was recognized for a nucleus of scientific hydrogeology in geological services. In line with the recommendations of the Water Conference, some participants expressed the wish to have United Nations organizations advise governments on the subject of co-ordination of activities, especially in countries where several agencies are dealing with large-scale groundwater programmes, resulting in possible overlapping and duplication.

(b) Proposals

The working group presented the following proposals for TCDC follow-up:

i. The United Nations Department of Technical Co-operation for Development should consider preparing a report on the localization and terms of reference of groundwater services within government agencies and organizations in developing countries, which will include proposals aiming at a better utilization of local expertise, in line with the recommendations of the United Nations Water Conference. The proposals would emphasize an integrated approach to water resources studies, development, and management. The report should also provide some guidance as regards the structure of groundwater services in developing countries and the minimal requirements in personnel, equipment, and resources which are needed in order for hydrogeologists to operate with efficiency.

ii. It would also be useful to make available a list of training organizations which now exist in developing countries in the fields of drilling, specialized mechanics (for compressors, rigs, pumps), topography, et al, and which would be ready to accept teachers from other developing countries.

iii. The possibility should be considered of organizing within (or attached to) existing organizations and with United Nations support a centre for groundwater management intended to provide short-term (two weeks to two months) diversified training courses for groundwater specialists--the course to deal with economics, geophysics, drilling, computer programming, etc.--so as to enable these specialists to acquire managerial experience.

3. Operation and Management of Groundwater Schemes (Lecture 12) and National Water Policy and Groundwater Management: The Institutional Dimension (Lecture 13)

(a) Discussion

A lively discussion by two groups, based on experiences in several countries showed the close links and interdependence between the topics of Lectures 12 and 13. The findings and conclusions reported below also clearly showed the need for TCDC to draw upon the experience gained in various areas having similar conditions and problems.

(b) Proposals

As regards national water policies, the working groups presented the following findings:

i. In all participating countries there exists some form of legislation, ratified or in the form of a draft, on groundwater resources; an important question covered in this legislation is the ownership of groundwater. It seems that a common problem, especially in the larger countries, is to reach the stage at which groundwater laws can be implemented, particularly laws for the control and monitoring of groundwater resources. In some countries, local communities take this matter into their own hands.

ii. Water pollution control acts exist in some countries but need to be made more effective. Proper laboratory facilities to detect groundwater pollution do not always exist and there is a need to raise public awareness of pollution problems through information and education.

iii. The need was noted for governments to plan ahead for the introduction of measures to monitor, control, and manage national groundwater resources before overexploitation, pollution, and other abuses occur, with their adverse effects.

iv. There is a need for better co-ordination between national agencies within the same country, each of which may possess information valuable to the others.

v. There is also need for better interaction between central and local authorities, especially in monitoring and control with improved feedback from remote areas.

On the basis of the above, it was proposed that DTCD should promote the exchange and evaluation of national experience between countries, and the recording of information for wider dissemination.

As regards operations and management, the working group found that the problems and their solutions vary greatly from country to country, depending on the country's location, resources, size, and other attributes. Generally maintenance is one of the greatest problems, especially maintenance of groundwater-based community water supplies; and the problem is compounded by the squeeze on gasoline and oil prices. More and more of the responsibility for operation and maintenance of rural groundwater-based water supplies is being assumed by local populations.

In the working group, emphasis was laid on community participation and the need for communities to share substantially in the cost of operation and maintenance: this helps the communities to feel that the installations belong to them and are their responsibility.

The group also stressed that equipment for groundwater use should be designed properly, with feedback suggesting improvements in such equipment being directed to manufacturers (as in the UNDP/World Bank Global Hand-Pumps Testing Project).

The need for standardization of methods, approaches, and equipment was stressed, as well as the setting up of proper systems for maintenance (as for example the "three-tier" hand-pump maintenance system in India).

It was proposed that DTCD, in the context of the IDWSSD, participate in promoting, through TCDC, an exhange of experience and expertise in operations and maintenance, including the collection and dissemination of information, with particular emphasis on simple, low-cost systems for maintenance.

VII. ROUND TABLE MEETINGS: RECOMMENDATIONS AND PROPOSALS

Round table discussions concluded the Colloquium, with a view to finalising proposals on the basis of comprehensive reviews. In accordance with discussions held within the four groups of the round table on TCDC, the following recommendations and proposals may be singled out:

A. Information Base

The essential prerequisite for further enhancement of technical co-operation among the developing countries rests in the establishing of national, subregional, regional, and international information networks on groundwater resources development. This represents an obligatory first step for any future co-operation involving research, training, consultant services, standardization of services and equipment, planning and management, and other aspects.

At national levels, information centres should be established, with clearly defined tasks. In several countries, such as Sudan, Mali, and India, such centres already exist.

Information centres should also be established at subregional and regional levels, possibly with the assistance of the economic commissions and other regional United Nations organizations or projects. Such centres should be so organized as to receive, process, store, and disseminate information through national centres.

For example, there are several centres in the Mediterranean and the western Asia region. In the Caribbean region, Venezuela offers a focal point in Dirección de Hidrogeología, Ministry of Environment, Caracas, for the first stage of a regional-subregional information network. In the region of Africa south of the Sahara, two to three focal points should be established.

At the international level the majority of participants agreed that the existing Centar za Vode, Zagreb, with support from the United Nations, could become an international institution for collecting and transmitting selected information on research, training, expertise, standardization, planning, and management of groundwater resources development. The institution should co-operate closely with regional, subregional, and national groundwater centres, as well as with the relevant United Nations organ organizations.

In partnership with Centar za Vode, DTCD would assist in identifying sources of knowledge (such as institutions and individual specialists) on all aspects of groundwater technology, supplies, and the like; promoting intercountry consultances; defining terminology; co-ordinating activities involving trans-national aquifers; and identifying and establishing links with international professional associations, such as the International Association of Hydrogeologists, the International Water Resources Association, and similar bodies.

B. Research, Education, and Training

It is recommended that whenever appropriate and feasible, working-expert parties be formed at sub-regional levels to identify groundwater problems and propose steps to resolve them. Such expert parties might evolve into subregional consulting bodies for screening and co-ordination of needs, methods, and technology.

Collection and dissemination of information on research programmes and results in different countries is an important step in improving the co-operation of developing countries in this field. DTCD and Centar za Vode should consider this activity a priority.

Regarding training, it is necessary to identify training centres and arrange in-service training for personnel from developing countries.

It is also recommended that opportunities should be created for an exchange of experts at the subregional level, including young professionals, for on-the-job training programmes.

C. Experts and Consulting Services

A roster of experts and consulting firms specialized in groundwater and related fields in developing countries should be prepared on national, regional, and interregional levels. DTCD may provide its existing computerized list of experts to national and regional institutions. The roster should include all qualified experts from developing countries (including universities, professional and administrative organizations, private firms, and the like), to identify the overall potential within each country. The same should apply at the regional and interregional levels.

It is necessary to promote strengthening of national consulting capacities in the groundwater field and stimulate (by financial and other incentives) a mutual exchange of consulting services that may enhance the capability of consulting firms in developing countries.

D. Standardization of Engineering Services and Equipment

In this activity of TCDC, a well-organized international information flow is indispensable. Equipment and materials are being manufactured in certain developing countries that are not known or scarcely purchased by other developing countries. A possibility to be explored is the joint manufacture of equipment, machinery, spare parts, and/or components within regions and subregions. The round table participants expressed the view that good possibilities exist for such joint enterprises.

Purchase of equipment and technology in the industrially developed countries may be more efficient and less costly if purchases are made jointly. Adequate information exchange is indispensable in making joint purchases.

E. Planning and Management

There are good examples of co-operation planning and development of groundwater resources among developing countries with similar hydrogeological features. Such co-operation is highly desirable. Neighbouring countries can form interdisciplinary teams for the study and development of transnational water resources.

An important issue in groundwater development planning is proper energy use. Local sources of energy (including new and renewable sources) should be considered.

The monitoring of groundwater resources for quality, quantity, and availability is an essential component in groundwater development and management. The participants recommended that a workshop or a seminar on this matter be held in the near future.

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Annex II

PROGRAMME OF THE COLLOQUIUM

Monday, 23 May 1983

Introductory Session

"The Role of TCDC in Groundwater Management," by Dr. Slavko Komar

"Introduction to TCDC in the Groundwater Sector, by Mr. Enzo Fano

Theme A: Groundwater Exploration and Assessment Technologies

Presentation of rapporteurs' lectures:

Surface Technologies: "Remote Sensing in Groundwater Investigations" (Lecture 1), by Mr. M. Oluić; and, "Geophysical Methods in Groundwater Investigations" (Lecture 2), by Mr. S. Kovačević

Subsurface Technologies: "Groundwater Exploration and Assessment Technologies" (Lecture 3), by Messrs. C. Plazek and Z. Zagorac

General discussion

Presentation of three country papers: India, Venezuela, Yugoslavia

Working group meetings on the subjects of Lecture 1-3 (Theme A)

Report of working groups on Theme A

Tuesday, 24 May 1983

Reports of working groups on Theme A (continued)

Theme B: Groundwater Exploration and Assessment Methodologies

Presentation of rapporteurs' lectures:

"Reconnaissance Report of Hydrogeological Investigations" (Lecture 4), by Mr. B. Biondić

Annex II (continued)

"Detailed Groundwater Investigations" (Lecture 5), by Messrs. D. Mayer and P. Miletič

Working group meetings on the subjects of Lectures 4 and 5 (Theme B)

Reception at the Town Hall of the President of the City Council, Mr. Aleksandar Varga

Presentation of five country papers: Indonesia, Libya, Pakistan, Thailand, Yemen

Theme C: Groundwater Development

Presentation of rapporteurs' lectures:

"Well and Pump Technologies" (Lecture 6), by Mr. R. Thomas

"Groundwater Project Concept and Design (Lecture 7), by Mr. B. Svel

Working group meetings on the subjects of Lectures 6 and 7 (Theme C)

Wednesday, 25 May 1983

Groundwater Development (continued): Special session

Presentation of rapporteurs' lectures:

"Children, Mothers, and Others, the Social Aspects of Groundwater Use" (Lecture 8), by Mr. M. Beyer

"Participation of Women in the Development and Use of Water" (Lecture 9), by Mrs. V. Tomšič

Working group meetings on the subjects of Lectures 8 and 9 (Themes B and C)

Report of working groups on Themes B and C

General discussion

Presentation of two country position papers: Mali, Tunisia

Theme D: Groundwater Management

Presentation of rapporteurs' lectures:

"Protection and Conservation of Groundwater Resources" (Lecture 10), by Mr. R. Thomas

"Institution Building and Training in Groundwater Exploration and Development (Lecture 11), by Mr. R. Dijon

Working group meetings on the subjects of Lectures 10 and 11 (Theme D)

Presentation of eight country papers: Zambia, Fiji, Mexico, Turkey, Ghana, Jamaica, Egypt, Iraq

Thursday, 26 May 1983

Morning

Three tours were organized for the participants to choose from:

(a) Guided city tour

(b) Visit to institutes and universities

(c) Visit to Geotehnika and other engineering firms

Afternoon

Presentation of five country papers: China, Bangladesh, Bermuda, Cyprus, Tanzania

Theme D: Groundwater Management (continued)

Presentation of rapporteurs' lectures:

"Operation and Management of Groundwater Schemes" (Lecture 12), by Mr. M. Beyer

"National Water Policy and Groundwater Management: the Institutional Dimension" (Lecture 13), by Mr. E. Fano

"Groundwater Management," by R. Acosta

Annex II (continued)

Presentation of a paper "Legal Aspects of the Protection of Groundwater Resources in Yugoslavia," by Mr. B. Petrik

Working group meetings on the subjects of Lectures 12 and 13 (Theme D)

Report of working groups on Theme D

It was proposed to constitute two working groups in preparation for round table meetings: (a) Middle East and Africa, and (b) Asia and the Americas

Cocktail party for colloquium participants given by the Centre for Water at the premises of the Hotel Intercontinental, Zagreb

Friday, 27 May 1983

Morning

Presentation of three country papers: Algeria, Republic of Korea, Tanzania

Round table, working groups

Round table, plenary session

Afternoon

Discussion and adoption of colloquium report

Concluding ceremony

Annex III

SUMMARIES OF COUNTRY PAPERS

A. BANGLADESH

Area: 144,000 km^2 Population: 90 million

1. General

Bangladesh forms part of the largest delta in the world, built up by three mighty rivers: the Ganges-Padma, the Brahmaputra-Jamuna, and the Meghna. With the exception of a few hilly areas, the country is flat, with elevations from 1.5 m at the southern border to more than 86 m above mean sea level at the northern border.

The climate of Bangladesh is typical of the monsoon climates of Asia. The country has an average annual rainfall of 2,100 mm, of which 85 per cent is from June to October. The annual evaporation ranges from 1,057 mm to 1,430 mm; and the potential annual evaporation rates range from about 1,200 mm to 1,300 mm. Being situated at the critical confluence of three mighty rivers carrying a combined flow of 1,480 billion m^3, the country faces perhaps the most complex hydrological problem in the world: this discharge, coupled with local precipitation, could inundate the entire country to an estimated depth of 11 m. Moreover, only 7.5 per cent of the total catchment areas lie within the country.

Geologically the area is underlain principally by poorly consolidated or unconsolidated rocks of Tertiary and Quaternary age. Unconsolidated alluvial deposits of Recent to sub-Recent age overlie the marine sediments and cover nearly all of the country except hilly areas. Based on geological criteria the country's groundwater system generally falls into two major areas: the Quaternary area and the complex geology area. The Quaternary aquifers are the more promising for development. The younger or recent alluvium, consisting primarily of unconsolidated sediments with sands generally exceeding 100 m in thickness, offer the best possibility for groundwater development.

Existing tube wells, found throughout the country except in Dhaka and some parts of the coastal areas, are less than 140 m deep. Based on these data the lithologic section to that depth for the greater part of the contry can be divided into three zones: (a) upper clay and silt; (b) silty to fine sand; (c) medium to coarse sand and gravel. Depth to groundwater in the dry season is generally within 6 m. Groundwater levels are highest from August through October and lowest in April and May, the range of fluctuation being 3 to 6 m. Recharge of groundwater occurs primarily through direct infiltration, which varies from 600 mm to 300 mm.

2. Economy

Agriculture contributes over 53 per cent to the GDP and together with agro-based industries accounts for over 75 per cent of the foreign exchange earnings and engages 77 per cent of the labour force. The per capita income is about $US 120, with a wide gap betwen urban and rural income. More than 85 per cent of the population are directly or indirectly dependent on agriculture. The major objective is to achieve a production level of 20 million tonnes of cereals by 1984/85, to make the country self-sufficient in food.

3. Use of Groundwater Potential

The country has an abundance of surface water during the monsoon season, causing widespread floods, but has little water during the dry season to meet irrigation and water supply needs. The construction of reservoirs is not possible because of the flat topography of the country. Lean-period withdrawals from rivers are also scanty because of considerable withdrawal by users in the upper riparian areas. Therefore, the use of groundwater has become essential.

4. Groundwater Extraction

As of 1980 groundwater extraction from known wells was estimated to be 3,430 million m^3, of which 82 per cent was for irrigation purposes. To attain self-sufficiency in food not later than 1985, with sustained growth thereafter, the country needs irrigation of at least 2.91 million hectares (ha) compared to the 1980 level of 1.47 million ha.

The estimated number of wells required for this by 1985 will be as follows:

Deep tube wells	25,000
Shallow tube wells	130,000
Hand pumps	500,000

With the assistance of UNDP, a hydrogeological survey of the country has been completed and areas suitable for tube wells demarcated. Several tube well projects consisting of thousands of deep and shallow wells financed from various sources--foreign assistance, credit, and the government's own resources--have already been completed and others are now under way. Many more are being planned.

5. Organisations Engaged

Several development agencies are engaged in groundwater development activities: the Bangladesh Water Development Board (BWDB), Bangladesh Agriculture Development Corporation (BADC), Bangladesh Public Health Engineering Department (BPHED), the Integrated Rural Development Programme (IRDP), the Bangladesh Krishi Bank, and others.

The rapid pace of groundwater development has brought new and important questions about the dependability of such resources, their indirect effects on other resources, the most effective means of utilisation, and the overall potential of groundwater resources. To solve these problems, a DTCD team is working in close co-operation with the local experts.

B. BERMUDA

Area: 53 km^2 Population: 55,000

1. General

In Bermuda, eight islands linked by short bridges and one causeway form the main landmass of approximately 52 km^2. These eight islands are laid down in the form of a chain some 50 km long and no more than 1.5 km wide at the widest point.

Annual average rainfall of 1,400 mm is reasonably evenly distributed throughout the 12 months of the year; but April, May, and June are the drier months, with an average of 90 to 115 mm.

The islands of Bermuda are of limestone formation laid down on an extinct volcanic pinnacle. Borings have located the volcanic rock about 200 feet below sea level.

2. Water needs

Tourism, including cruise ship visitors, attracts approximately 600,000 tourists a year. The average length of stay of tourists is five days.

There are approximately 21,000 residential dwelling units, comprised of houses and apartments, and some 4,000 other buildings, including shops, offices, hotels, schools, churches, warehouses, and post offices.

3. Groundwater Resources

All the land mass of Bermuda is underlain with groundwater. The quality of the water varies according to depth, distance from the shoreline, and the type of geological strata at sea level. The variation is from near seawater quality of total dissolved salts (TDS) 35,500 parts per million (ppm), to potable water of TDS 400 ppm. The latter--naturally potable groundwater--is moderately hard. The total hardness varies from 200 to 260 ppm and most of this hardness is temporary.

Groundwater investigations were initiated in 1969.

The report "Groundwater Hydrology of Bermuda," published in 1974, identified five freshwater lenses suitable for development for public water supply purposes. All the lenses have freshwater nuclei, but three of the nuclei are small and the corresponding lenses are considered as brackish, for development purposes.

Observation profile boreholes have been installed in all the lenses and read-ins with a down-the-hole conductivity probe are taken monthly. Profile and groundwater contour maps are prepared quarterly.

In 1979 a UNDP project executed by DTCD was initiated, with the following purposes:

(a) to provide the Public Works Department with a suitable micro-computer to allow the transfer of its data bank and mathematical model from Washington State University to Bermuda;

(b) to investigate further the lithology of the substrata of Bermuda and obtain a better understanding of the behaviour of the marsh areas; and

(c) to refine the mathematical model, so as to manage and forecast more effectively the safe yields of the limited potable and brackish water resources of Bermuda.

The Public Works Department now invests approximately 100,000 $ West Indies Dollars per year in groundwater investigation and monitoring.

4. Development of Groundwater Resources

Bermuda has no rivers or streams and the very limited number of water ponds are located at sea level and hydraulically connected with the underlying brackish water or seawater. Hence groundwater has been used since the earliest times to supplement artificial rainwater catches. Initially this water was derived from hand-dug wells sunk in the lower-lying areas. Consequently by 1975, when the Water Resources Act required the registration of existing wells, there were approximately 1,000 private boreholes in Bermuda, generally providing water for nonpotable domestic purposes.

In 1931 a private water company was incorporated to extract water from the main central lens and develop a piped-supply of nonpotable water for flushing and washing. The resource was initially of potable quality but due to overextraction quickly turned brackish. By 1979, despite added extraction points the total dissolved salts of the water supplied was 2,000 ppm.

The Public Works Department installed its first abstraction borehole in 1970 and concentrated on the development of the potable water nucleus of the main central lens. Initially, to meet public demand during summer drought periods, and to substitute groundwater for the increasingly more expensive water, provided by a 170,000 gallons-per-day (GPD) seawater distillation plant installed in 1965 primarily to ensure that a new hospital under construction had an adequate supply at all times.

In the central groundwater lens the Public Works Department has installed some 150 boreholes (3/4 and 1-1/2 HP submersible pumps) for the abstraction of potable and brackish water. To treat water abstracted from the brackish zone of the lens, three brackish-water reverse-osmosis plants of 125,000 GPD output were commissioned in 1981.

Boreholes have been installed in a second lens with a reasonably potable water nucleus, to provide supplies to water truckers delivering make-up water to premises at the western end of the island. The demand of these water truckers ranges from zero during the witnter months to 250 m^3/day during a dry weather spell.

Work is in hand at developing a small lens at the east end of the island, with an estimated safe yield of 300 m^3/day.

C. CHINA

Area: 9,597,000 km^2 Population: 1,005 million

1. Groundwater Resources in China

Groundwater resources are widely distributed in China. In order to evaluate them, extensive hydrogeological mapping (at scales of 1:200,000 and 1:500,000) and reconnaissance have been done since the early 1950's. Such investigations have already been completed in two-thirds of China's territory, excluding the Qinghai-Tibet plateau and part of the high-mountain and desert region. More detailed exploration and research work has been done for water supply in municipal and rural regions.

In the arid and semi-arid zones of northern China, surface water is usually scarce, and groundwater development is essential. Even in the more humid regions of southern China, especially in karst, coastal regions, or basins of redbed, seasonal shortages of water are often inevitable. In such areas, groundwater can play an important role. With the expansion of industry and agriculture, the demand for groundwater continues to increase. It is essential to evaluate water resources correctly. Comprehensive collection of basic data and thorough investigation of hydrological balances are indispensable for such evaluation. This work is now in progress in a nationwide scale.

The natural groundwater resource in the whole country is estimated to average 800 billion m^3/year. Of that amount, 300 billion m^3 is in aquifers of granular sedimentary deposits in plain regions, 300 billion in fissured aquifers of mountainous regions, and 200 billion in karst regions.

2. Present Status of Groundwater Development

According to incomplete statistics, the total yield of groundwater over the country is about 55 billion m^3/year. Dependence on groundwater decreases from north to south. The largest demand for groundwater is for irrigation, amounting to 80 per cent of all the groundwater used. Other groundwater demands include industrial uses and public water supply.

(a) Irrigation. In the northern part of China, over two million new wells have been drilled since the early 1950's. Annual groundwater use amounts to 40 billion m^3. The areas of irrigated land are being enlarged to ensure stable crop yields despite drought. Flood control has been instituted, saline-alkaline soil has been improved, and the water needs of the public have, to a large extent, been satisfied.

At present, the total cultivated area in China is about 1.5 billion mu, and the irrigated area is about 700 million mu, of which 170 million mu (24.3 per cent) are irrigated by groundwater.

(b) Urban and Industrial Water Supply. According to incomplete statistics, there are 181 big and medium sized cities in the country, among them 61 using groundwater as the main water source. Of these cities, 51 are located in the north. There are 40 cities supplied by both surface and underground water. Groundwater is used as the main water-supply source for many industrial cities in northern China, such as Beijing, Shenyang, Xian, Baotou, and Taiyuan. In some big cities the pumping rate may exceed one million m^3/day in each. Geological surveys for water supply have been carried out in all big and medium-sized cities.

Annex III (continued)

D. CYPRUS

Area: 9,250 km^2 Population: 700,000

Groundwater is the most important water source for Cyprus. It accounts for about 80 per cent of the water consumed on the island. The main groundwater-consuming sector is agriculture, with a share of about 85 per cent of total groundwater used in the government-controlled areas. With the figures for 1973, prepared for the whole of Cyprus, irrigated agriculture, even with its high share in groundwater consumption, was practiced in only 11 per cent of the total cultivated area of Cyprus. The eagerness of the farmers to expand their irrigated land, together with the additional requirements for water to supply the domestic needs of the expanding towns and villages, put serious pressure on the aquifers of the country, the most important of which had reached the stage of overdevelopment.

The conditions in Cyprus present an example to be avoided by other developing countries which are now implementing groundwater projects or planning to do so.

In Cyprus there are four main aquifers and a number of smaller ones. In order of importance, these are, the western Mesaoria aquifer, the southeastern Mesaoria aquifer, the Akrotiri aquifer, and the Kyrenia limestone aquifer. The first three are porous aquifers, while the last one is karstic.

In the figures for the year 1973 it has been estimated that pumping from the western Mesaoria aquifer was about 84 million m^3, while safe yield was estimated to be about 60 million; from the southeastern Mesaoria aquifer pumping was about 44 million m^3, while safe yield was about 22 million; and from the Akrotiri aquifer 16 million m^3, with estimated safe yield of 14 million m^3. The overpumping in these three aquifers totalled 48 million m^3, or 50 per cent of their capacity.

Groundwater in Cyprus is the property of the state, yet almost all groundwater consumed for agricultural purposes is used by private individuals or companies, who under normal conditions have received permits wells or boreholes and use groundwater. The permits are issued by the

District Officer, who is the administrative authority for his district. Until 1951, when Cyprus was still a British colony (independence was gained in 1960) the District Officer alone, without any technical help, handled all water-use problems. In 1951, when part of the western Mesaoria aquifer was depleted, the law was amended so that the District Officer--still considered the responsible authority for issuing drilling permits--had to consult the Department of Water Development before issuing a permit for areas which the Government declared "protected areas." However, this law did not help much in protecting the aquifers, because there was no provision giving power to any government authority to alter the conditions of existing well permits so as to reduce or control pumping. Consequently, some parts of the aquifers became depleted or salinated, and signs of seawater intrusion were detected. In 1964, another piece of legislation was passed known as the "Water Supply (Special Measures) Law," giving poser to responsible authorities to impose new conditions on the permits already existing in the areas declared by the Council of Ministers to be subject to the law.

Unfortunately this law could be imposed on only two of the three endangered aquifers. In the southeastern Mesaoria aquifer the farmers responded so vigorously, with support from the farmer unions, that the government yielded and withdrew the law for that area.

As a result, the Akrotiri aquifer, which is a shallow aquifer sensitive to overpumping, has been saved by control measures under this law, during drought periods, while the southeastern Mesaoria aquifer is now very near to destruction, mainly due to salination. The government now is obliged to invest huge amounts of money to transport expensive surface water from other areas in order to keep the farmers of this area at their villages.

It should not be concluded, however, that inadequate legislation alone is responsible for the situation. One of the main reasons for it was that the exploitation of the aquifers started well before any hydrological survey was initiated. In fact, hydrological surveys followed development, testifying that overpumping was occurring.

Another point worth mentioning here is the need for tight legislation to control drilling operations. In Cyprus, private boreholes nowadays are drilled by private drillers; and despite the fact that they are not allowed to drill unless the farmer has secured the necessary permit, a considerable amount of illegal drilling has been done, especially in the southeastern Mesaoria aquifer. Unfortunately, on one hand the procedures which have to be followed when illegal drilling is reported are quite slow, and on the other hand the penalties imposed by the courts of justice for illegal drilling are rather moderate. Thus, illegal drilling is not effectively discouraged and this handicaps efforts to control pumping and to protect groundwater resources.

Now an upgrading of the hydrological and hydrogeological surveys is being carried out to the extent that economic resources allow, and a new institutional setup for the control and utilization of the water resources of the island is under study.

E. EGYPT

Area: 1,001,000 km^2 Population: 45 million

The overall strategy for groundwater development in Egypt is based on the government policy of moving population away from the narrow strip along the Nile, to improve overall living conditions.

The groundwater reservoir under the Nile Delta and Nile Valley offers very good possibilities as a source of fresh groundwater. At present about 20 million citizens use groundwater for drinking purposes. In 90 per cent of the Egyptian desert, the only source of water is the groundwater.

The strategy for groundwater development in the Nile Valley is based on the conjunctive use of surface water and groundwater for irrigation in new lands at the desert fringes of the valley, and to control water-logging. An early step will be to provide irrigation to reclaim lands bordering the presently irrigated areas: such water will be drawn from underneath the presently irrigated lands. The necessary changes in techniques of irrigation and water management, as well as the organizational changes involved, will require considerable time. There will be pilot areas, each equipped with 60 tube wells. The evaluation of these two pilot projects will provide guidelines for the planning and design of other projects.

Indigenous waters in the Egyptian deserts are of uncertain quantity, quality, reliability, and replenishability. These factors must be ascertained by survey and investigations before water can be allocated to different uses.

A recent programme was organised by DTCD, with UNDP support, to study the management of major regional, transnational aquifers in north-east Africa between Sudan and Egypt, to assess groundwater potential and to provide guidelines for ecologically sound agricultural development and other forms of development in extremely arid regions. Such activities, carried out by national agencies in Egypt and Sudan, are a step toward the long-term objectives of further transnational development in North Africa and in the Arabian Peninsula.

Table 1 provides some preliminary statistical data estimating the utilization of groundwater aquifers in Egypt in 1980 and in the year 2,000.

Table I. Annual Groundwater Extraction and Potential in Egypt, to the Year 2000 (Preliminary Figures)

Groundwater basin	Annual extraction in m^3 million (Year 1980)	Annual potential in m^3 million (Year 2000)
I. NILE VALLEY		
Nile Delta	1,600	2,100
Upper Egypt	1,300	2,800
II. WESTERN DESERT		
Kharga	90	109.4
Zayat	-	14.2
Abu-Tartur	-	21.8
Dakhlia	198	416.9
West Mawhoob	37.4	37.5
Abu-Muncar	15.0	47.0
Farafra	1.27	81.3
Karawein	-	192.0*/
Bahariya	34	122.4
SIWA	43	?*/
Northwest coast	60	124*/
III. EASTERN DESERT		
Wadi Qena	-	50*/
Wadi Laqeita	0.6	25*/
Wadi Abbadi	-	25*/
Wadi Nattash	-	50*/
Coastal Plains	1.0	?*/
IV. SINAI	150	?*/

*/ Further studies and investigations are needed.

F. FIJI

Area: 18,300 km^2 Population: 680,000

In Fiji there is no adequate institutional setup to organise and manage the development of water resources in general, and groundwater in particular. There is a need also to have a water development policy that is consistent with the overall economic and development plans of the country. An effect of the absence of adequate institutional arrangements is the lack of a programme for gathering data. Water legislation exists in a draft form but to date it has not been enacted.

There is a shortage of trained manpower in the groundwater field, at both the professional and the technical levels. As a result the main activity of present staff is answering ad hoc requests for groundwater supply in specific areas, and not enough time is available to carry out proper studies assessing groundwater resources.

All equipment and materials used in water development are imported. This naturally leads to high prices, lengthy delivery time for equipment and spare parts, and high cost for repairs and for the external expertise needed.

The fact that the country consists of several islands leads to certain logistical problems in implementing projects away from Suva headquarters.

Hydrogeological problems include the difficulties of exploration in young volcanics, overdevelopment of coastal aquifers, and the high concentration of iron and manganese (higher than WHO standards) in water from recharge schemes along the three major rivers.

Basically, groundwater development in Fiji is in its infancy and is having teething problems.

G. GHANA

Area: 238,500 km^2 Population: 12 million

Groundwater occurs in quantities exploitable by boreholes in most areas of Ghana. Yields are small but sufficient to meet the needs of rural settlements and a few small urban communities. About 60 per cent of the population of Ghana live in about 47,000 communities with populations of less than 2,000 persons. Most of them can be adequately supplied by means of hand-drilled or hand-dug wells. Groundwater sources are considered unnecessary for irrigation because of the abundance of surface water.

Crystalline rocks (mainly granitic gneiss and schist) underlie more than half of the country, mainly the more densely populated areas. They weather to a sand and clay mixture that has low permeability and generally covers the rocks up to a thickness which ranges as high as 20 to 25 m. Wells completed in the sand-clay mixture usually yield small amounts of water that often is turbid. Higher yields are generally obtained from boreholes completed in the somewhat more permeable partially-weathered rock zone. The highest yields (in the range 7.5 to 15 litres/second) are obtained in boreholes penetrating shear zones in the underlying unweathered rock. It is believed that there are many such shear zones, which may be located by systematic investigations.

Relatively poor results have been obtained in the rest of the country, which comprises mainly sedimentary rocks. This major sedimentary unit, known as the Voltaian (age) formation, has not been extensively explored because of its low population density. Like the crystalline rocks, the Voltaian formation is characterized by permeability through jointing and fracturing. The Volta Lake, a man-made power reservoir with a surface area of 8,750 km^2, is bounded almost entirely by this formation. The infiltration over 15 years has proved insignificant. Borehole success in the Voltaian terrain has been greatest in areas along the rim of the basin, where the rocks are folded and more fractured.

Not much work has been done to estimate the amount and method of recharge, despite the large groundwater development programmes that have been implemented. It is obvious, however, that in most places the recharge is through rainwater infiltration. The quality of groundwater is generally good except for the presence of iron and manganese in a number of locations, sometimes in high concentrations. Saline water is found in areas along the coast and also in the Voltaian formation, where high chloride levels have been encountered. Water from shallow wells in the sand-clay zone is often turbid with colloidal matter.

The Ghana Water and Sewerage Corporation, a wholly government-owned agency, is responsible for the provision, distribution, and conservation of water in Ghana for public, domestic and industrial purposes. Since present groundwater is sufficient only for domestic use, the Corporation is planning the development of groundwater as well as of surface water. A unit of the Corporation, the Drilling Unit, which is about to be upgraded into a Groundwater Development Department, is responsible for field operations, including exploration, development, and monitoring. Ghana has about 40 years of drilling experience: its progress towards technical and managerial self-reliance in groundwater development has been significant but not always systematic. The equipment being used ranges from cable tool rigs to rotary rigs equipped with down-the-hole hammers. Most of the equipment, however, is old and in need of repair or replacement. Difficulties that have existed for a long time include frequent equipment breakdowns, an inadequate supply of spare parts and consumables, and inadequate logistical support, including poor communication with drilling crews in the field.

In recent projects, however a high level of production drilling has been made possible by external funding enabling the purchase of modern equipment; a steady flow of spare parts and consumables; full logistical support, including mobile field camps and radio communications; and a supply of foreign personnel to aid in such functions as overall project management, maintenance of drilling equipment, and supervision of field operations. The first such project started in 1974, and acquainted the local staff with organization and management of large, high-production groundwater development operations. At the subprofessional level, training programmes in drilling and the maintenance of drilling equipment were carried out. Hydrogeological technicians were trained, and welders were taught to retip drilling bits. Field trials in search of a reliable hand pump started early in this programme, initially limited to a few makes of pumps. These trials have continued for the past eight years, the range of pump types under test increasing over the years to include all promising pumps on the market. Currently these trials are part of the World Bank programme for the development of a hand pump.

Another bilaterally-funded programme for the installation of 3,000 hand-pump-operated boreholes followed this programme. It provided opportunity for local professional and subprofessional staff to expand their experience and to improve their skills in the various technical operations and the organisation and management of groundwater development operations.

For the future, programmes of various sizes are being considered to supply over 4,000 communities, with populations between 200 and 2,000, with hand-pump-operated boreholes. These range from a programme supplying 550 hand pumps per year sustained over 15 years to a 750-pumps-per-annum programme sustained over 10 years. Dug wells designed for all possible protection against pollution are also being planned for smaller communities, through community self-help programmes.

H. INDIA

Area 3,287,500 km^2 Population: 700 million

1. Introduction

Growing recognition, in recent years, of the role of groundwater in providing assured supplies for irrigation, domestic, and industrial requirements has led to the accelerated development and utilisation of groundwater in India during the past two decades. At present 43 per cent of the water requirements for irrigation are supplied by groundwater. Dependence on this source has recently increased because of the introduction of high-yielding varieties of crops and the adoption of a multicropping pattern, for both of which timely and asured water supply for irrigation is a prerequisite. Using groundwater in canal areas offers a means of stabilising the water table, as well as rectifying imbalances in the groundwater system, which result in waterlogging.

2. Central Groundwater Board

The Central Groundwater Board, in its regional hydrogeological surveys, has covered an area of 1,77 million km^2, which is a little more than half the area of the country. For evaluating aquifers, more than 4,500 exploratory boreholes have been drilled so far, at depths of 200 to 700 m, employing 59 drilling rigs. To reappraise groundwater conditions periodically, the areas covered under the hydrogeological surveys are studied every third to fifth year. Through these studies an area of over 0.5 million km^2 has so far been found worthy of groundwater development.

3. Hydrographic Network Monitoring Programme

For periodic assessment of the behaviour of the groundwater system and changes in its chemistry, the country employs a national groundwater observation network of about 5,000 stations in the various basins and subbasins. Each station at present covers about 700 km^2. This is considered rather high, and it is proposed that the number of stations is increased to about 10,000 by 1985, making the observations broad-based and intensive. Observations from these stations are presently recorded five times a year; tests of chemical quality are performed twice a year in the pre- and post-recharge periods. A programme has already been launched to monitor the behaviour of the deeper aquifers by installing small-diameter piezometers and equipping them with self-recording facilities. Based on the observations recorded, reports by year and by decade are being brought out for agency use in planning and development and also for scientific research having to do with development and conservation of water resources.

4. Training Facilities

To meet the needs for trained manpower, regular training programmes on the techniques of hydrogeological surveying, exploration, evaluation of potential, development, and management are being organised. A 12-week course is conducted during the winter season for the young in-service officers of federal and state organisations. For six weeks, this course consists primarily of classroom lectures on the theory and applications of hydrogeology, drilling, geophysics, hydrology, hydrochemistry, aerial photographs, and remote sensing techniques; and for another six weeks, intensive field training. Under this programme, more than 500 in-service officers have been trained so far.

Special short-term programmes for the in-service officers of Asian, African, and other countries are also being organised. The Central Groundwater Board has assigned a number of officers to African, Middle-East, and Asian countries to render guidance in field operations and training of personnel.

Training of middle- and top-level scientists is also being undertaken through the organisation of seminars, symposia and workshops on various subjects. A seminar on assessment, development and management of groundwater resources was held on 29 and 30 April 1983.

5. Equipment

The country has launched an organised programme of research and development to provide equipment to meet growing needs. Though it has at present the necessary technical know-how to manufacture drilling equipment of various types and capacities, emphasis is being laid on the manufacture of rigs capable of drilling down to 500 m, to which depth most production tube wells are drilled. The general depth of heavy-duty tubewells in the alluvial areas is at present 200 to 300 m, except in certain areas where drilling has been done to the depth of more than 700 m. In addition, small capacity down-the-hole hammer rigs (200 m) and percussion and combination rigs (500 m) are being manufactured in the country. The number of drilling rigs of various types available in the country at present exceeds 1,000.

To study borehole geophysics, a multichannel electric logger has been developed and production of it has already started. The country is also producing medium-duty compressors, heavy-duty pumps, and also ejector-type pumps of very low capacity for use in the small water-supply tube wells for public health purposes. The India Mark II hand pump has been accepted internationally as a pumping device for village water-supply schemes.

In order to cope with the problems posed by energy crises the world over, alternative means of energy are being produced for pumping devices at low-capacity tube wells. In addition, defluoridisation and desalination equipment is being produced for use in areas where groundwater contains fluoride and chloride beyond permissible limits.

6. Groundwater Development: Status, Policy, and Programme

Of late, groundwater exploration and development have gained momentum not only in India but also the world over, to cope with the increasing demand for fresh water due to population expansion and industrial and agricultural growth.

The Government of India attaches great importance to the concurrent use of ground and surface water resources in a co-ordinated. planned manner. While exploitation of groundwater can keep down the water table (within limits), it must also be recognised that surface water irrigation will also add to the groundwater potential. In other words, development of both ground and surface water is complementary and there is need for an integrated planning of the use of the two so that an optimum balance between them can be struck.

An additional area of 13,76 million ha is proposed to be brought under irrigation between the period 1980-85. Of this, 7 million ha would be irrigated by groundwater. In addition, increased water supplies will be needed for industrial growth and to meet the requirements of the urban and rural population of India. Groundwater will be a major source of supply for industrial and public health purposes. Of the 5,720,000 villages in the country, nearly half have yet to be provided protected water wupplies. For the majority of these villages, water will have to be supplied from the groundwater sources. Under the International Water Supply and Sanitation Decade programme, safe drinking water is to be made available to all the villages in the country before 1990.

The full development of groundwater resources may pose a number of management problems. Studies on all possible aspects, including artificial recharge, omptimum water use, recycling of waste water, and prevention of the pollution of groundwater are already being undertaken to equip scientists, engineers, and planners with a high level of knowledge and the proficiency to manage situations likely to arise in the future.

I. INDONESIA

Area: 1,491,500 km^2 Population: 160 million

Indonesia includes some large islands--mainly Sumatra, Java, Kalimantan, Sulawesi, and Irian Jaya--and thousands of smaller ones, all in the equatorial-tropical zone.

Annual rainfall ranges from 1,000 to 2,000 mm per year, diminishing eastwards. It mainly occurs during the rainy season (80 per cent in October to March). To remedy the water deficit during the dry season, the development of groundwater resources is being considered. Providing water for agriculture year-round is very important in support of the national five-year programme to increase agricultural production (mainly from rice paddies), with the ultimate goal of achieving national self-sufficiency in food supplies.

At present about 10 projects are being carried out for groundwater development in Indonesia. The criteria for selecting groundwater projects are (a) good hydrogeological potential; (b) intensive cultivation; (c) shortage of water in the dry season; and (d) possible involvement of farmers in the operation and maintenance of the pumps and irrigation systems.

The Indonesian islands, which extend as a belt from Sumatra to Timor, are formed essentially of folded Tertiary and Pleistocene sediments and volcanic rocks, through which a linear belt of active Quaternary volcanoes has been extruded. Erosion of these deposits and subsequent deposition have developed extensive alluvial plains between the volcanoes and along the coast. The best-producing aquifers in Indonesia are (a) limestone along the northern coast and southern coast of Java, (b) Tertiary and Pleistocene sandstone in Sumatra, (c) Quaternary volcanic deposits in Java, and (d) alluvial plains along river valleys. The main impermeable formations are Tertiary clays and clayey alluvium derived from the Tertiary sediments. Quaternary deposits are among the best water-bearing formations.

Shallow groundwater has been used for centuries for domestic purposes and for small-scale irrigation schemes in Java. At present many towns and villages develop shallow groundwater for domestic purposes.

Groundwater quality is good for drinking water supply and irrigation (pH = 7; mineral content is very low).

Major ongoing groundwater development programmes (extending until 1985) include:

(a) Irrigation for 30,000 ha of paddy land and crops. This involves the drilling of about 500 production wells, each well with a depth of between 100 and 180 m. The well design is as follows: conductor pipe 16 inches, hole diameter 12 inches, diameter of casing and screen 8 inches. Piezometric water levels are approximately 15 to 20 m; specific capacity about five liters/sec/m, average discharge Q = 40 to 60 liters/sec.

(b) Drinking water supply for 25 major towns and 37 smaller towns at subdistrict level.

J. IRAQ

Area: 435,000 km^2 Population: 14 million

In Iraq the main problems in the field of drinking water supply to the rural population are due to the following adverse natural conditions: (a) scarcity of rains in the desert region and consequent nonavailability of surface water for storage; (b) relatively high gypsum content in the soil, with consequent salinity of the subsoil water, especially in shallow aquifers; and (c) scattered population in the rural areas, mostly shepherds who roam vast areas with their camels and sheep.

It is therefore desirable to carry out extensive exploratory drilling in search of deep aquifers holding water of good quality. However, the magnitude of this task--in terms of the quantity of work, the time required, and the necessary financial commitment--is such that it appears necessary to seek an alternative. This alternative should give quick results, should be dependable and comparatively cheap, and should involve a minimum amount of drilling. To this end, the following technologies are being contemplated:

(a) use of satellite images and aerial protography to locate freshwater aquifers, to the extent of their reliability;

(b) use of various geophysical methods; and

(c) a minimum of exploratory drilling, to confirm the results of the above-mentioned surveys.

Other methods may also be utilized.

In short, international expertise is sought to determine the most appropriate and economical technologies in the search for groundwater of good quality, for rural water supply.

K. JAMAICA

Area: 11,000 km^2 Population: 2.3 million

The Water Resources Division is the government agency charged with the responsibility for (a) the collection, computation, compilation, and dissemination of hydrologic data; (b) carrying out of water resources investigations; and (c) providing of technical advise to the Underground Water Authority.

The Undergound Water Authority was established by an act of Parliament (Underground Water Control Act, 1959) to regulate well drilling and groundwater extraction in the islands.

The major available surface water is to be found on the northern coastal zone, while the majority of the two million population resides on the southern coast. Rainfall varies from above 7,500 mm/year in the northern mountain slopes to less than 750 mm/year on the southern coast.

As suitable dam sites are not available in the limestone areas, there is a growing dependence on groundwater to meet the needs of irrigation and domestic supplies. Source assessment has been completed for approximately 80 per cent of the island, at different levels of sophistication.

Several tools were used in the assessment, including geophysical exploration, isotope analysis techniques, remote-sensing (low-elevation colour and infrared photography) and satellite data, exploratory drilling, groundwater tracing, artificial recharge, and pilot schemes.

The problems associated with groundwater development are, among others, the following:

(a) overextraction in some coastal aquifers, resulting in saline intrusion;

(b) contamination of the groundwater aquifer by sodium-enriched effluent from bauxite/aluminum plants;

(c) a low level of skill in drilling, in both the private and public sectors (there is an urgent need to upgrade the skill of drilling teams);

(d) frequent breakdown of drilling machines, which are old and need to be replaced with new equipment;

(e) difficulty in recruiting professional staff because of the low level of remuneration; and

(f) The need for conservation in the use of water, especially in irrigation.

The water Resources Division is willing to share the experience it has gained in tackling the hydrogeological problems of Jamaica. It seeks immediate help in the training of drillers and in the formulation and development of a national water plan.

L. KOREA (REPUBLIC OF)

Area: 98,500 km^2 Population: 37 million

Crystalline rocks such as granite and metamorphic rocks of pre-Cambrian to Mesozoic age crop out extensively in the country. Mesozoic sedimentary rocks occur mainly in the southeast of the peninsula. None of these formations contains a high-yielding aquifer.

The crystalline rocks are mostly unsuitable for groundwater development, except for fractured and weathered zones. Most of the sedimentary rocks include shale and tightly cemented sandstone.

The alluvium forms aquifers that are moderately to highly permeable but relatively thin, and occur along the narrow river valleys and in coastal plains. The yield of groundwater in the alluvium is 300 to 800 m^3/day per well on average.

The main target areas of groundwater development in Korea are alluvial plains in which soft permeable strata are well enough developed to supply sufficient groundwater. However, as water demand has increased steadily and steeply over the years, hydrogeologists have turned their attention to deep-well drilling in crystalline rocks, and this has been carried out successfully in selected locations. According to recent statistical data, groundwater yields from tube wells in crystalline rocks may reach up to 300 to 800 m^3/day from depths of 50 to 90 m.

In the course of the last 15 years, tens of thousands of wells have been drilled by government or private companies for irrigation and industrial purposes. A need has arisen for groundwater management and the establishment of a groundwater data bank.

For its part, The Korea Institute of Energy and Resources (KIER) is carrying out hydrogeological mapping to delineate hydrogeological and groundwater conditions and also to collect well data.

M. LIBYA

Area: 1,760,000 km^2 Population: 3 million

1. General

More than 95 per cent of Libya con be regarded as truly arid, with only relatively small areas along the coast near Tripoli and Benghazi having average rainfalls in excess of 250 mm/year. Despite its very dry climate, however, the country has considerable potential for groundwater development. The rate of groundwater extraction has increased from about 650 million m^3/year in the early 1970s to approximately 2,000 million m^3/year today. However, morethan 80 per cent of this amount comes from nonrenewable reserves. It has been estimated that if 50 per cent of the surface water runoff could be harnessed it would represent only one to two per cent of the projected water demand in the year 2000.

Groundwater needs will increase as the demand for water accelerates, because of the financial assistance being granted to farmers to purchase pumping equipment, the creation and extension of large-scale agricultural projects, and the increased importance assigned to agriculture in achieving the national goal of self-sufficiency in food production. Another factor is the deterioration of coastal aquifers through seawater intrusion, and the establishment of inland agricultural projects which shift the geographical distribution of water demand.

2. Groundwater Investigations

A detailed knowledge of aquifers has been acquired as a result of petroleum exploration. The main technical problems are: (a) lack of up-to-date maps; (b) lack of government staff at subprofessional or higher-grade technician levels; and (c) difficulties of access in desert areas.

3. Groundwater Development

Presently 98 to 99 per cent of the water used in Libya comes from underground sources. The situation is unlikely to change significantly in the foreseeable future, even with the planned increase in desalinated water and the possible recycling of waste water.

The Sarir-Jalo-Kufra area is the region where the most striking increases in groundwater supplies are expected to develop. If the scheme in Sarir and Tazirby in southeast Libya is implemented, one could see 700 million m^3/year (compared with the current annual average of 160 million m^3/year) being transported to the coastal strip.

4. Groundwater Management

In 1970 the Libyan Government acknowledged the need to control the exploitation of groundwater and established the Soils and Water Division in the Ministry of Agriculture. In 1972 the General Water Authority was established. In late 1970s the Secretariat of Agricultural Reclamation and Land Development was established (SARLD).

The granting of drilling licenses is vested in the Water and Soil Department of SARLD. The Water Law was promulgated in 1965; it was complemented by more detailed regulations in 1982.

5. General Policy Guidelines

(a) Domestic Use. In certain locations water demand can be met only through desalination and long-distance transport of water. Emphasis is being placed on reduction of demand and a more efficient utilization of water. Thought is being given to introducing a new water-pricing policy to lower the demand.

(b) Agricultural Use. Water conservation through improved irrigation practices will have an important role in future planning. In addition, readjustment of cropping patterns, shifting to crops of the "minimum-water-requirement" type, is being considered. Research on the cultivation of crops that are tolerant of saline water will be intensified.

(c) Industrial Use. Emphasis will be placed on waste-water treatment, recycling of water, and establishment of industries that consume low quantities of water.

(d) Groundwater Monitoring. Although much as already been done in the monitoring of groundwater, this function will be given increased attention.

N. MALI

Area: 1,240,000 km^2 Population: 7 million

1. General

The country is crossed by two major rivers, the Senegal and the Niger. There are also many small rivers.

The country is mostly flat, with highlands reaching up to 600 to 1,000 m: Tambaoura (670 m), Mandingue (570 m), and Bandiagara and Hombori (1,080 m).

The rainy season is from June to September; the dry season from October to May. Mali is divided into three rainfall zones: the southern zone, with from 1,200 to 1,500 mm yearly rainfall (Sudanian zone); the middle zone, with from 400 to 1,200 mm yearly rainfall (Zahelian zone); and the northern zone (Sahara), with less than 200 mm yearly rainfall (desert zone).

For the last 15 years the whole country has been undergoing droughts which have exerted a heavy strain on the population, on agriculture, and on cattle breeding. One of the consequences of the drought has been the lowering of water levels in wells down into the bedrock.

2. Hydrogeological Units

In Mali, the best aquifers are those related to the limestones of Kautiala San and Jaurdiah.

In the north, the Adrar des Iforas groundwater resources are located in the Cretaceous continental sediments. They are tapped at depths reaching 400 m.

Along the river valleys of the Senegal and the Niger, water is found in Quaternary deposits.

In the rest of the country the groundwater is found in the fractured zones of hard-rock formations.

3. Needs

In Mali there are about 10,000 villages, with populations ranging from 200 to 4,000 habitants. It has been estimated that one borehole yielding one m^3/hour will meet the needs of 200 persons; and that 30,000 boreholes and wells would be needed to meet the needs of the entire rural population.

4. Programmes

Four large-scale groundwater drilling projects are being developed at the present time:

UNDP/DTCD project: More than 600 pumps have already been installed.

Helvetas project: (Switzerland); about 300 pumps installed.

Aqua Viva (non governmental organization sponsor): 460 pumps, operated by either feet or hand, and solar pumps installed.

Japanese co-operation project: In early stages of implementation.

Most of the pumps are operated by hand or foot. Some solar pumps have also been installed.

An organization for well-digging, "Operation Puits," created ten ago, has constructed about 200 wells with diametres of 1.80 m. Average depth of the wells is about 70 m.

Other small projects associated with agricultural activities have constructed some 200 boreholes and wells.

Additional projects about to be implemented are these:

World Bank project for 300 production boreholes equipped with hand pumps.

Project of the European Economic Community: 80 wells.

Communauté des Etats del'Afrique de l'ouest (CEAO) project: 250 boreholes and 250 wells.

Liptako-Gaurma project: 150 boreholes that are going to be transformed in 70 wells.

The German and Italian organizations are also financing water-well drilling operations (about 600 boreholes each).

5. Problems

The main problem is the lack of resources. Mali is among the least-developed countries. All projects so far have been financed by foreign financial resources.

Another problem is the selection of appropriate technologies for pumping equipment, especially hand pumps. In Mali there are about 15 types of hand pumps. Their maintenance is done by the population, but most of the pumps are inadequate and cannot stand up to the hard use they get (15 hours of pumping per day). The India Mark II pump seems adequate. It is now being manufactured in the country, with international assistance.

Another problem is the need for training. As projects expand, additional qualified personnel are needed.

O. MEXICO

Area: 1,972,000 km^2 Population: 75 million

Agricultural and industrial development and population growth have caused a rapid increase in Mexico's needs for water, especially for groundwater from tube wells down to 300 m (or in exceptional cases, 1,000 m). Hydrogeological surveys have been done by various government institutions. Geological, topographic, edophic, climatic, local magnetometric, mineral, and stratigraphic maps have been prepared on the basis of data available and direct exploration methods.

Based on this documentation, two valleys have been identified which represent the most serious cases of overpumping. Observations of water-level lowering were carried out in two water wells, and isopiezometric maps were prepared in order to estimate the changes occurring in related areas. Drastic measures of control were decided on and enforced.

Mexico is divided into six zones:

(a) Northern zone, with arid to semi-arid conditions, and very limited groundwater potential. According to statistical data, the last useful rainfall occurred 14 years ago. Sudden rains producing torrential flows occur at times. The prevailing lithology consists of extrusive Tertiary rocks and alluvia of Quaternary age.

(b) Northeastern zone, with pockets of the Mapimi type and permeable and impermeable calcareous rocks. Drilling reaches the depth of 200 m in synclinal structures.

(c) Coastal zone of Gulf of Mexico, with sedimentary rocks, particularly significant as an oil-bearing area.

(d) Pacific zone, generally composed of granitic impermeable rocks, production known through sands and "tucurguay."

(e) Central "meseta," consisting of igneous rocks (basalts, ryolites, andesites, tuff, volcanic debris, and alluvia overlying basalts).

(f) Yucatan platform, covered with Recent sediments (limestone).

Currently, the most developed aquifers in Mexico are alluvia, fractured basalts, and (locally) the ryolite and calcareous rocks of Monterrey.

The Mexican government has enacted a federal law requiring particular care of water in dry zones and the obligatory installation of level-measuring instruments in each water well.

A problem is the penetration of saltwater in the area of Manzanillo, along the Pacific Coast.

P. PAKISTAN

Area: 804,000 km^2 Population: 85 million

Groundwater constitutes a major component of the water resources in most of Pakistan. For rural and urban water supply, groundwater is the primary source; and at the present state of development, groundwater for irrigation uses about a third of the water supply.

In Pakistan major groundwater development for irrigation has taken place in the last two decades. Initially, groundwater was developed through major public projects which were begun with the primary object of overcoming waterlogging and salinity problems. This demonstration of tube wells in the public sector has resulted in the private use of tube wells on a large scale, their numbers increasing 14 per cent annually. At present groundwater extracted annually from private tubewells is about three times of the pumpage from public tube wells.

Large-scale groundwater development has followed the comprehensive programmes of hydrogeological and hydrologic investigations that have been carried out over the years starting from 1954. Initially these programmes were started with technical co-operation from industrialized countries, but with the development of local capability these programmes are now handled by local personnel, with the foreign assistance confined largely to financial support for the acquisition of equipment. During the last 25 year the groundwater resources of Pakistan have been investigated in detail in all areas of interest as regards economic development. These investigations have defined the extent and the properties of the vast Indus basin aquifer, which extends over an area of about 340,000 km^2 and which represents a groundwater resource of the greatest importance for the economy of the country. The recharge to the Indus basin aquifer, in the area co-extensive with the canal irrigation system, has been estimated at about six million ham., of which about 70 per cent is usable for irrigation.

The development of groundwater in Pakistan is carried out on a limited scale by traditional methods, using dug wells and "karezes," but mainly by the use of tube wells. The most extensive groundwater development has taken place in the Indus basin, for irrigation in both the public and the private sectors. Groundwater development in the public sector has been done in projects which have been planned taking into consideration all the technical and economic factors. Considerations of "economy of scale" favour the adoption of large-capacity public tube wells (averaging 90 litres per second); and for their operation electric networks have been provided. However, private tube wells have grown in numbers that are practically uncontrolled; and a local technology has developed under which wells are drilled manually to depths of 30 to 50 m and produce an average discharge of 30 litres per second. The private tube wells are equipped with locally manufactured centrifugal pumps and operated with low-speed diesel engines or electric motors. Electric power is available for only a third of the private tube wells, the total number of which has increased to about 190,000.

About 13,000 public tube wells are used for irrigation; and groundwater is the primary source for urban water supply for most towns. Lahore, a major city, gets its supply of 600,000 m^3/day from about 170 tube wells.

Institutions have developed in Pakistan for the exploration, development, and monitoring of groundwater, with the leading role played by the Pakistan Water and Power Development Authority (WAPDA).

For the effective management of groundwater resources, a start has been made in the promulgation of groundwater legislation in one of the four provinces. For the protection and conservation of groundwater resources, monitoring functions are being performed by a monitoring organization of WAPDA.

A number of problems are related to groundwater development. The requirement for economical production of groundwater, in the face of rising energy prices, calls for improvement in the efficiency of the wells and the pumping equipment. Where indigenous technology has evolved, it needs study and improvements in design. The deterioration of wells and its effect on the environment also requires research to develop effective and economic methods of rehabilitation. To manage groundwater properly, it will be necessary to construct valid groundwater models, with continuous improvement of their hydrologic parameters, so that problems of degradation in water quality can be dealt with in a timely manner: this work has to be carried out simultaneously with monitoring. Groundwater recharge also deserves attention.

Q. THAILAND

Area: 514,000 km^2 Population: 50 million

1. Groundwater Availability

In Thailand, groundwater is commonly available in rocks of almost every type except solid granite. So far, alluvial sediments and limestone are acknowledged to be the two best aquifers. In other hydrogeological rock units, such as clastic sedimentary rocks and metamorphic and volcanic rocks, groundwater mainly occurs in the bedding planes and fractured systems.

The country has been divided into seven major groundwater regions: the northern highland, the upper central plain, the lower central plain, the Korat plateau, the Mae Klong basin, the eastern provinces, and the peninsula. The principal aquifers in the northern highland and upper central plain are the river-floodplain and terrace deposits. The thickness of the river-floodplain aquifer ranges from 13 m in the highland to 150 m in the upper central plain. The shallow wells normally yield more than 30 m^3/hour and wells drilled to the depth of 100 to 150 m yield more than 100 m^3/hour. In the river terrace aquifer, wells to the depth of 200 m normally yield 150 to 280 m^3/hour.

The lower central plain is formed by a sequence of clastic sediments at least 2,000 m thick. Within the upper 610 m, the sediments are divided into eight principal sandy artesian aquifers, separated by thick clay layers. The co-efficient of transmissivity of these sandy aquifers is in the range of 40 to 130 m^3/hour.

In the Korat plateau, groundwater is mainly abstracted from the fractured zone of sedimentary rocks, mostly sandstone and shale, which cover most of the plateau. The average yield is normally less than 10 m^3/hour, but yields as high as 50 m^3/hour have been obtained in areas where the complex fractured systems can be located. At the central part of the plateau, usable groundwater potential is limited by the occurrence of rock salt and gypsum.

Three hydrogeological units of unconsolidated sediments can be mapped in the lower Mae Klong basin: the river terrace, the deltaic plain, and the recent Mae Klong floodplain. The floodplain aquifer is a very shallow and productive aquifer. More than 5,000 jet wells have been constructed by the villagers for their small-scale agriculture. The jet wells normally yield more than 40 m^3/hour at a depth of about 20 m. The deltaic plain is in hydraulic continuity with the lower central plain and groundwater conditions within this area are similar to those encountered in the lower central plain. The terrace aquifer is relatively less productive. Well-pumping rates do not normally exceed 25 m^3/hour at a depth of about 70 to 100 m.

The alluvial aquifers in the eastern provinces are limited both in depth and aereal extent; wells drilled in the alluvial aquifers in this part yield only 7 to 10 m^3/hour. Deep groundwater wells drilled in metasedimentary rock and metamorphic rock yield more than 20 m^3/hour and have been drilled in many places where the complex fractured systems can be located.

The main groundwater resources of the peninsula occurs in clastic sediments of the eastern coastal plain 100 to 300 m thick. Wells drilled in this region normally yield from 10 m^3/hour up to 100 m^3/hour. In addition to this, coastal aquifer limestone is the second important aquifer of the peninsula. Wells in limestone normally yield 10 to 200 m^3/hour depending on the size, depth, and complexity of the solution channels.

2. Groundwater investigation

A programme for groundwater investigation was undertaken by the Department of Mineral Resources in 1955. Under this programme, the hydrogeological map of the Korat plateau was compiled, and was published in 1978. Hydrogeological maps of the northern, central, western, eastern, and southern parts of Thailand have been completed and are being published, at a scale of 1:500,000. Detailed studies of groundwater resources in many subbasins have also been carried out by means of surface and subsurface geophysical surveys, drilling operations, and pumping tests. Reports of the detailed studies of these subbasins are available.

At present, the Department of Mineral Resources operates eight electrical-resistivity survey teams and one seismic refraction team, to locate wells in areas of low groundwater potential and in complex areas. The geophysical survey teams are also used in the detailed studies of the subbasins, along with other feasibility studies. A countrywide airborne survey for the study of natural resources is in process and will commence by October 1983. A programme of groundwater simulation studies, coupled with the investigation of land subsidence in the Bangkok area, is now under way.

The main problems encountered in the groundwater investigation programme are of a financial nature. The national budget set for investigation is only about two per cent of the total budget for groundwater development, and the insufficiency of the budget will result in a shortage of trained personnel and proper equipment.

3. Status of groundwater development

Groundwater development can be classified at present into two categories:

The first is the development of groundwater for specific end uses, such as urban water supply and irrigation. Now more than 1,000 high-yield wells are in service for these purposes.

The second category is the provision of safe drinking water for rural areas throughout the country. In this category, the National Potable Water Project aimed to provide at least 30,000 villages with potable groundwater and pointed out that at least 50,000 groundwater wells should be drilled in order to meet this goal. Up to now, only 23,000 wells have been completed, serving 18,000 villages. A plan to accelerate drilling operations, with sufficient financial support, was set up in 1981: under this plan, five government agencies are to complete at least 4,000 wells per year.

R. TUNISIA

Area: 163,600 km^2 Population: 7 million

The country faces the Mediterranian Sea to the north and the Sahara desert to the south. The northern and eastern parts of the country are hilly and mountainous, with elevations up to 1,500 m. The central and southern parts are flat.

Rainfall is more abundant to the northwest (400 to 1,500 mm/year) than in the central part (150 to 400 mm.) The southern part--about half the country--gets less than 150 mm/year.

Most of the geological formations are Mesozoic and Cenozoic, with Quartenary plains and valleys. Water resources amount to four billion m^3 of surface water and 1.5 billion m^3 of groundwater, of which about one-third is extracted from dug wells (mainly shallow wells), and two-thirds from drilled wells.

The present rate of extraction is in the range of 900 million m^3/year, including about 180 million m^3 for drinking water and the rest for irrigation, this allocation being made through a master plan fcr water resources development.

In Tunisia water resources management and conservation is the subject of national legislation enacted in 1975 which gives priority to the satisfaction of needs for drinking water.

One of the main water problems in Tunisia is that of salinity, with one-third of the total water resources containing more than 3,000 parts per million of dissolved solids.

Another is the intrusion of saltwater into coastal aquifers as a result of overpumping. To offset this, protection areas have been established by law, within which water extraction is limited or forbidden. Artificial recharge schemes have also been developed to inject underground, through recharge wells, the excess surface water that would otherwise be lost to the sea following rainy periods. In central Tunisia, floodwaters are spread over flat plains for irrigation and for recharge purposes.

In Tunisia all groundwater activities are entrusted to the Ministry of Agriculture through the Bureau for Inventory and Hydrological Research (BIRH), which has a local office in each of the six regions of the country. The BIRH includes some 20 hydrologists/hydrogeologists and 100 subprofessionals organized in specialized teams (geophysics, well logging, pumping tests, hydrochemistry, and surveying). A national network of wells and boreholes for the monitoring of groundwater resources is operated by the BIRH. Water resources data are processed through a computer center where studies using mathematical models are being carried out.

BIRH has at its disposal one drilling rig with a 150 m capacity which is utilized exclusively in drilling for piezometres. Drilling of exploitation tube wells is the responsibility of a national company (RSH) which operates 25 rigs to depths of 200 to 700 m (two rigs have a capacity of 2,000 m).

S. TURKEY

Area: 780,500 km^2 Population: 45 million

The geology of Turkey is characterised by widespread tectonism. About one-sixth of the country is covered by alluvium and one third by metamorphic rock.

Water-bearing units range from Paleozoic marble to Quaternary alluvium.

In many plains, the most important aquifers occur in Quaternary and Pliocene alluvial deposits. The Cretaceous and younger limestones are karstic and discharge large volumes of water through springs.

The average annual precipitation for the entire country amounts to about 670 mm, or an equivalent water input of about 518 billion m^3; it could be concluded that Turkey is rich in water resources. Approximately 166 billion m^3 is estimated to flow as surface runoff. However, since 1923, the surface water supply has not been sufficient to meet the domestic water needs of many cities, villages, and towns. The development of groundwater therefore started in the 1920's. Until 1949 several government institutions carried out local studies of groundwater resources, and drilled wells.

Between 1952 and 1956 water wells were drilled in various regions of Turkey by the State Hydraulic Works (DSI).

The groundwater law, promulgated in 1960, is intended to protect groundwater resources and to encourage the public to use groundwater with maximum benefit for the country's economy. According to this law, groundwater is the property of the State and its development is regulated.

In reconnaissance and planning stages of the groundwater investigations, the annual safe groundwater yield from 345 plains has been estimated at 9.5 billion m^3/year. Of this, five billion m^3/year of groundwater were utilized to irrigate 600,000 ha of land.

Up to the beginning of 1983, groundwater irrigation has been accomplished for 217,000 ha of land, through the drilling of 4,916 exploitation wells for 538 "land and water cooperatives" areas. Other types of irrigation using groundwater are based on reimbursement-of-cost plan, mostly in the lands of the State Reproduction Farms.

Another type of irrigation utilises groundwater in irrigation canals when surface irrigation water is insufficient.

About 4.5 billion m^3/year of groundwater resources are available for domestic and industrial use.

Water-well drilling activities are undertaken for three purposes by the State Hydraulic Works in Turkey: (a) exploitation well drilling; (b) domestic and drinking-water well drilling; (c) exploratory well drilling.

Several types of maps exist at various scales (1:500,000 to 1:100,000) for the plains and basins for which groundwater potential has been determined. A hydrogeological map is to be completed next year in collaboration with the International Association of Hydrogeologists.

Tracing groundwater flow is a well-known technique used in Turkey for investigation of regional hydrogeological features in karstic aquifers. One mathematical model has been made in Turkey and one electrical analogue model was constructed in 1970 for the Thrace basins. Besides these, geophysics and remote-sensing techniques are being utilized for investigations of groundwater.

Improvements are being sought in the following areas:

(a) training of drilling personnel in a new technique (mud engineering flashing), and other skills;

(b) new methods for karstic investigations, since one-third of the country is covered by karstic limestone; and

(c) new methods for geophysical projection, photogeological interpretations, and remote-sensing techniques for groundwater investigations.

T. VENEZUELA

Area: 912,000 km^2 Population: 15 million

Systematic hydrogeological explorations in Venezuela started with the elaboration of the map of porous media in the region of Llanos (80,000 km^2). Abundant information provided by the petroleum industry was utilized.

As Venezuela is an oil-producing country, many data are available on subsurface geology, as well as topographic maps, aerial photographs, and other basic information, such as the electrologging data of oil wells. In the analysis of thousands of electrologs, some 800 were selected according to the spacing of oil wells (5 to 10 km).

The study included sections, block diagrammes, and stratigraphic columns in order to show spatial distribution and the relationship among various permeable and impermeable media. Several types of maps were prepared, showing the number of permeable strata, the thickness of permeable and impermeable media, and the number of impermeable strata. These maps involve the terrains down to 500 m depth, divided in intervals: 0-100 m, 100-200 m, 200-300 m, and 300-500 m.

This survey made possible a preliminary understanding of the distribution of porous media in the main petroleum-bearing part of the country (80,000 km^2) during a period of only eight months.

Subsequently, the hydrogeological map of Venezuela (scale 1:500,000) was elaborated, including basic information about the extent and the types of aquifers in the country. The map is a basic tool for further programming of hydrogeological exploration and the explotation of groundwater. This work was done in close co-operation with Yugoslav experts. A study covering 450,000 km^2 south of Orinoco was carried out by national hydrogeologists. The work consisted of gathering and interpreting data from some 6,000 water wells. The lithologic map, which served as a base for the elaboration of the hydrogeological map at the scale of 1:1,000,000, was prepared by interpretation and adaptation of geological maps and by field survey in critical zones.

Systematic hydrogeological exploration was performed in three areas of the flat region "los llanos" in order to assess the groundwater potential needed urgently for agricultural development in this vast section of the country. The llanos cover a surface of 300,000 km^2, from the Andes in the north to Rio Guanare in the south. The three areas in which systematic exploration was performed are in the eastern, central, and western parts. In each of them, all hydrogeological features have been determined and an evaluation of renewable groundwater reserves has been made. The exploration consisted of exploratory water-well drilling, detailed sampling of rocks and water, and chemical analyses of minerals. All exploratory water-wells were later converted into observation wells for measurement and monitoring of groundwater-levels.

In addition, a considerable number of test wells were constructed for the determination of hydrogeological parametres of the aquifers. The results in the three areas are as follows:

(a) Mesa de Guanipa (east). Surface infiltration is 22 per cent of total precipitation. Transmissivity of the aquifer varies from 1,000 to 3,000 m^2/day. Renewable reserves of groundwater are approximately 350 x 10^6 m^3/year.

(b) Guárico (centre). Infiltration is 18 per cent; transmissivity varies between 500 and 2,500 m^2/day; and the renewable reserves are around 400 x 10^6 m^3/year.

(c) Bocono-Masparo (west): sub-andean region. Infiltration is 15 per cent; transmissivity 1,000 to 4,000 m^2/day; and the renewable reserves are 260 x 10^6 m^3 per year.

In all three areas, groundwater is of good quality for domestic and agricultural use, although in Mesa de Guanipa it was found to be slightly corrosive.

The results of these explorations, including mathematical modelling and interpretation, make possible the effective management of ground-water resources by national authorities.

U. YEMEN ARAB REPUBLIC

Area: 195,000 km^2 Population: 8 million

The Tihama plain covers an area of 18,000 km^2, 450 km in length and 40 km in average width. Geographically, it lies between mountain highlands to the east and the Red Sea to the west. The mountain highlands, which form the catchments of seven major streams or "wadis," rise to altitudes as high as 3,5000 m. The Tihama plain rises to elevations of 300 to 350 m above mean Red Sea level. Average annual rainfall ranges between 50 and 350 mm on the plain, while on the catchment it varies from 350 to 1,500 mm. The mean monthly rainfall never exceeds average monthly evaporation. Open-water evaporation has been estimated at 2,400 to 3,000 mm. The estimated average annual area devoted to crops is 2,350 km^2.

The principal aquifer of the Tihama plain is constituted of Quaternary alluvium consisting of beds, layers, and lenses of semiconsolidated and unconsolidated gravel and sand with clayey and silty matrix. The principal source of aquifer recharge is the rainfall occurring on the upper catchment, covering an area of about 32,500 km^2. A considerable portion of the rainfall appears as surface runoff and drains into the Tihama plain. About 40 to 50 per cent of surface water (base flow and spates) infiltrates the aquifer. The maximum thickness of the alluvium is not known; however, it generally exceeds 200 m in most parts of the region.

The groundwater balance has been computed for 1981-1982 as follows:

Annual recharge	402 10^6 m^3
Annual discharge	1,182 10^6 m^3
Annual storage depletion	780,10^6 m^3

Theoretically, the present rate of depletion would result in an annual decline of water levels of about 0.4 m over the whole Tihama plain. Actually, however, it would be higher in areas of intensive pumpage than in areas of recharge.

Three major consequences of excessive pumpage can be foreseen: (a) abandonment of irrigation wells due to higher pumping costs; (b) intrusion of seawater into the aquifer and abandonment of well fields; and (c) other socioeconomic problems, including those of population migration.

The above computations indicate the need for immediate control of the present rate of aquifer depletion. The urgency of the problem requires international assistance, technical as well as financial.

V. YUGOSLAVIA

Area: 256,000 km^2 Population 23 million

Yugoslavia is a country of sharp topographical contrasts. Flatlands predominate in the north. The southern Alps, the Dinaric Mountains, and the Carpatho-Balkan Mountains occupy the remaining parts. The hydrographic network is dense. The Adriatic coast, including more than 1,200 islands, is much indented. Mean annual precipitation in Yugoslavia may reach as high as 1,000 mm.

The territory of Yugoslavia can be subdivided into three large hydrogeological regions, the Pannonian, inner, and karst basins, filled with up to several thousand m of Neocene and Quaternary sediments. Porous rocks dominate under the low and flatland of the Pannonian. The alluvial sediments may in places yield up to more than 200 litres per second per well.

The inner region extends in the central part of Yugoslavia between her extreme northwestern and southeastern ends. The land is mountainous, and built of various Paleozoic to Quaternary formations. Impermeable igneous, metamorphic, and compact sedimentary rocks are predominant. Insulated carbonate rocks and alluvial deposits represent the main aquifers.

The karst region is a vast continuous belt at the southwest part of Yugoslavia, parallel to the Adriatic coast, extending from Italy and Austria at the northwest end to Albania at the southeast. The region is built of calcareous and dolomitic sedimentary rocks, the thickness of which measures in places about 5,000 m. This area underwent intensive tectonic deformation with faults, some of them with throws exceeding 1,000 m. Groundwater of the fracture type has carved out an immense number of corrosional and erosional surfaces and underground morphological features. The region is known worldwide as a typical karst area: local names for some morphological features of karst have even been introduced into international terminology. There are 230 springs having minimum discharges exceeding 100 litres per second.

In Yugoslavia, groundwater is utilized primarily for domestic community and industrial purposes, and less for agriculture. Groundwater management is carried out jointly by the agencies concerned within the framework of federal and state water laws. Permanent inventories and annual assessments of groundwater resources are obligatory.

Systematic explorations for groundwater on Yugoslavian territory began in the last century. Comprehensive regional and local explorations have been stimulated by the expanding demand for water, the construction of numerous hydroelectric plants, and the need to dewater mines and drain agricultural soil. Intensive explorations have stimulated engineering firms and geological institutes to develop many teams of specialists.

Specialists in remote sensing exist in all major exploration agencies and companies, as well as in the universities. Thirteen teams specialize in photogeology and infrared scanning; seven teams in remote-sensing studies, using satellite data; and five teams in airborne geophysics.

Applied geophysics are dealt with by a small number of specialized companies. Altogether there are 42 teams for terrestrial geophysical surveys (22 teams for the resistivity surveys, nine teams for seismic exploration, five teams for magnetometry, and six teams for gravimetry).

Experienced hydrogeologists, engaged in various field, laboratory, and desk research work, exist in all research organizations. In total, there are 88 teams, but their subspecialization varies.

Exploration drilling has also been highly developed. There are some 50 companies dealing with this activity. Most of them are small groups assembled to fulfill the needs of their own organizations. Only four large companies have extensive international experience and equipment for exploratory and production drilling for water. In total, there are 154 rigs for exploratory drilling. Of these, 140 are rotary, nine are percussion, and five are combination rigs. Forty fully equipped test-pumping teams have been organized, mainly within individual companies.

Laboratories that can carry out water analyses are established in most towns. Some 90 of them provide services for complete chemical and biological analyses.

Some 25 years ago Yugoslav engineering firms specializing in research, design, and water development started contracting for the execution of a great number of groundwater exploration and development projects abroad, almost all of them in developing countries. The construction of numerous hydroelectric plants and reclamation schemes executed by Yugoslav companies has also required the service of a large number of groundwater specialists. Dozens of Yugoslav hydrogeologists and other groundwater experts have participated in projects of the United Nations organizations.

ANNEX III (continued)

W. ZAMBIA

Area 752,600 km^2 Population: 6 million

1. General

The mainstay of the economy of Zambia has for a long time been copper. At the moment the government is shifting to agriculture because of the world economic recession, especially in the prices of base metals. Zambia, like many other countries in southern Africa, does not get enough rainfall for its requirements. The shift to agriculture has therefore increased activities in groundwater development for irrigation.

2. Groundwater resources

Three important hydrogeological units can be identified. These are:

(a) The pre-cambrian basement complex, which consists of intrusives and old sedimentary rocks. The upper subdivision, consisting mostly of sedimentary rocks, is a better aquifer than the lower.

(b) The Katanga group, in which bedded copper deposits occur. The Katanga rocks are between 500 and 690 million years old. The rock types found in this group are limestones and dolomites, interdigited in the old basement rocks. The Katanga-group rocks are the best aquifers, with yields reaching up to 20.0 litres per second per borehole. Most industrial and agricultural development is in the proximity of the Katanga formations, which are rich in mineral resources.

(c) The Kalahari sandstones, extending from Botswana to the western province of Zambia. Drilling problems are encountered in these formations, which are underlain by clays and shales. A considerable amount of collapsing occurs during drilling. This problem has been offset by the use of "ordex" drilling. This is a method in which the casing is set simultaneously with drilling.