PN AAAV-364 45946

WATER AND SANITATION
FOR HEALTH PROJECT

Operated by
CDM and Associates

Sponsored by the U.S. Agency
for International Development

1611 N. Kent Street, Room 1002
Arlington, Virginia 22209 USA

Telephone: (703) 243-8200
Telex No. WUI 64552
Cable Address WASHAID

YEMEN SANA'A BASIN WATER RESOURCES ASSESSMENT

WASH FIELD REPORT NO. 164

JUNE 1986

Prepared for
USAID Mission to the Arab
Republic of Yemen
WASH Activity No. 175

WASH FIELD REPORT NO. 164

YEMEN SANA'A BASIN WATER RESOURCES ASSESSMENT

Prepared for the USAID Mission to the Arab Republic of Yemen
under WASH Activity No. 175

by

David Laredo
Joe M. Haratani
and
William G. McMullan

June 1986

Water and Sanitation for Health Project
Contract No. 5942-C-00-4085-00, Project No. 936-5942
is sponsored by the Office of Health, Bureau for Science and Technology
U.S. Agency for International Development
Washington, DC 20523

Table of Contents

Chapter **Page**

Chapter **Page**

APPENDICES

FIGURES

TABLES

TABLES **Page**

ABBREVIATIONS

lcd	liters per capita per day
l/s	liters per second
l/s/m	liters per second per meter
Mm	million meters
mm	millimeters
Mm^3	million cubic meters

EXECUTIVE SUMMARY

Background

This assessment was requested by AID/Yemen in recognition of the severity of the water resources situation in the Sana'a Basin. The World Bank, at the request of the Government of Yemen, prepared an Action Plan for the basin early in 1985. Subsequently, two governmental agencies requested AID/Yemen to join with the World Bank in implementing the plan. The preliminary phase of a comprehensive three-year water resources study of the Sana'a Basin sponsored by the USSR was expected to end in early Fall 1985. The Action Plan predicated much of its technical basis on the USSR study. These two actions led directly to AID's request to WASH for a team to visit Yemen in October of 1985.

This report, therefore, represents the WASH team's effort for the period of October 1 to 23, 1985. The team had limited success in obtaining either the results or data from the USSR study; it assembled a database, however, of almost 60 documents and reports (see Appendix F), interviewed approximately the same number of people (see Appendix A), and made several field trips.

On the basis of the information and discussions obtained during the in-depth briefings held at the WASH office in Washington, D.C. (September 12 and 13, 1985), the initial briefing session in Sana'a (October 2, 1985), and discussions with the AID/Yemen Mission Director and individual staff members, the objectives for this engagement may be stated as follows:

- Provide the AID/Yemen and the Asia and Near East Bureau with a better understanding of the Sana'a Basin water resources situation.
- Frame the short- and long-term critical issues which must be resolved and present viable options for projects or programs related to these issues.
- Present recommendations for USAID/Yemen interventions pertinent to the Sana'a Basin water resources situation, and the water sector as a whole, which have low-risk or high-success potential.
- Review the World Bank Action Plan for the basin and make recommendations for USAID/Yemen interventions in view of the foregoing objectives.
- Review USAID/Yemen's last completed intervention (Project No. 028) and continuing rural water supply (Project No. 044) and determine their effectiveness regarding the Yemeni water resources sector institutions involved.

Statement of the Problem

This assessment verified the conclusions reached by many investigations into the basin's water resources situation. The groundwater in the basin is being "mined" (that is, more water is being extracted than can naturally be recharged), as indicated by drastically falling water levels (depending on the

location in the basin, 16 to 38 meters over the past 13 years). Past studies indicate the basin's groundwater availability (surface water sources are nil) may be exhausted in 5 to 25 years. Most work to date, however, has been concentrated over limited portions of the basin, and it can be correctly stated that as of mid-1985, there was an insufficient database for accurately determining the water resources capability of the basin.

Further, the problem is compounded by the following factors:

- An arid climatic setting beset by drought conditions
- Dependence on a complex groundwater system that receives limited recharge and a lack of knowledge regarding the mechanics of the groundwater system
- Population growth in and around Sana'a and uncontrolled well-drilling and pumpage by private landowners
- The inability to protect or manage existing groundwater resources.

Water use trends provide further insight into the magnitude of the problem. The National Water and Sewerage Authority (NWSA) is providing approximately 9.1 million cubic meters annually for Sana'a (a per capita rate of approximately 100/lcd for all demands plus losses). While this unit value is relatively low for an urban water supply, the gross value represents almost a fourfold increase in 12 years. By 1995, the city's population is projected to grow by between 60 percent to 100 percent, depending upon the various projections.

Irrigation use is driven by the uncontrolled pumping from the several thousand wells in the basin (estimates range from 1,000 to 6,000, and the USSR study is said to have inventoried over 3,000 wells.) The pumping from these wells is roughly estimated at 40 to 80 Mm^3 annually. This value is some five to ten times that for all demands in Sana'a. If the past years' trends in new well installation continue (approximately 300 annually) the irrigation demand value could grow at the rate of 15 percent annually.

The challenge for Yemen Arab Republic Government (YARG) is obvious: the rate of increase in all demands must be controlled and new water sources developed. While easy to conceptualize, the solutions to the crisis situation (as discussed in the main body of this report) will be extremely difficult to implement.

The basin's problems are recognized by the Central Planning Organization (CPO), YARG's agency responsible for development planning and most of the other institutions involved in the water resources sector. CPO representatives indicated that they were close to adopting the various elements of the World Bank Action Plan as national policy. Further, the basin was to be given priority in the nation's third five-year plan (FY 1987 - FY 1991).

While the problems are known and the basin's significant problems can be traced to uncontrolled pumping by thousands of private irrigation wells, no one government agency has the ability or responsibility to control or protect the aquifer. Further, only one agency, the National Water and Sewerage

Authority (NWSA), serving the water supply needs for Sana'a, has significant activity in the Sana'a Basin. NWSA's utility responsibilities as a water supply provider have been seriously hampered by the overall situation in the basin, and NWSA does not have the power to mitigate the adverse effects of the overpumping.

Other institutions involved in the water resources sector are the Central Planning Organization, the nation's development planning group; the High Water Council, organized to act as the agency to make national water policy (which is really an agency on paper only, as they rarely meet and have made no policy); the Rural Water Supply Division of the Ministry of Public Works; the Ministry of Agriculture and Fisheries, through its Directorate of Irrigation; and the Department of Hydrology (DOH) of the Ministry of Petroleum and Minerals (formerly YOMINCO). Only the DOH in YOMINCO offers any promise as an institution which can play a national role in Yemeni water resource planning. NWSA is the most active agency and should best fulfill its role as a service providing agency rather than branch out into national water resources planning.

Water Resources

The water resources component of this assessment has relied primarily on available published data from previous investigators; information from YARG representatives, donors, and local contractors; and limited field reconnaissance. The conclusions of this study are presented in the paragraphs that follow.

Hydrology

The Sana'a Basin is located in an arid region where annual precipitation is typically 200 to 300 mm or less, and where evapotranspiration far exceeds available moisture. Available climatic records also indicate extended drought conditions in this region of the Yemen Arab Republic.

- Surface run-off is correspondingly infrequent, and most wadis are ephemeral. When run-off does occur, it is often torrential, of short duration, and carries high sediment loads. All prevailing hydrometeorological conditions combine to limit the amount of recharge available for groundwater replenishment.

Hydrogeologic conditions in the Sana'a Basin are complex, incompletely known, and reflect a geologic history characterized by structural disruption and volcanism. Water-bearing hydrostratigraphic units include the basin's alluvial deposits, various volcanic units, and Mesozoic sedimentary strata. Traditionally, acting as the area's primary source of groundwater, the alluvial units were subject to agricultural-related overpumpage during the early 1970s. As water levels in the alluvium rapidly declined, attention focused on the deeper bedrock units for new sources of groundwater. Serious exploitation of the Cretaceous Tawilah Sandstone aquifer has resulted.

Some 300 to 400 meters thick, groundwater in the Tawilah occurs under unconfined and artesian conditions and is controlled primarily by the presence of fracturing. Transmissivities thus vary with location as much as two orders

of magnitude (10 to 1,000 m^2 per day), with permeabilities of 0.05 to 1.0 meters per day. Well yields and specific capacities exhibit similar variability. Fracturing may also hydraulically connect the Tawilah to the overlying alluvium and volcanics.

Groundwater in the Tawilah appears to move from the southwestern and southeastern flanks of the basin toward the north. Structural discontinuities and volcanic intrusives may disrupt the pattern, although available subsurface geologic data are inadequate in terms of defining the aquifer system.

Tertiary and Quaternary volcanics in the basin overlay the Tawilah and also contain some groundwater, again as a result of fracturing and weathered zones between lava flows. Transmissivities and well yields are variable. The thickness of these units is variable, ranging up to hundreds of meters. Depth to groundwater is variable, tends to parallel topography, and is found under unconfined and perched conditions. Springs discharge from the volcanics at selected locations in the basin. Fracture systems in the volcanic units may allow recharge to the underlying Tawilah Sandstone in some locations.

No information exists regarding the hydrogeology or groundwater potential of deeper geologic units, such as the Kohlan Sandstone, within the Sana'a Basin.

Water Resource Availability

The Tawilah Sandstone serves as the primary source of groundwater in the basin. Primarily as a result of overexploitation, water levels in this aquifer have been dropping rapidly, in some cases up to six meters annually, with cumulative declines of 18 to 38 meters reported. Estimates of groundwater availability in the Tawilah, and inflow to the Sana'a Basin vary widely. The differences result primarily from disagreement over the amount of recharge the aquifer receives and the methods used for calculation of the estimates. Recent isotopic dating results for Sana'a Basin aquifer samples suggest that the groundwater is fossil (2,000 to 20,000 years old) and that little or no recharge has occurred.

Two basic conclusions may be drawn regarding the extent of groundwater resources in the Sana'a Basin. First, there is insufficient hydrogeologic data to allow a full understanding of the aquifer system(s). Second, regardless of what the resource is, it is finite and insufficient in terms of sustaining indefinite growth and unmanaged exploitation.

Future Water Sources

Additional groundwater is probably available in the Tawilah aquifer if tapped, depending on the practical constraints of cost, access, logistics, and land ownership, that result from deeper drilling and more distant drilling from the demand centers. If additional exploitation of the aquifer is unavoidable, it would be logical to evolve and implement national policy that assigns priority to water use allocations and enforces conservation and management of the limited resources available. The focus of new development in the Tawilah should be on serving areas that receive significant recharge and on developing withdrawals on a sustained (safe) yield basis. Guidelines for additional exploration and development should be: (1) to acquire sufficient data to

understand the hydrologic system and (2) to monitor and manage groundwater exploitation on a finite resource basis.

Information on the groundwater potential of deeper units, such as the Kohlan Sandstone, is lacking and should be obtained by way of a phased program of investigation and exploration.

Stream flow monitoring, data, and information on which to assess the feasibility of augmentation by way of surface water impoundment schemes are unavailable. Mean annual flow, peak discharge, and other information with which to assess firm yield should be obtained. (Although the USSR study has reportedly evaluated various watersheds in the basin, the results of its efforts were unavailable for review.)

Recommendations

Recommendations for AID interventions include a mix of project options related to the national water resources sector as well as specifically to the Sana'a Basin. The recommended overall AID program strategy is to provide full support for the World Bank Action Plan, without being completely tied to its preconditions. Several low-risk options are presented for consideration by USAID. One group of low-risk options is closely related to the water resources problem in the Sana'a Basin. Projects that USAID already has in its authorization process or has under consideration, such as the Irrigated Farms Project (IFP), and a communications activity, are included in this group. Other recommendations are described below.

Training

Training is an obvious option for AID/Yemen interventions. Numerous such programs in almost every sector have been implemented over the past dozen years. The training option recommended herein is directly related to the World Bank Action Plan and to the creation of the Water Management Division (WMD). The program has been referred to here as the "institute model," as it is based upon establishing a water resource institute in Sana'a.

This proposed "institute model" of training would work as follows: WMD and DOH's senior managers would determine the number of new positions needed. Engineers and geologists would be recruited (some may come from DOH's present staff) and given 9 to 12 months of intensive training in hydrology. Once the program ended, they would receive at least a certificate and return to or start work with the Department of Hydrology.

The training program offered (actually higher level education and field work equal to a master's degree) would be given in Sana'a. Expatriate or local trainers would present the classroom work. The course would be designed based upon WMD's program and how the DOH would function under WMD in its short- and long-term program. The program described could enroll approximately 30 trainees and the curriculum geared to water resources and hydrology pertinent to WMD's role and activities.

Within the framework of the World Bank Action Plan, several projects, accomplished separately or combined in single or several technical assistance package(s), are recommended for consideration by AID/Yemen. These include:

a. A comprehensive master planning study of the water supply needs in the Sana'a Basin. The project would be basinwide but would concentrate on Sana'a city, and its environs, and would include the study of feasible interbasin transfers of surface or groundwater and alternatives for groundwater augmentation.

b. Technical assistance to NWSA for provision of short-term relief in the existing Sana'a well fields. The city's wells will require deepening within the next five to six years, and the project referred to here would provide the technical assistance only, to implement the needed improvements; and includes program design, project award, and monitoring and supervision of the contractors' activities.

c. Implementation of an exploration program to estimate the potential groundwater reserves in the Tawilah Sandstone aquifer. This program will include the technical assistance for program design, geographical data interpretation, project award and monitoring, and supervision of the contractor's activities.

d. Implementation of a program that tests the potential of the Kohlan Sandstone aquifer. The technical assistance will include the program design (deep well-drilling, aquifer testing, and geophysical investigations), project award and monitoring, and supervision of the contractor's activities.

e. The technical assistance and advisor services required to design and implement a hydrologic monitoring network for the Sana'a Basin. The network would use the USSR study as the basis for program design. Selected existing wells, new wells, meteorological and surface water monitoring stations (existing and new) would be incorporated into the network. The program would include continued sampling and analyses for use in technical support for water management decisions, and to provide hands-on training for Yemenis.

Cost of Recommended Interventions

The "institute model" training program and five technical assistance projects described in the preceding section represent a total investment of approximately $6.3 million (US$) plus approximately $20 million (YR). The individual projects would run from 15 to 24 months and provide a total of approximately 254 expatriate person-months plus approximately 830 Yemeni person-months and all support costs. Further details are provided in Chapter 5; it is important to recognize, however, that these costs have been purposely estimated on a conservatively high basis due to incomplete data.

World Bank Action Plan

A detailed review of the World Bank Action Plan is presented in Appendix D and is further discussed in Chapter 5. The Action Plan provides a framework for long-term action which effectively melds technical and institutional approaches to implement the start of a national water management plan. Recommendations were made (See Appendix D) pertinent to changing certain

elements of the plan. Inherent in all of the recommendations was the belief that a much greater component of donor assistance would be required for several years in order for the WMD to be successfully established. Cost estimates were prepared for an expanded program of six years in duration, furnishing 338 man-months of expatriate advisory services and 3,000 to 4,500 man-months of Yemeni man-months for technical and administrative support. The rough estimates came to approximately $12 million (US$) plus $122 million (YR). If this total is combined with the "institute model" training program the total cost of the program would be approximately $6 million (US$) annually for five years (i.e., $30 million total equivalent dollars).

It is recommended that USAID/Yemen take a lead role in coordinating water sector activities among all potential donors. The annual cost of $6 million for five years could be used as the starting point for such discussions.

Conclusions

The Sana'a Basin's water resources situation is rapidly approaching the crisis stage. While the situation is recognized at the highest levels of government, no concerted action is being taken either to solve or to even alleviate the problems.

The World Bank Action Plan provides a framework for definitive action and should be implemented. Several low-risk options are worth pursuing, especially those which involve the engineering projects which will quantify the water supply needs of the basin and determine the available resources, in and out of the basin, which can be developed to meet these needs. The four such projects outlined herein would represent an investment of approximately $6 million (US$) (including the Yemen Rials (YR) equivalent in US $). AID/Yemen is wise, however, to take a cautious approach in providing assistance until the overall picture becomes clearer, especially actions required by YARG and intentions of other donors regarding the World Bank Action Plan, and other interventions these donors may be contemplating.

Time available for action is however, growing short. While the cautious approach is wise, interventions by AID/Yemen within the framework of the World Bank Action Plan, even without co-donor support, could act as the catalyst for widespread actions on several fronts. AID/Yemen must make the necessary decisions regarding such interventions.

Chapter 1

INTRODUCTION

1.1 Authorization for this Assignment

This Sana'a Basin Water Resources Assessment was authorized by a request of USAID/Yemen to the USAID sponsored Water and Sanitation for Health Project (WASH). The assessment was to determine the following:

- The extent to which the basin's water resources, under current trends in water use, would be adequate in the future
- The components of water demand and the manner in which the use trends could be modified to optimize the available water resources
- The manner in which the program of USAID/Yemen could contribute to the optimum use of the basin's resources.

In addition, the assessment would include two specific items:

- A detailed review and a determination of the Action Plan for Water Resources Management in Sana'a Basin (prepared in February 1985 by the World Bank, working with an Action Team composed of senior managers of many YARG agencies involved in the water sector.
- An assessment of the extent to which AID's Water Systems Management Project (No. 028) accomplished its purpose of enhancing NWSA's capabilities.

  (Appendix B presents the complete scope of services for the Basin Assessment, together with the full text of the Action Plan referred to previously.)

The WASH Operations Center mobilized the team of David Laredo, Joe Haratani, and William McMullan to carry out the assignment. Team member expertise included institutional analysis, engineering, and geology and hydrology. The team arrived in Sana'a, Yemen Arab Republic, on October 1, 1985 and worked through October 23, 1985.

1.2 Background

The AID/Yemen request represents a definite departure from the Mission's Water Sector strategy of recent years. Despite the growing recognition of the seriousness of the water problems facing the YAR, AID's strategy was one of noninvolvement, except for a five-year continuation of the Rural Water Project. This strategy was justified by the lack of progress by the YARG in the policy and planning aspects of the Water Sector and the politically sensitive nature of many of the issues requiring action. Over the past few years, actions by bilateral and international lending agencies have put

increasing pressure on the YARG to address pressing national water sector issues, especially those in the Sana'a Basin.

Many past studies have indicated the scarcity of water in this basin. Indeed, the groundwater in the basin is being "mined" (that is, more water is being extracted than can naturally be recharged), as indicated by drastically falling water levels (depending on the location in the basin, 16 to 38 meters over the past 13 years). Various forecasts indicate that the basin's groundwater availability (surface water sources are nil) may be exhausted in 5 to 25 years. Most work to date, however, has been concentrated over limited portions of the basin. It can be correctly stated that as of early 1985, the basin's water resource capability could not be accurately predicted.

Two related milestones gave cause for AID/Yemen to rethink its role in the water sector: the issuance of a World Bank Action Plan for the Sana'a Basin and the expected completion in late 1985 of the preliminary phase comprehensive study sponsored by the Government of the USSR concerning the water resources of the Sana'a Basin.

1.2.1 Sana'a Basin Action Plan

Early in 1985 the World Bank, responding to a request of the Central Planning Organization (CPO), organized an Action Team which assessed the needs of the Sana'a Basin and prepared the Terms of Reference for a broader sector assessment, which would lead to the development of a Sana'a Basin Water Management Plan (See Appendix B).

The Action Plan's short term activities required the YARG to institute a series of legislative changes to control groundwater exploitation in the Sana'a Basin. These included: extension of the protection zone around Sana'a, in which private well-drilling will be limited or prohibited; the licensing of all wells and well-drillers; and charging for water extracted from the aquifer.

The thrust of the Action Plan's long-term solution involves establishing a Water Management Division (WMD) to act as the technical arm of the High Water Council (See Chapter 3 for a description of the HWC). The WMD would formulate national and basinwide policies for water use and resource allocation, and be the national agency responsible for collection and analysis of all data pertinent to surface and groundwater availability and use. Further, starting with the Sana'a Basin, the Water Management Division would perform or administer studies which, when taken all together, will lead to the formulation of a National Water Management Plan.

The Action Plan can be considered a culmination of a series of studies that all recommended that the policy-making for water use and resource allocation be centralized. The High Water Council was organized for this express purpose, but has proven to be a weak and ineffective body regarding the performance of its mission. Providing the Water Management Division as a "technical secretariat" to the HWC (in effect, the WMD would have a national purview, with wide responsibility and power) on the surface appears to be a logical step in allowing the HWC to carry out its responsibilities. (Specific discussion on the World Bank's Action Plan is presented in Appendix D.)

The Action Plan has prompted interest amongst several donors. The UNDP has indicated its willingness to prepare an assessment of how that organization could help fund the expatriate advisors called for in the plan. The Government of the Netherlands and West Germany have also indicated their interest in providing funds to implement the project, especially on a co-donor basis. Both the CPO and Ministry of Public Works requested that AID/Yemen participate, alone or in conjunction with the World Bank, in the long-term program.

The World Bank has also indicated its willingness to be a major participant in creating the WMD and the follow-up studies. The Bank, however, has strongly indicated that its participation depends on the YARG's instituting the package of legislative changes required and increasing NWSA's tariff by 90 percent over the next three to five years.

1.2.2 USSR Study

The Action Plan predicates the Water Management Division's long-term activities predominantly on the results of the comprehensive three-year study of the Sana'a Basin's water resources being conducted under the sponsorship of the USSR. This study is expected to contain more comprehensive and detailed data than virtually all of the previous studies conducted in the basin. Preliminary results of the USSR study were expected to be available during the WASH team's period of activity in Sana'a; the report, however, was delayed. Several discussions, a review of the preliminary conclusions, and a single section of the final report represented the information on the USSR study made available to the WASH team.

1.3 Report Methodology

1.3.1 Objectives

The initial objectives of this study are generally described in Section 1.1 and in Appendix B. On the basis of the information and discussions obtained during the in-depth briefings held at the WASH Office in Washington, D.C. (September 1985), and the initial briefing session (October 2, 1985) and individual discussions with the AID/Yemen Mission Director and individual staff members, the objectives for this engagement may be stated as follows:

- Provide the Mission (and Asia and Near East Bureau) with a better understanding of the Sana'a Basin water resources situation.

- Frame the short- and long-term critical issues which must be resolved and present viable options for projects or programs related to these issues.

- Present recommendations for USAID/Yemen interventions pertinent to the Sana'a Basin water resources situation, and the water sector as a whole, which have low-risk or high-success potential.

- Review the World Bank Action Plan for the basin and make recommendations for USAID/Yemen interventions in view of the foregoing objectives.

- Review USAID/Yemen's last completed and continuing projects and determine their effectiveness regarding the Yemeni institutions involved.

1.3.2 Methodology

The WASH team's methodology for this assignment included interviews, briefings, review of reports/documents, and analysis. Some 60 persons were interviewed and approximately 65 reports/documents were reviewed, and analysis to determine the range of future water demand compared to aquifer yields was prepared (See Appendix A, and Appendix D).

Field trips were made on October 4, 16, and 17, 1985 by individual team members to obtain first-hand observations of the basin's geologic setting and to get a general understanding of the terrain and general conditions in the basin. An initial briefing to USAID/Yemen personnel on the objectives, work plan, schedule, and report outline was conducted on October 2, 1985. A great deal of valuable information was received from USAID/Yemen personnel and contractors at this briefing. An additional briefing was given to AID/Yemen personnel on October 19, 1985, and a presentation of the entire draft report was given to AID/Yemen on October 22, 1985.

1.4 Constraints to Water Resources Management in the Sana'a Basin

Water resources management issues in the Yemen Arab Republic are complex technically, due to the arid conditions, and extremely politically sensitive, due to the relatively short time the nation has been developing as a modern state. The Sana'a Basin offers its own set of unique problems within the national sector. This subsection presents several important constraints to effective planning and management for the Sana'a Basin's water resources, which became apparent during the early stages of the work conducted for this assessment. In effect, the subsection will act to frame the overall problem and is presented here as a preamble to the remainder of the report.

These constraints include:

- Virtually no significant quantity of surface water exists; therefore, there is almost total dependence on groundwater as the only available supply source for the basin.

- The aquifer is an extremely complex physical system, with low recharge potential.

- Little comprehensive data are available for the basin.

- The aquifer is being stressed by uncontrolled pumpage from thousands of privately owned wells used for irrigation purposes.

- No one institution is capable of exerting sufficient control either to manage or to protect the groundwater resources. (In fact, because the wells are privately owned, YARG institutions are finding that their activities are in danger of being curtailed by the overall situation.)

These constraints are elaborated upon in the following three sections of this report.

1.5 Social and Institutional Overview

1.5.1 Introduction

The Yemen Arab Republic ranks among the least developed countries in the world. In the last several years, the nation has benefited from an unprecedented level of remittances from an estimated one million Yemenis, working mainly in oil-producing Arab nations. The in-country population was estimated in the early 1980s at approximately 6.5 million, with approximately 75 percent engaged in agriculture, with a per capita GNP of about $510 (US$) (World Bank 1983). (This value is the "official" value, published in many macro-economic statistical compilations. A large "underground" economy exists, however, and the actual total of remittances is not really known. Some economic analysts have estimated that the actual GNP per capita is now two to three times this "official" level.(26)(54)*

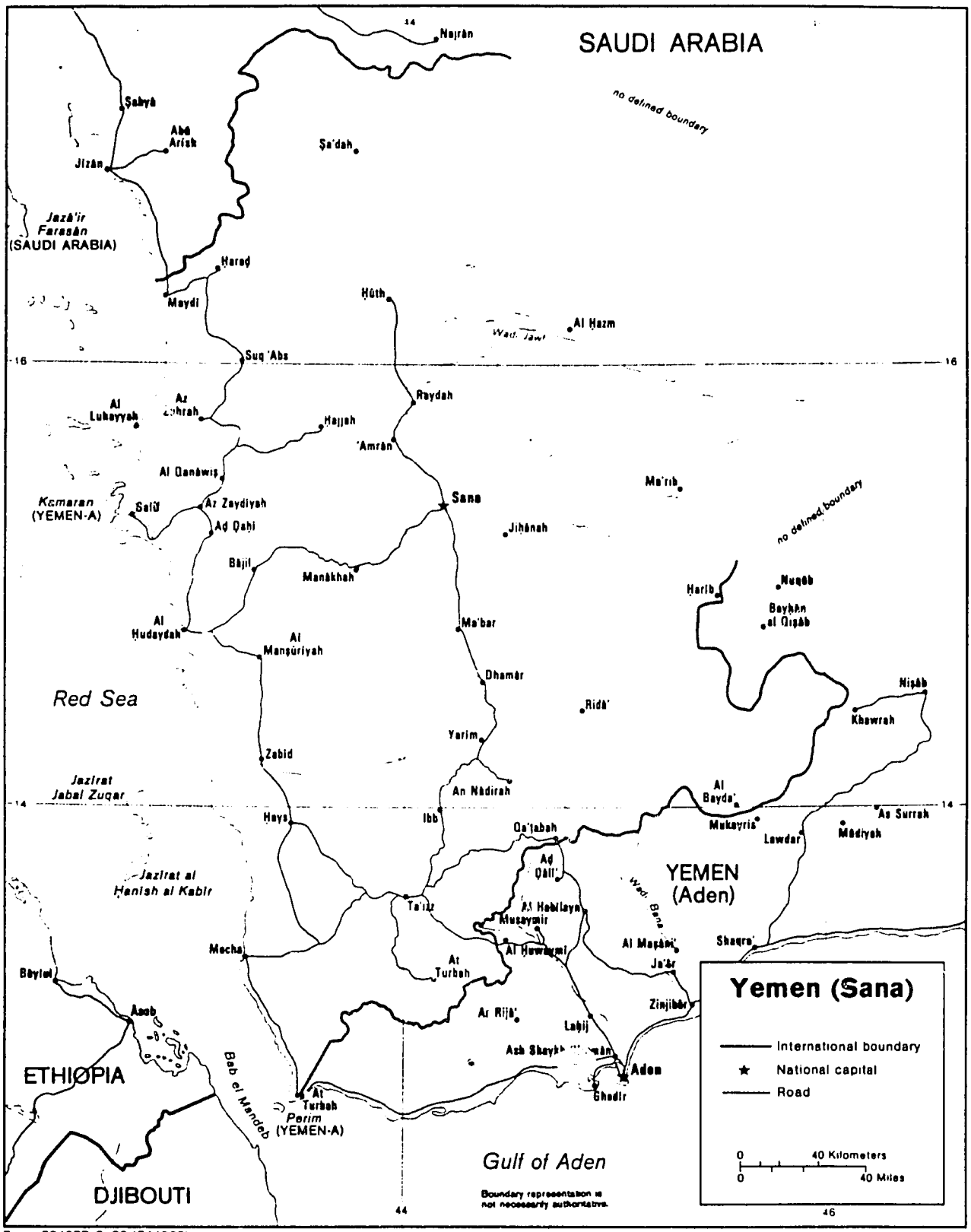
Approximately 90 percent of the population is rural and is spread over 30,000 settlements organized around 15,000 villages. Urban centers (with a population of more than 2,000) number 106, including all 11 governorate capitals. The total estimated population in the five largest urban centers, including Sana'a (the capital), Hodeidah, Taiz, Ibb, and Dhamar (see Figure 1-1) was approximately 700,000. National population growth rates are estimated at approximately 2.5 percent, with rates for urban areas at approximately 5 percent.

A religious aristocracy ruled the country before the 1962 revolution, and there was virtually no contact with Western nations. The republic, born in 1962, suffered a major civil war and several economic shocks in just under a decade. Stability has generally reigned since 1972, but northern tribes, dominant in national politics prior to the revolution, are said to have the same role today.

Enormous development strides have been made during the last 15 years. Health indicators are, however, still low (life expectancy is 42 years, infant mortality 190 per 1,000 live births), and nutritional levels are low throughout the population. Sanitation facilities are virtually nonexistent in rural areas, and an estimated 10 to 15 percent of the rural population has access to potable water. The educational sector has advanced rapidly, especially in urban areas; progress in providing rural public schools, however, is slow. The literacy rate is estimated at approximately 13 percent (population over age ten), and much lower for females.

Yemen's 1975-1982 period of peak growth was aided by large flows from bilateral and multilateral donors, and massive inflows of remittances from its workers abroad ($1.0 billion to $1.2 billion (US$) in the late 1970s and early 1980s). Budget deficits and balance-of-payments problems caused the government in 1983 to make adjustments in the economy. The rial was devalued (for the

*Throughout this text, the numbers in parentheses refer to references listed in the Bibliography (Appendix D.)



Base 504377 2-80 (544968)

Figure 1-1. Location Map

first time in more than ten years), imports reduced, and tax revenues increased. The budget deficit remains high, but expenditures have stabilized regarding the Gross Domestic Product, with 1984's budget expenditures actually declining with respect to the GDP. In July of 1984, oil was discovered in the nation's northeastern (Ma'rib) region. While little official information is available, there are strong indications that commercial quantities have been discovered, making Yemen's long term economic prospects much brighter than the early 1980's economy would indicate. Oil revenues are, however, several years away, and the government seems intent on keeping the economy in line until the expected oil revenues are available.

1.5.2 Institutional and Social Issues

The work, research, and interviews conducted for this assessment made apparent many political, sociocultural, and institutional issues which affect Yemeni development planning. Some are obviously not unique to Yemen; because water resources development is so politically sensitive in water-short Yemen, however, these issues take on added significance and have profound effects on planning and implementation. These issues are discussed in the following paragraphs.

Lack of Government Control: Central government authority is limited. It is greatest in and around the nation's urban centers. Many areas in the countryside are virtually autonomous of government control. This was quite evident in field trips made as part of this assessment. It was not uncommon when traveling but a few miles from the center of Sana'a to observe men armed with automatic rifles and to be stopped by unofficial roadblocks. Government authority is said to be growing, but progress is slow. The central government's strategy in consolidating its power is to do so by gaining consensus for its actions amongst the many special interests and tribal factions in the country. This necessarily is a slow process. Often a state of inaction results, especially if controversial political decisions or actions are involved. Implementation of development projects, especially involving water resources, often suffers due to this "don't make waves" philosophy.

Government's action is often reflected by specific institutions. The High Water Council, organized in 1982 to act as the body to control all YAR water resources, is weak and ineffective. The Council's problems can be traced back to lack of the political will to make the controversial decisions necessary for proper allocation of water resources.

The limited span of government authority makes implementation of the legislative requirements in the World Bank Action for the Sana'a Basin (See Appendix B and Section 1) almost an impossible task. High-level managers of the National Water and Sewerage Authority (NWSA), the body charged with implementing these requirements, stated on several occasions to various team members that their task was virtually impossible. They claimed that even in and around Sana'a city, it would take a long time to control pumping from private wells, let alone extract a fee for groundwater use. Further, they stated that there was virtually no way for their staff to force compliance in the countryside, short of using hundreds of military personnel; this represented a course of action that they were less than even remotely enthusiastic about pursuing.

Immature Institutions: Government ministries are all so new (they have been in existence for 10 to 15 years at most) that they suffer from lack of adequately trained personnel and exhibit inadequate management systems, especially those related to internal decision making, and external linkages which would foster and coordinate interministerial cooperation. This has led to a situation in which virtually all ministries are dependent on expatriate personnel. Ministry personnel are almost completely involved in activities geared to only keep track of their many donor programs. It often appears as if the donor programs drive the sector. This situation causes policy-making, program planning, and objective setting, all proper responsibilities of senior ministry personnel, to be treated as secondary priorities.

The dearth of trained public administrators and technocrats often leads to situations where it becomes difficult to find adequate counterparts for foreign donor projects. Often projects flounder or are badly delayed, and the opportunities for Yemenis to gain experience are lost. Yemenis who have had adequate training (especially those technocrats who have been educated abroad) are often thrust into high-level administrative posts, thereby removing them from an implementation role. In many cases, because their training was technical, they lack the managerial skills necessary for administration.

Lack of adequate counterparts was cited as a major problem by almost every contracting group and most expatriate advisors interviewed. This lack was cited as a major constraint to effective institution building in AID/Yemen projects with YOMINCO's Department of Hydrology and strongly implied as a cause for less than adequate results of the AID/Yemen program for NWSA (both interventions in the late 1970s and early 1980s--see Chapter 2).

Massive training needs were cited by almost every senior manager interviewed. In most cases, the attitude reflected was that training should be provided outside the organizations for higher-level technical personnel. Internal training was acceptable for technical level personnel. There is a lack of clear-cut policy in almost every water sector institution. This, together with inadequate decision-making machinery and a cultural bias of only having faith in the top man's word, forces almost all of the decisions to be made by the most senior officials. This situation leads to bureaucratic malaise on a day-to-day basis and can cause implementation nightmares.

This situation was vividly illustrated to all team members throughout this assignment. Often high-level officials, including Deputy Ministers, Directors General, and the most senior line managers, were often unavailable for discussions due to the offices crowded by dozens of citizens who had complaints and problems for which they wanted personal assurances of immediate action. Often, these complaints involved minutae which could have easily been handled at lower levels. During the interview, seemingly endless interruptions were encountered from telephone calls (not screened by secretarial personnel, and which often involved trivia) and requirements for signatures on dozens of documents pertinent to a wide range of topics. In one case, a senior official informed a team member he could not set a specific time for an appointment, because he could not estimate what the demands would be on his time. He suggested our visiting the office and perhaps a few free moments would be available for discussion.

Lack of Donor Coordination: Little coordination seems to exist between and amongst international lending institutions and bilateral donors. This situation stems in part from the lack of ministerial coordination. In many instances cited in the literature reviewed and interviews conducted for this engagement, however, it appeared that projects were sometimes "brokered" to various agencies. This situation is exacerbated by ministries not fostering donor coordination.

Traditional Attitudes: An additional and perhaps subtle point that must be recognized when designing water resource programs for Yemen is the enormous changes that the country has undergone in such a short period of time. These changes can often give off mixed signals.

After the 1962 revolution, western donors flocked to a country that had experienced virtually no contact with the west for centuries. Simultaneously, hundreds of thousands of Yemenis left for work abroad, and through their remittances caused enormous economic changes to take place, especially in rural areas. This combination of events has aided the YAR in making quantum leaps from an almost totally undeveloped nation toward a more modern one.

Little indication exists, however, that the availability of new technology caused measurable shifts in cultural attitudes pertaining to education, health care or nutrition, or central government authority. Families may be affluent in "western style" material goods such as vehicles, well pumps for irrigation (and in some cases their own drilling rigs), and television sets, but lack basic sanitation facilities or easy access to potable water. Thus, the outward trappings of a "modern" society should not be confused with either the acceptance of western values or the adoption of new philosophies or modes of living.

Traditional Practices Concerning Water and Land: The nation's ties to its traditions can best be illustrated by Yemeni attitudes toward land and water rights, and qat.

Land and Water Rights: Development in Yemen's water sector is complicated by traditional principles of resource allocation pertinent to land and water, based upon a combination of Islamic and customary law. (A review of the pertinent principles is presented in Appendix C.)

The modernization trends have had no effect on these traditions. Yemenis consider that it is their absolute right to use any of their land (and the groundwater under it) as they see fit. (This presents a "dichotomy of self-interest," as the Islamic focus (See Appendix C) on water use is that it is basically ownerless and should be used to promote overall community welfare). Programs which can be interpreted as infringing upon or altering the traditional belief in land ownership will, at best, take many years to implement, and in the worst case end in failure.

Qat: Qat is a plant whose leaves act as a mild stimulant when chewed. "Chewing" is a daily national pastime for most adult males in Yemen. It is an expensive habit, with sufficient leaves for "good chews" costing between $35 to 100 (YR) daily. Notwithstanding the expense, the practice goes on with almost ritual observance. "Formal" qat chews are held late in the afternoon.

Most activity grinds to a halt; in neighborhoods and villages, many important business decisions are made and disputes settled.

Qat has a measurable effect on the water resources sector of the Sana'a Basin as well as the national agricultural sector. Production has been increasing to match growing demand and escalating prices. As a result, qat is one of the leading cash crops in Yemen. Almost all of the plantings are irrigated, and in the Sana'a Basin the largest portion of the well irrigation is used for qat cultivation.

1.5.3 Conclusions

The material in subsections 1.5 through 1.5.2 was presented to provide background information for the remaining sections of this report. The issues discussed had a profound effect on the WASH team. Experiencing most of them first hand made it clear that the challenge in conceptualizing water resources management options and specific interventions was to determine the types of options available in terms of their implementation requirements and to be familiar with the social, political, and economic milieu. The key factor in implementation was allowing sufficient time to allow all forces to coalesce. Thus, the options presented in Chapter 5 were examined in view of this section. The options were adjusted to fit within the issues framework outlined in this subsection, and the technical and institutional requirements presented in Chapters 2 through 4.

1.6 Report Organization

This report is organized into five chapters and six appendices. After this introductory chapter, the report is arranged as follows:

Chapter 2 - Presents an overview of the institutions with activities relating to the Sana'a Basin water resources sector.

Chapter 3 - Reviews the basin's water resources situation, including the hydrologic and geologic conditions.

Chapter 4 - Presents a discussion of the water use patterns in the basin with projections of future conditions.

Chapter 5 - Presents recommendations for AID/Sana'a's future programs.

Appendix A - List of Persons Interviewed

Appendix B - World Bank Action Plan.

Appendix C - Traditional Principles of Resource Use.

Appendix D - Review of World Bank Action Plan.

Appendix E - Other Long-term Options.

Appendix F - Bibliography.

Further, because water resources planning must consider all facets of geography -- political, physical, geologic, and hydrologic -- reference is made here to Figures 3-1 through 3-4. These figures provide a general geographic background for this report. Figure 1-1 is a location map showing the national setting and larger cities.

Chapter 2

INSTITUTIONAL SETTING

2.1 Introduction

2.1.1 Overview

This chapter of the report scribes the programs, activities, and responsibilities of the signifi ant YARG institutions involved in the national water sector, with a focus on the Sana'a Basin. The problems in the basin, in large measure, can be attributed to the thousands of private wells extracting water for irrigation. Prior to 1985, there was no legal basis for control over these extractions.

In mid-1985, specific legislative changes were implemented by YARG, thereby establishing a basis for control (see World Bank Action Plan, Appendix B). NWSA, the agency charged with interim control responsibility, has, however, been reluctant to embark on the necessary program (Section 1.5.2). Thus, except for NWSA, the water resources institutional activities in the basin are almost peripheral to the main problem -- that of controlling groundwater exploitation.

This section, therefore, focuses on describing the institutions whose operations and activities are most affected by, or have a significant effect upon, the water resources condition of the Sana'a Basin. The discussion will include information pertinent to the institutional capacity of these agencies. In addition, a review of donor activities and trends will be presented to determine whether programs "in the pipeline" will affect the basin's water resource situation.

The major YARG institutions operating in the water resources sector are as follows:

- The Central Planning Organization (CPO) in the Ministry of Development
- The High Water Council (HWC), whose Chairman is the Minister of Electricity, Water Supply, and Sewerage
- The National Water and Sewerage Authority, an autonomous agency attached to the Ministry of Electricity, Water Supply, and Sewerage
- The Directorate of Irrigation (DOI) in the Ministry of Agriculture and Fisheries (MAF)
- The Rural Water Supply Division (RWSD) of the Ministry of Public Works
- The Department of Hydrology (DOH) in the Ministry of Petroleum and Natural Resources (formerly known as the Yemen Oil and Mineral Corporation (YOMINCO).

More governmental agencies are involved in the water sector. The Ministry of Health is ostensibly responsible for environmental health; the Ministry of Municipalities and Housing has a minimal program in rural sanitation; and the Department of Industry can control the importation of drilling equipment. The role of these institutions is slight, however, compared to those mentioned above; therefore, further discussion of them has been omitted.

2.1.2 Some Key Points

The following points are worth reviewing with regard to the Sana'a Basin and the national water resources sector as a whole:

- The water resources of the Sana'a Basin, as currently developed, refer to the groundwater. Availability of surface supplies is nil.

- NWSA is the largest single water user in the basin. Because it has the responsibility to provide Sana'a city's water supply, its wells in total, extract more water than any other single entity. Because NWSA acts as an operating utility, however, its activities have necessarily been limited to resource planning for the small area of the basin in and around its well fields. NWSA will be the organization most affected by water resources development in the Sana'a Basin.

- The largest type of use in the basin (and the largest volume of groundwater extracted) is for irrigation. Virtually all of the wells (outside of those operated by NWSA) are private. The actual number of private wells is unknown, but estimates range from 900 to 6,000. (The USSR study has ostensibly inventoried some 3,000 wells.)

- The MAF's role in irrigation activities is all outside the Sana'a Basin. (This is not surprising, because most irrigation in the basin is on a private basis.) The MAF's role as counterpart Ministry for the USSR study, however, makes it the Ministry which controls the most comprehensive and detailed database for the basin.

- The DOH in YOMINCO has been identified herein as the institution with potential for having a major long-term water resources management role. Thus, the description of DOH in Section 2.6 is presented in great detail, tracing the history and activities of this institution.

- RWSD's role in the basin is restricted to providing rural water supply to communities of 800 to 2,000 persons. The demands these systems place on the basin's water resources is relatively low.

A review of the main institutions involved in the water sector is presented in the following sections.

2.2 Central Planning Organization (CPO)

2.2.1 Organization and Responsibilities

The Central Planning Organization is part of the Ministry of Development, with the Minister acting as Chairman of the agency. CPO's responsibilities include setting policy and establishing objectives, priorities, and strategies relating to national development and establishing YARG's Five-Year Plans to meet the objectives and implement policy. CPO also coordinates foreign donor assistance, acts as the official statistical office for YARG, and is responsible for conducting the national census (next scheduled for 1986).

Two main groups in CPO affect the national water sector -- the Office of Technical Assistance and the Office of Capital Projects. These groups combine efforts to prepare the Five-Year Plan, and each coordinates with donors depending upon the type of assistance involved. As projects develop, the various ministries and authorities submit reports to the appropriate group for comments. The proposed projects are then reviewed and endorsed if they fall within the policy or strategy framework set forth in the Five-Year Plan. While the Central Planning Organization is not directly involved with the execution of water projects, as YARG's national planning agency, the CPO has a significant impact on the types of projects implemented and the composition of donor assistance.

2.2.2 Activities Affecting the Water Sector

The Second Five-Year Plan (1982-1986) had limited success. While the investment total is expected to reach almost 86 percent of the target level, the pattern of investments was out of line when compared to the Plan's projections. (The water sector was one in which more investments were made than planned.) The deviation of investment patterns can be attributed to governmental actions taken early in the Plan to relieve severe strains on the national budget. In 1983 (the Plan's second year), YARG decreed that for the duration of the Five-Year Plan, annual budgets would include new project starts only for projects that were assured of external donor support. Thus, the Second Five-Year Plan became essentially donor driven.

As a result of the nature of CPO's responsibilities, however, the policies and priorities which formed the basis of the plan are still official YARG policy.

Work is about to commence for preparation of the nation's Third Five-Year Plan (for years 1987-1991). The World Bank is assisting YARG with funds for its preparation. A team sponsored by the West German Aid Agency (GTZ) is working in the CPO and is expected to play a prominent role in developing the Third Plan.

According to information obtained through discussions with various members of CPO's staff, the Third Plan will reflect a greater emphasis on the water sector than the last plan. The renewed interest was said to be based upon several factors, not the least of which was the "crisis" situation regarding the water resources sector of the Sana'a Basin. The strategy outlined in the World Bank's Sana'a Basin Action Plan was said to be close to being adopted as official policy, and the framework of the plan, but not necessarily every

detail, would come under the CPO's policy "umbrella." These discussions gave strong evidence that the Action Plan outlined a project that had a high level of "official" interest. It was also apparent that there was significant recognition of the water problems in the Sana'a Basin.

2.3 High Water Council

2.3.1 Organization and Responsibilities

In early 1982, in an effort to coordinate all of the activities concerning water resources and prepare a general policy and plans for water resources development, YARG formed the High Water Council. The Council's goals, responsibilities, and membership, as defined in its establishing legislation, are as follows:

Goals

- Coordination between all authorities and ministries concerned with water
- Coordination of all studies of water resources for the purpose of drinking, irrigation, and power
- Preparation of a general policy and plan for the development of water resources

Responsibilities

- Proposals for and coordination of water resources studies
- Proposals for legislation and for decrees for coordinating uses of water resources, preparing programs for water use and for exploitation within the framework of a national policy and approved plans
- Study and evaluation of all information, reports, statistics, and maps which the General Secretary obtains from all authorities, ministries, and agencies
- The following-up with action of the useful development of water resources in the interest of the public-at-large.
- The organization of and collaboration in symposiums, conferences, and meetings, nationally and internationally

Membership of High Water Council

- Minister of Electricity, Water, and Sewerage: Chairman
- Deputy Minister of Ministry of Electricity, Water, and Sewerage: Deputy Chairman
- Deputy Minister of Ministry of Agriculture and Fisheries: Member

- Deputy Minister of Ministry of Public Works: Member
- Deputy Minister of Ministry of Municipality and Housing: Member
- Deputy Minister of Ministry of Al Awkaf (Islamic Affairs): Member
- Deputy Minister of Ministry of Central Planning Organization: Member
- Deputy General Manager of Cooperative Organization (CYDA): Member
- Director General of NWSA: Member
- Director General of Geological Survey: Member
- Director General of Rural Water Supply Office, Ministry of Public Works: Member
- Director General of Meteorology and Civil Aviation: Member
- General Manager of Tihama Development Authority: Member
- Water Resources Specialist: General Secretary.

2.3.2 Activities Affecting the Water Sector

The establishment of the High Water Council, a national organization to coordinate and manage the water resources of the Yemen Arab Republic, had been strenuously recommended by USAID reports and by other donors as well as by the World Bank. To date, the Council has been a weak and almost totally ineffective organization. Efforts to coordinate water-sector activities have been nil. The overall situation in the sector can be considered worse than when the HWC was appointed, as evidenced by the conditions in the Sana'a Basin and reports of other urbanized areas in Yemen becoming water-short.

The reasons cited by many interviewees for the HWC's lack of activity include:

- The varied special interests represented on the HWC look after their own programs and as such cannot act in concert to establish a coherent national policy.
- The lack of qualified staff and YAR's general lack of experienced water resource planners act to prevent the HWC from receiving the data and other information they require to make policy.
- The political sensitivity of the required decisions leads to inactivity (See Chapter 1), because making no decisions makes "no waves."

2.4 National Water and Sewerage Authority (NWSA)

2.4.1 Organization and Responsibilities

NWSA was established in 1973 and given responsibility to locate, exploit, and distribute water for domestic, commercial, and industrial use and to provide sewage disposal services in accordance with public health requirements for the nation's urban areas. The law established NWSA as an autonomous agency allowing it to design and operate public facilities; fix, impose, and collect fees for services; and undertake activities necessary to protect its underground water sources against pollution. NWSA is attached to the Ministry of Electricity, Water Supply, and Sewerage, with the Managing Director reporting directly to the Minister.

NWSA was established as an autonomous agency and was expected to act on a self-sustaining basis. Its personnel system is independent of the national civil service system, thereby allowing the Authority to offer attractive terms of service with salary levels adequate to attract and keep competent employees. As of June 1985, its staff numbered approximately 1,200, including approximately 80 Yemeni engineers and only 2 expatriates. Figure 2-1, on the following page, presents a general organization chart for NWSA.

Its tariff structure requires approval by the National Cabinet. Its overall revenues have been adequate over the past several years to provide sufficient funds for operation and maintenance.

NWSA is now responsible for water supply service for Sana'a, Hodeidah, Taiz, Ibb, and Hajjah and sewerage service for Hodeidah and Taiz (See Figure 1-1). The sewerage system for Sana'a is under construction. Most of the collection sewers and trunk lines have been installed, and the main pumping station and sewage treatment system (a series of oxidation ponds north of Sana'a) are expected to be completed for the plant to be on line in mid to late 1986.

NWSA assumed control of the existing water systems in Ibb and Hajjah in 1983. Tenders have been let for extensive improvements to the Ibb water system. Other tenders included construction of a complete sewerage system (including treatment) for Ibb, and new water supply and sewerage systems for Dhamar. Contracts are expected to be let by the end of 1986, and new facilities are expected to be on line two years hence. (Several donors including the World Bank, the governments of Germany and the Netherlands, and the Arab Fund, are participating in the $120 million (US$) project.) Selected system characteristics of NWSA's service are shown in Table 2-1.

2.4.2 Activities Affecting the Water Sector

NWSA is the largest single user in the Sana'a Basin. The source of supply for Sana'a is 25 wells in two wellfields (one northwest with 15 wells, one to the east of Sana'a with 10 wells) having a rated capacity of 420 liters per second, or approximately 36,000 cubic meters daily. According to NWSA's operating reports for the first six months of 1985, these wells delivered an average of approximately 25,000 cubic meters a day to the water system. Further discussion on the trends in supply/demand requirements and the

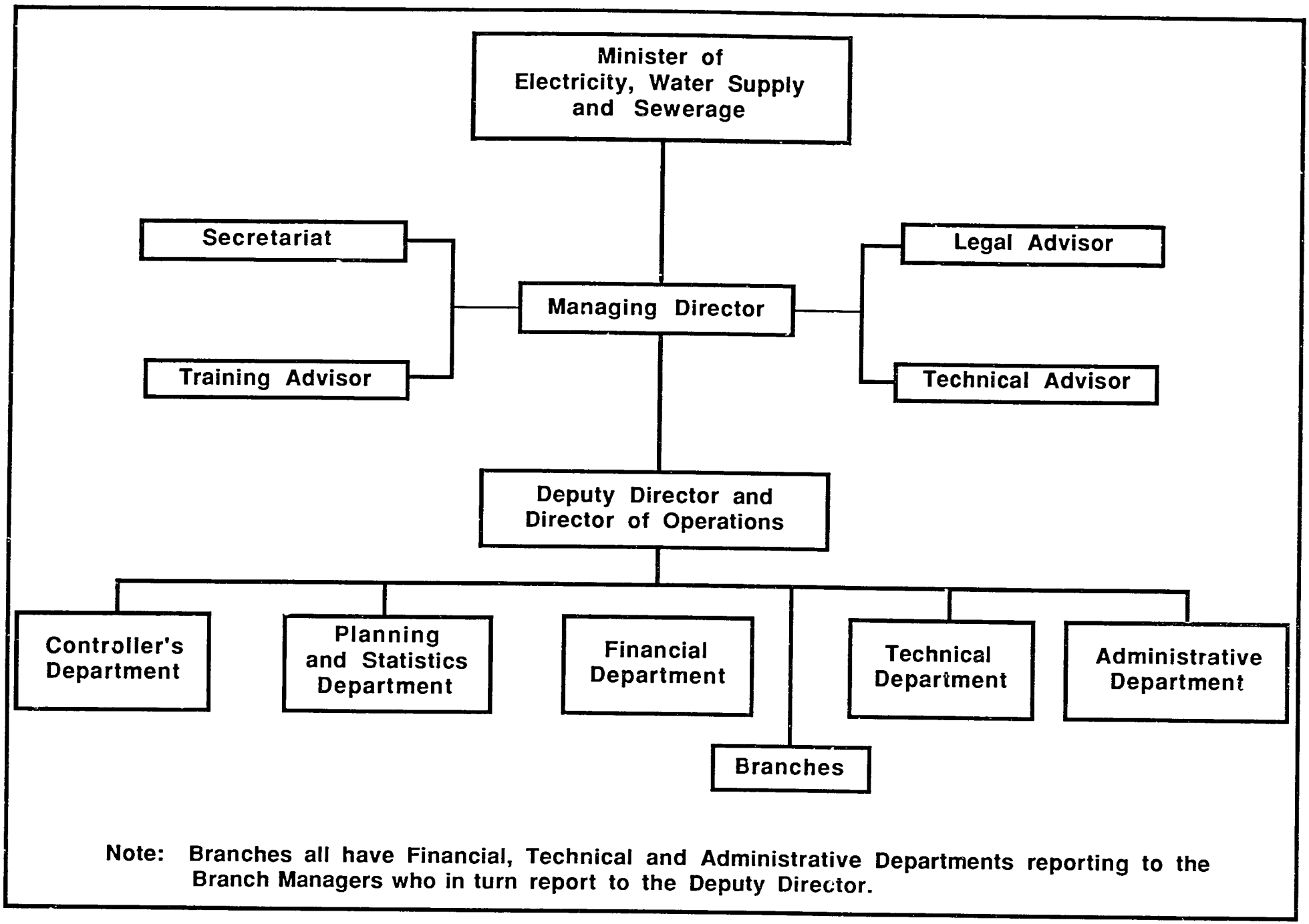


Figure 2-1. NWSA Organization Chart

Table 2-1

Selected System Characteristics

	WATER				WASTEWATER		
System	Total Population* (1)	Population Served Directly (2)	Number of Connections (3)	Average Daily Production (CM) (4)	Population Served (5)	Number of Connections (6)	Average Daily Flow (CM) (7)
Sana'a	282,000	211,000	35,200	25,200	—	—	
Taiz	149,000	111,000	18,600	12,200	16,000	2,300	2,000
Hodeidah	90,300	68,000	11,300	9,100	40,000	6,600	5,400
Ibb	32,000	23,000	4,000	2,400	—	—	
Haffah	16,600	12,000	2,100	800	—	—	
	569,900	425,000	71,200	50,400	56,000	8,900	7,400

*Notes: 1. Columns 1, 3, 4, and 6 from NWSA quarterly reports, values rounded to nearest 100.
2. Columns 2, 5, and 7 estimated by WASH.

potential of these wellfields to furnish future supplies is presented in Chapter 4.

It is worth noting, however, that the 25 wells now operating include ten new wells constructed in 1981 to replace ten existing wells in the northern wellfield. These original wells were abandoned due to declining water levels. During the next few years, NWSA expects to be faced with similar problems, and new wells, or a combination of new wells plus deepening existing wells, will be needed to maintain Sana'a's water supply.

Sana'a's demand has been driven by enormous population growth rates rather than natural increases in individuals' demands. Chapter 4 discusses water use in the basin and trends in demand. Given the trends in the groundwater level declining (indicating uncontrolled withdrawals) and the increasing water demands, the city is on a collision course in terms of demands outpacing available supplies.

2.4.3 Donor Trends

NWSA's formulation and all of its past facilities have benefited from vast amounts of donor aid from the World Bank, USAID, several European governments, and the Arab Fund. NWSA was formed under World Bank tutelage in the early 1970s, and the Bank has contributed to almost every project in the nation's five largest urban areas. AID has contributed to the Taiz water supply and wastewater systems and provided funds for a training program at NWSA (TMSI project), which was completed in 1984. A brief evaluation of this project is presented in the next section.

A project sponsored by the Government of Germany (approximately $1.5 million (US$)) is about to commence for immediate water and sewerage improvements and feasibility studies for 11 secondary cities throughout the country. These include Hajja, Sa'ada, Yarim, Rada'a, Al Baidha, Zabid, Al Mokha, Al Mansuriya, Beit Al Faqi, Amran, and Bajil. The total population of these cities is about 120,000 (range of 7,000 to 26,000). It was reported by CPO and NWSA that negotiations between the Government of Germany and YARG for partial financing, preparation of tender documents, and construction for facilities in these cities will commence in November of 1985.

Another project sponsored by the German Government is under negotiation, or about to commence in early 1986. The project will provide four advisors to NWSA--one to advise the Managing Director directly, and three others to provide training in operations and maintenance to the branches. This project is a necessary addition to NWSA's daily operations. No further donor assistance is in the pipeline for NWSA. With the construction of the Ibb and Dhamar Systems commencing in early 1986 and the feasibility studies for the 11 secondary cities expecting to lead to further construction starting in early to mid 1988, however, NWSA's overall program is probably at its limit.

Discussions held with several NWSA senior managers (Training Director, Computer Center Manager, Operations Chief, and Sana'a Branch Manager) indicated that training was a continuous need. Training programs appear to receive a great deal of internal attention but limited budgetary support. Almost all of the managers indicated that donor support would be essential to

provide the impetus needed for sizable programs. The training program about to commence under German aid appears to be the first in a series of such programs, and NWSA can be expected to approach other donors for similar help.

2.4.4 Institutional Development

NWSA has shown steady growth and a maturation as an institution. It has a growing reputation as a service delivery agency and continues to enjoy growing with international lending agencies and bilateral donors. The weakest link in the organizational structure is in its branches. These are in need of training support, and this question is being addressed by the German sponsored training project (specifically directed at the branches). AID/Yemen's last intervention with NWSA was Project No. 028. This project was to provide across the board in-house training to almost every group in NWSA, and offshore training to a selected group of engineers and technicians.

The 1981 evaluation of this project indicated the project was less than satisfactory.(34) NWSA's operating problems prompted the Managing Director to use the manpower provided by the consultant more as day to day operators, partially giving up much of the long term benefits expected from the project. There have been many improvements in NWSA's organizational strength, its systems and procedures, and its general outlook, however. Many of these improvements can be traced back to AID/Yemen's Project No. 028 and are discussed below.

NWSA's revised organization (shown in Figure 2-1) is along the lines recommended by the contractor. The new Department of Planning and Statistics issues quarterly reports presenting statistics and performance indicators useful for measuring operational effectiveness. This group works with the training manager to plan the in-house training programs and with the Technical Department in planning projects which require donor support.

The Training Manager (a new position created as per 028) is basically a one-man show. His enthusiasm for initiating training efforts is fairly successful on a small scale. The branches have most operators receiving training (albeit rudimentary training) each year as part of an on-the-job program provided on a semiformal basis by supervisory personnel. The Training Manager indicated that he intends to use the Training and Development Plan developed under AID aegis (48) as the basis for achieving NWSA's long-term training objectives. He claims, however, to have been hampered by a lack of budget and a somewhat less than enthusiastic reception from donors.

The new branch training project is a positive step, and the Training Manager is hopeful that this project will give impetus to others. It is significant to note that NWSA's staff numbers some 1,200, more than double the number in 1981, and represents an increase larger than that recommended Project No. 028, with the mix of qualifications also varying from the recommendations. The increase, however, is a strong indication of NWSA's determination to increase its staff to the necessary levels. The total of 80 engineers is larger by far than any other institution in the water resources sector. This group's size and the large increase in overall staff can be traced back to the recommendations of Project No. 028, which called for a strong recruiting drive directed at increasing staff size.

NWSA managers interviewed stated that they had more responsibility for directing their groups than previously. Staff meetings with the Managing Director and Deputy Director were more frequent, and the agendas of these meetings generally were adhered to, thereby allowing most problems to be discussed. This delegation of responsibility and improved communications were specific recommendations of Project No. 028.

The financial system has improved, with the general ledgers being computerized (three years of records are now in NWSA's computer file). The billing and collection system is also computerized, and NWSA's 35,000 accounts in Sana'a are billed monthly. (Outstanding amounts owed were said to be approximately 15 percent of the total, but no independent verification of this value could be made).

Histories of each account are available. These files may be scanned to measure use per account (measured by meter readings) by month, by quarter, or by year. (Nine months of user histories and billings are now in the computerized files.) The manner in which the billing records are maintained allows some high-level management information data to be developed. It is easy to obtain the range of use per month, quarter, or year for all user classes. Further, because the records can be sorted by mailing zip codes, area demands can be evaluated. This information is valuable for system operation, leak determination, and tracking of illegal accounts.

Most of the financial, billing and collection, and computerized record-keeping system can be traced to recommendations from Project No. 028. Generally, Project No. 028 recommendations have been followed in most areas discussed above. NWSA has a long way to go in solving its problems. A start has been made, however, and in no small measure AID/Yemen played a prominent role through the 028 Project. If there is one general criticism of Project No. 028, it is that while conceptually it was correct in terms of what was needed, the time frame may have been too short for proper implementation to occur while AID's contractors were "on the ground." Future interventions should reflect this point.

NWSA is now at the point in its history where projects similar to the AID/Yemen's sponsored Project No. 028 could probably be carried out with much greater success. Counterparts are available, and as an institution NWSA is better positioned (due to increased staff, and institutional development), to perform an adequate role in implementing most programs.

2.5 Rural Water Supply Department/Ministry of Public Works

2.5.1 Organization and Responsibilities

The Rural Water Supply Department (RWSD) was established in the Ministry of Public Works in 1972. Initially, it was charged with the responsibility for implementing water supply projects throughout the nation, except for the cities of Sana'a, Taiz, and Hodeidah. Over the years, NWSA has assumed responsibility for more and more of the larger urban areas, thereby leaving the RWSD with prime responsibility for settlements under 2,000 population. Figure 2-2, on the following page, presents RWSD's organization.

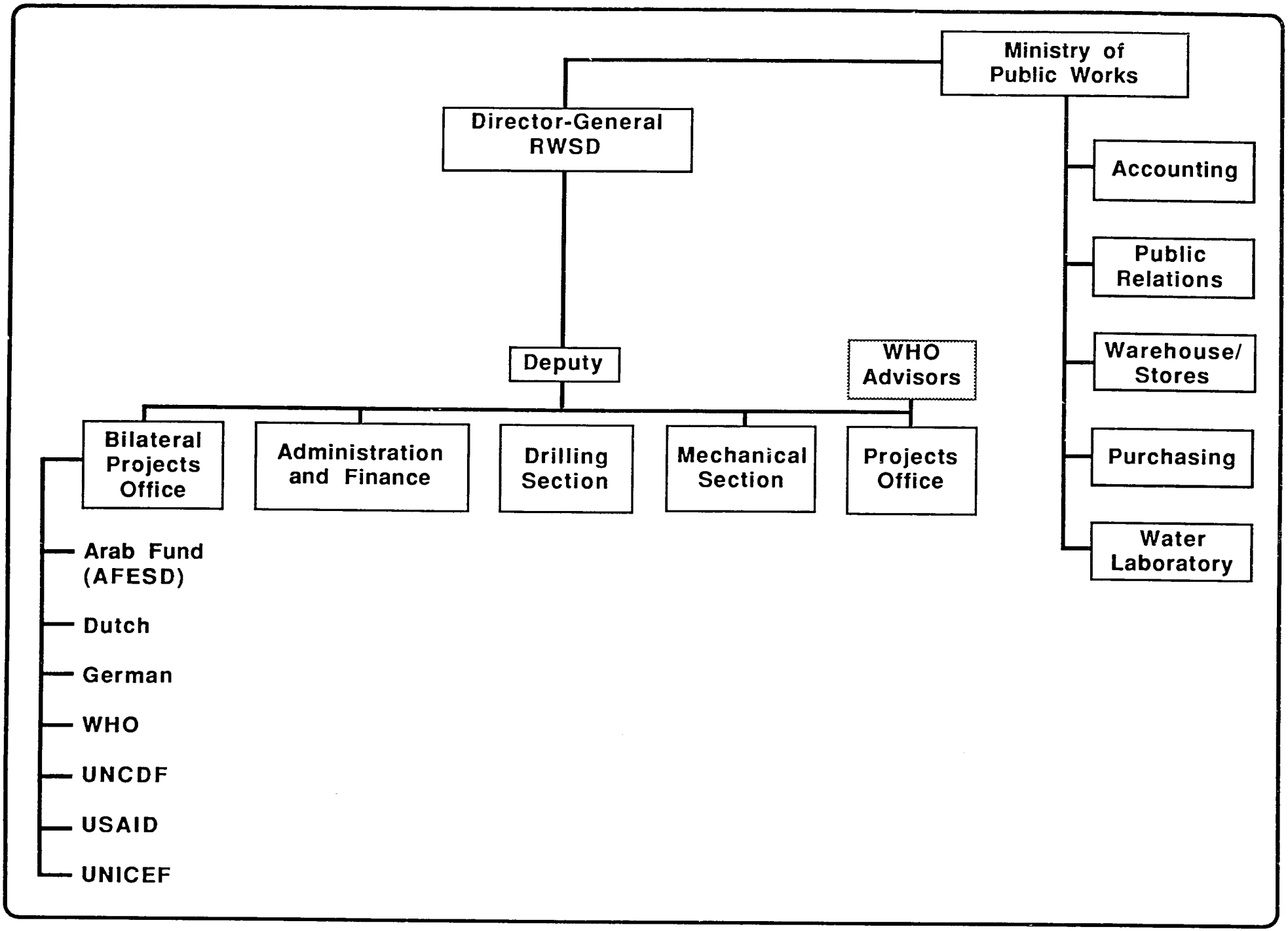


Figure 2-2. Rural Water Supply Department - Ministry of Public Works - 1984

The RWSD's program level is set, for the most part, by donor funds. Although budget information from RWSD was unavailable, one of the expatriate staff estimated the total budget for 1984 to be approximately $80 million (YR). Most of the budget allocation was said to be for salaries, per diem, and office expenses with perhaps 10 percent in project expenditures such as welldrilling contracts.

During the past five years, the RWSD has signed agreements with donors amounting to more than $50 million (US$). It is estimated that approximately 70 percent of this total is directly used for water system costs. (This is equivalent to an expenditure rate of around $7.0 million (US$) annually over a five-year span). Adding RWSD contributions of $2.0 million (US$) annually, the total RWSD sponsored program could be expending $9.0 million (US$) annually for projects. If the average project costs US $100,000 (US$), the program could build 90 projects a year. Project No. 044 is now capable of completing around 45 projects and, according to expatriate sources in RWSD, the sum of all other donor and RWSD programs completes an equal number of systems annually.

Although a rate of 90 systems completed annually is laudable, it pales when compared to the 30,000 settlements in 15,000 villages that RWSD is responsible for.(26) Unless the completion rate is increased at least fivefold, RWSD will not begin to make headway in accomplishing its mission.

2.5.2 Impact on the Water Sector

While RWSD and its donors are completing a water system every four days, because of their small size and scattered locations, the systems individually and collectively have, for all practical purposes, no impact on the nation's water resources. In terms of the human resources, RWSD must compete for technical staff (with all other line agencies) for its staff from a limited talent pool. The RWSD program probably has a greater impact on the nation's pool of technical talent than on its environment. On the other hand, if RWSD were so inclined, it could design its program not only to construct water systems, but also to train surveyors, designers, construction supervisors, and a wide range of technical trades which would be beneficial to both the national water resources sector and national development.

2.5.3 Donor Activities

See Table 2-2 for a brief description of continuing donor activities. The list does not include activities such as offshore commodity procurements, which have been completed. Most donor funded programs require little impact from RWSD resident staff. RWSD's major contribution is in designing, tendering, and supervising well construction and the development of surface water sources. Practically all of the field surveys, system designs, and construction supervision are performed by expatriate staff. Most donor programs, except for Project No. 044, operate as a series of turnkey projects requiring little or no local community participation. Project No. 044 requires community contributions to its projects. Often the Local Development Authority (LDA) is responsible to organize and manage local contributions. Where LDAs do not exist, some other village organization or committee takes on these

Table 2-2

RWSD - Donor Projects

Country or Organization	Cost (U.S.$)	Components	Estimated Duration	Implementing Agency	Status
1. Saudi Project	$26.1 million	50 complete systems, including wells, tanks, pumps, generators, pump houses, transmission and distribution lines for towns of 1,500 to 12,000	Phase I (drilling) 11-22-83 to 8-85, to be followed by Phase II- civil works - and Phase III - pump installation. Project expected to last about 5 years (completed).	Saudi Projects Office with Al-Watani (Yemeni Construction Company)	Drilling phase expected t last 15-17 months, until Spring 1985
2. Iraqi Assistance	$4 million	30 deep wells, and sometimes the provision of pumps and generators	March, 1982 to May, 1984 (completed)	Iraqi contractors with 3 drilling rigs, 13 technical staff, & 1 Chief-of-Party	34 wells drilled
3. UN Assistance:					
UNICEF	$1,984,000	50 water resource development projects, including tanks, pipelines, pumps & generators	30 May 1982 to 31 December 1984 (extended)		50 systems for primary hea care centers. 3 completed
UNCDF	$2,087,000	45 projects—resource improvements, including tanks, pipelines, pumps & generators	30 May 1982 to 30 October 1984. Agreement will probably be extended		52 projects surveyed. All commodities imported. Proj status unknown.
UNDP	$1.7 million	Technical assistance to RWSD	Concluded		Not to be continued
WHO	$349,000	Technical assistance to RWSD	To end April 1986		2 advisors on board
4. Japanese Assistance:					
Phase I (grant aid)	$1,980,000	5 complete systems in Sana'a, Haffah and Taiz	10 August 1982 to 15 March 1984 (completed)	Nisshoiwai Corp. Nissako Corp.	
Phase II (grant aid)	$2,009,000	2 complete systems for 17 villages	7 March 1981 to 15 March 1984 (completed)		
Phase III (loan)	$2,678,000 $6,667,000	3 projects for 16 villages	Consulting agreement signed 31 July 1981. Duration unknown (completed)		
5. Arab Fund for Economic and Social Development	$2,396,419 (200,000 Kuwaiti dinars)	10 projects, including pumps and fittings, pipelines, extensions, civil works, technical services, & establishment of regional offices			
6. Dutch Projects	$2,787,456	14 projects, including civil works for wells previously drilled by Dutch project in Radah and Dhamar	4 October 1983 to August 1985 (extended)		2 staff in country Program being revised
7. German Assistance for Dhamar Earthquake Rehabilitation	$2,192,982	45 sites to provide tanks, pumps, and distribution systems	12 March 1981 (continuing)	KPS Corp. has been selected as contractor	Some commodities used for for projects in Dhamar unde 044 supervision. Two advise arrived September, 1985.
8. American Government-USAID					
Phase 1	$6,900,000	55 projects	28 July 1980 to 30 September 1984 (extended)	TransCentury Foundation	Extended for 5 years from October 1984 to September 30, 1989. Emphasis to shift to institution building
Dhamar 1	$ 500,000	18 projects			
Dhamar 2	$1,358,000 $8,758,000	71 projects			

responsibilities. On an average, local contributions to No. 044 projects make up approximately 30 percent of the total.

The last five-year period indicates that the level of donor contributions to RWSD is on the wane. UNICEF withdrew its support in 1983, and the Japanese and Arab Fund activities have been completed. A newly arrived two-man German team is trying to determine what is left of the commodities contributed last year by the Government of Germany, and then hopes to use the remaining commodities for systems in the Dhamar Province. The WHO/UN contingent, which conducts all of RWSD's field surveys and designs, is scheduled to be phased out by Spring 1986. The Dutch team is restructuring its program to use unexpended funds from two earlier projects, and is adding approximately $1 million (US$) in new funds. In sum, there are fewer donors and less donor funds now than there were in previous years.

The RWSD budget appears to be under continuous pressure with the $80 million (YR) allocation representing only a portion of the original budget request. RWSD's nonexpanding budget, together with the downward trends in donor support could act to produce a shrinking RWSD program during the next few years.

2.5.4 Institutional Development

From its inception more than ten years ago, the main purpose of the WHO/UN/UNICEF intervention was to build up RWSD so that its program, even at a reduced scale, could be carried out with its own resident staff. RWSD is no closer to that goal today than it was ten years ago. If the WHO/UN contingent pulled out today, it would leave some 1,200 site specific systems designed, of which only some 300 have been built. The RWSD could continue its program constructing the remaining 900 systems. When this design resource is exhausted, however, RWSD would have to contract out for surveys and designs, or would have had to train its staff to perform these tasks.

Thus, little opportunity exists for middle management staff to gain meaningful experience working with the RWSD program. Under present operating conditions, all decisions appear to be made by the Director General. Maybe the best any donor can do is to stay on board long enough to be on the scene ready to jump in when a break in the pattern comes, whether it be its conversion into a semiautonomous authority, or even a change in top management. Beyond the possibility of these types of opportunities appearing, little opportunity exists for carrying out any meaningful or effective institution building, other than to continue training lower-level professional and technical staff, both on the job and in the classroom.

2.6 Yemen Oil and Minerals Corporation (YOMINCO), Department of Hydrology

2.6.1 Introduction

Known as YOMINCO, the Yemen Oil and Minerals Corporation is responsible for the inventory, exploration, and development of the YAR's petroleum and natural resources. In addition to these functions, YOMINCO's Geological Survey Board (GSB) also includes a Department of Hydrology (DOH), which was formed principally as a result of USAID's involvement in the "Water Survey of North

Yemen," in the late 1970s. An organization chart for YOMINCO is presented in Figure 2-3, which follows.

The DOH's responsibilities include collecting, organizing, and conducting water studies throughout the YAR and collecting surface and groundwater hydrologic data, to receive relevant data from all other sources.

Although the assigned responsibilities of the DOH appear clear-cut, it is not the only YARG institution collecting hydrologic data. (These include MOA, NWSA, Directorate of Meteorology, and Civil Aviation). There is no evidence of either coordination or cooperation in these efforts.

The work involved in this assessment led to the recommendation that the DOH play a role in national water resource planning efforts (See Chapter 5). Thus, it is of benefit to review history and level of activity (almost all of which can be attributed to past and present donor involvement), and general level of expertise of the DOH.

2.6.2 Previous Donor Involvement

USAID

The DOH was initiated by way of USAID's Project No. 0025, "Water Survey of North Yemen." Started in 1974, this project included groundwater hydrologic investigation of the Amran Valley and, to a lesser extent, the Sana'a Basin. Technical experts furnished from the U.S. Geological Survey (USGS), and Yemeni DOH personnel, began a groundwater survey that included collection of basic data, detailed studies of selected areas, development of groundwater monitoring networks, and on-the-job training. Limitations on the availability of USGS personnel eventually required the assistance of a U.S. consulting firm to complete the project, extended beyond the original 1976 completion date.

USAID's assistance to the DOH continued with the "Water Resources Planning and Management Project," initiated in 1980. The focus of this project was to establish a fully operational Department of Hydrology within YOMINCO. Services provided included short- and long-term training and the establishment of additional monitoring sites. This project ended in 1982 and was AID's last involvement with DOH.

Several problem areas related to this last project and DOH were cited by their USAID contractors and individuals associated with the project, including:

- DOH had inadequate numbers of properly trained personnel with which to fulfill its mission.
- No commitment was made by the Director General to make DOH activities a priority at YOMINCO.
- Neither recognition nor cooperation was forthcoming from other agencies.
- DOH authority which would allow it to have input to YAR water resource planning was lacking.

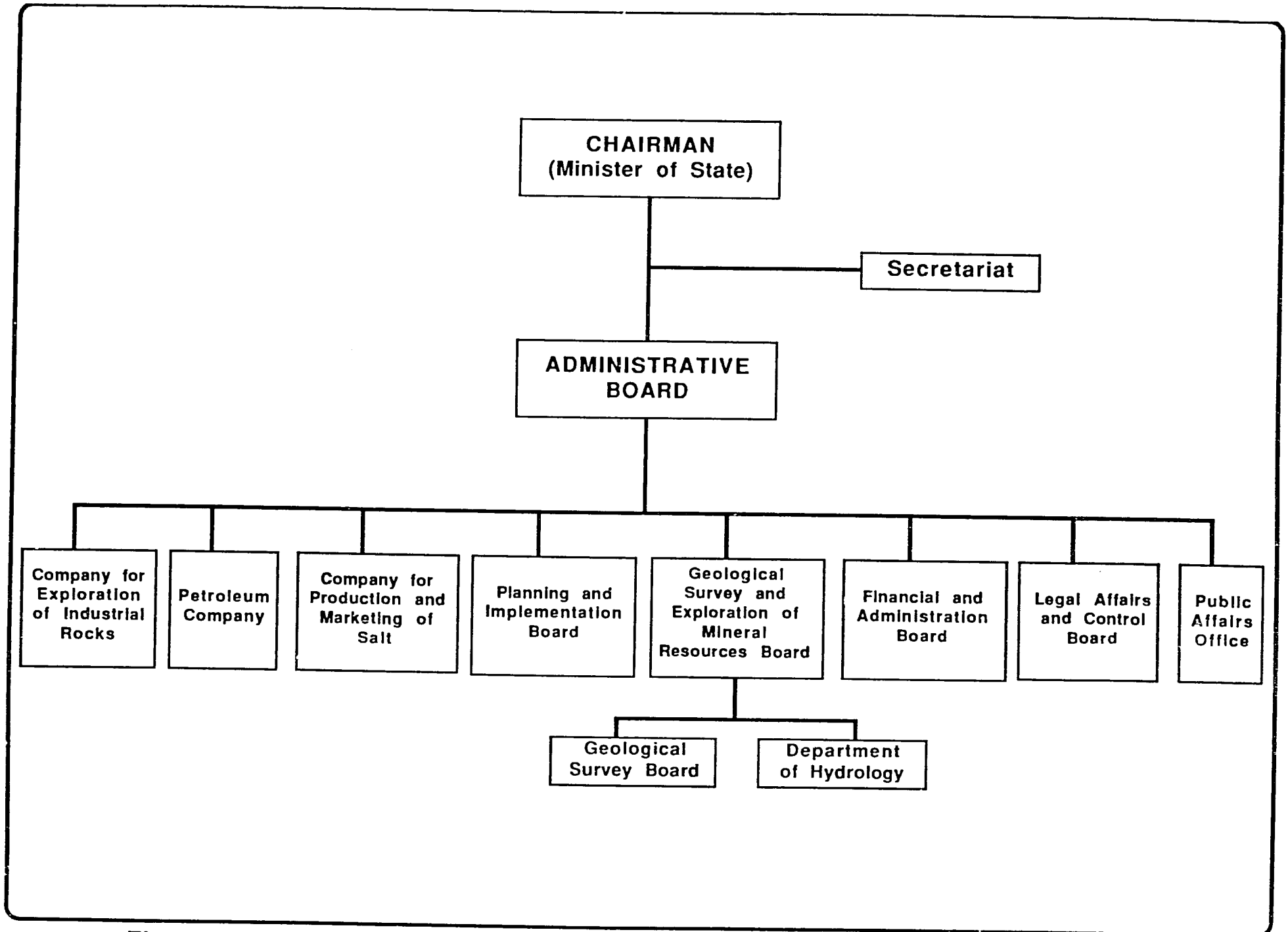


Figure 2-3. Organization Chart Yemen Oil and Minerals Corporation (Oct. 1984)

Dutch Aid:

The Dutch nonprofit organization TNO-DGV Institute of Applied Geoscience began work with the DOH in April of 1982 on a project known as the Water Resources Assessment Project -- Yemen Arab Republic (WRAY-1). The objectives of the WRAY-1 effort included:

- Strengthening DOH technical capabilities
- Assisting in hydrologic data collection, compilation, and analysis
- Conducting hydrologic field investigations of the Sada area and Wadi Surdud
- Assisting in scoping future water resource investigations.

Part of the Dutch effort has focused on organizing the scattered information on water resources in the YAR, resulting in a hydrologic data summary published by the DOH and TNO/DGV in 1984. (This document was compiled primarily by the Dutch, with only minor input from DOH staff.)

Field efforts at Sada and Wadi Surdud are being supervised by TNO/DGV expatriates, with assistance from the DOH staff.* The Dutch efforts toward strengthening DOH staff capabilities have focused primarily on this type of on-the-job training. Two DOH personnel have been selected for one year training courses in geophysics and hydrology in the Netherlands. Upon completion (estimated mid-1986), two additional candidates will be recommended for similar training.

Interviews with the TNO/DGV staff regarding their experiences on the WRAY-1 project have led to the following observations:

- The organizational structure in DOH is lacking.
- There is no management training of supervisory staff and little delegation of authority.
- Technical skills are limited, at best, to basic data collection; little, if any, analytical or interpretive capability is available.
- Some DOH staff could function in basic data-collection tasks with additional training.
- Interagency friction inhibits DOH's ability to fulfill its responsibilities.

The Dutch also emphasized the specific need to evolve effective working and training relationships with the Yemeni staff on a long-term, consistent, and personal basis -- something which they suggest has not necessarily been achieved by past donor efforts.

*These field efforts have since resulted in two published works -- WRAY-3 Report -- Water Resources of the Sadah Area, November, 1985, WRAY-4 Report -- Water Resources of the Wadi Surdad Area, January 1986. Both by J.A.M. VanDerGun.

TNO/DGV have recently proposed the WRAY-2 Project, involving three expatriates and DOH staff. This effort will begin in 1986 and includes the following activities:

- Continuation of WRAY-1 efforts in training and staff development
- Continuation of selected monitoring activities at the Wadi Surdud project area
- Initiation of hydrologic studies in the Ma'rib area.

A preliminary organization chart for the WRAY-2 Project is shown in Figure 2-4 on the following page.

2.6.3 Existing Conditions/Status

Staff and Capabilities

The Department of Hydrology is estimated to have approximately 30 staff distributed in six "sections:" Groundwater, Surface Water, Water Quality, Data-Collection, Administrative, and Technical Assistance. According to the WRAY-1 Co-Project Manager, approximately ten staff have a relevant academic background, ten are technicians with varying degrees of training and experience, and approximately ten are considered support staff. It appears that the only functional technical sections are Groundwater, Data Collection, Technical Assistance (also known as the "consulting" section), and perhaps Surface Water. Data compilation appears to be done primarily by the Dutch, with some assistance from the Yemenis. Of these sections, it appears that the first two are involved primarily in the WRAY Project work. The Technical Assistance Section provides geophysical technicians and other staff to the other sections as well as do other YARG agencies.

It appears that as many as 25 DOH and GSB staff have been exposed to varying degrees of training and instruction under the auspices of WRAY-1 and previous donors. According to the TNO/DGV staff, however, a significant number, possibly up to one-third of DOH staff, are minimally productive. TNO/DGV staff believe, however, that the Department does contain a capable core staff in the area of basic groundwater monitoring and geophysical data compilation. Until the DOH's general level of expertise is increased (a stated objective of the Dutch program), work task definition, supervision, analysis, and use of mini-computer equipment will be performed by the Dutch expatriate staff.

Discussions with the TNO technical staff, DOH employees, and members involved in the former USAID projects further indicated that DOH staff field skills include selected areas of basic groundwater monitoring and sampling, surface and borehole geophysical survey techniques, map-based data compilation, and selected surface water monitoring activities. The benefit of past instruction and training afforded by previous USAID technical assistance has apparently been lost. Most, however, reportedly do not have the necessary theoretical/analytical background to be functional beyond the hydrologic technical level without further training and education. This limitation is viewed as a significant constraint to the potential of DOH's to contribution to national water resource planning in Yemen, without continued expatriate support and training.

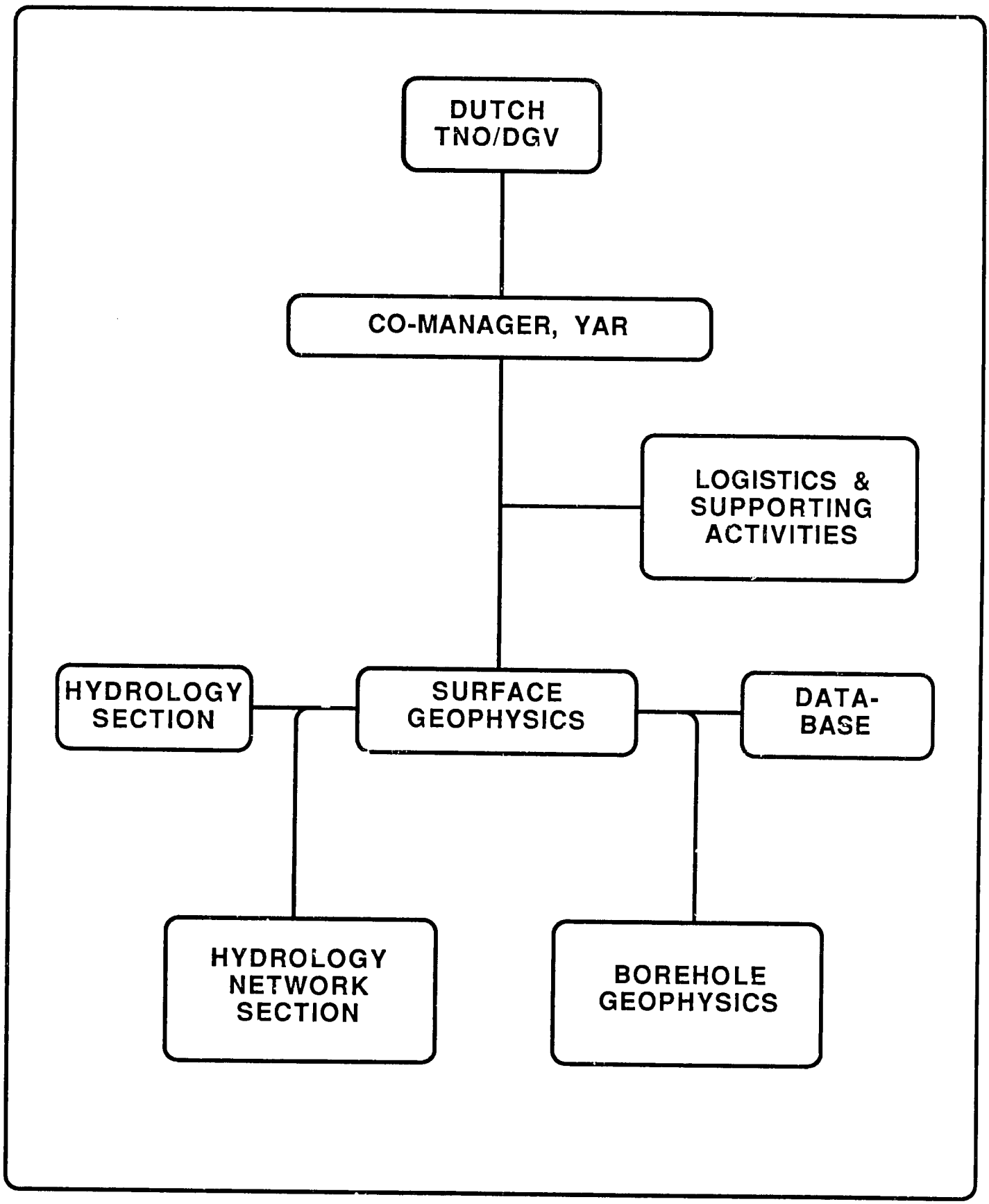


Figure 2-4. Preliminary WRAY-2 Project Organization Chart

2.6.4 Institutional Support

Previous consultants have suggested that the Department of Hydrology does not belong within YOMINCO. The primary objections are as follows:

1. No commitment from the Director General to make DOH activities a priority

2. No external authority or political clout

3. No cooperative recognition from other YARG agencies.

Interviews conducted as part of this study confirm these concerns. Discussions with the Director General of the Geologic Survey Board indicate the following:

- The primary function of the GSB is to provide geologic mapping and surveying.

- The DOH is needed only to help fulfill this function.

- Once geologic surveying in the YAR is completed, the Director would have no objection to transfer of the DOH to a newly formed Water Management Department.

Given this, it is clear that adequate institutional support and commitment within YOMINCO to make the activities of the DOH a priority is not forthcoming. With the discovery of petroleum in North Yemen and the current reorganization of YOMINCO, it is likely that the DOH will continue as an orphan department, because the focus of YOMINCO activities further shifts to oil exploration and development.

2.6.5 Reorganization

YOMINCO is being reorganized as the Ministry of Petroleum and Mineral Resources. The agency is currently functioning under YOMINCO organizational structure with the Minister of Finance as Acting Minister. According to discussions with the GSB Director General, a new Minister should be appointed in the near future. It was also indicated that the emphasis for the new Ministry will be on petroleum exploration/development. This comes as no surprise, given the discovery of oil in the Ma'rib area and increased activity by way of the granting of exploration concessions. The Ministry's organization has not yet been officially established. Discussions with TNO/DGV, the GSB Director General and the Yemeni WRAY-2 Co-project Manager, indicate that the new Ministry will have two main sections, one for petroleum and the other for minerals, each headed by a Deputy Minister. Ostensibly, the DOH and GSB would be under Minerals, thereby further depreciating the water resources planning potential of the Department of Hydrology.

2.7 Ministry of Agriculture and Fisheries

2.7.1 Organization and Responsibilities

The Ministry of Agriculture and Fisheries (MAF) was one of the first agencies established by YARG. MAF's role in the water sector is carried out through its Directorate of Irrigation (DOI), and three semiautonomous agencies: the Tihama Development Authority (TDA), which was created in 1973 to implement development projects in the nation's coastal plain, the Southern Uplands Rural Development Unit (SURDU), created in 1976 to implement integrated rural development in the Ibb and Taiz regions; and the Ma'rib Dam Authority, created in 1983 to implement the construction of the Ma'rib dam in northeast Yemen. These three semiautonomous agencies are nominally under MAF. In reality, however, they function as separate entities, with MAF exerting little more than a coordinating function for their activities.

The MAF is organized to reflect its major activities. The autonomous agencies, plus the DOI, the Fisheries Division, and the Forestry Division, are listed as line organizations responsible to the Deputy Minister, who is turn is responsible to the Minister. The MAF's Deputy Minister sits as a member of the High Water Council.

The TDA and SURDU were established under the sponsorship of the World Bank. Many foreign donors have joined with the Bank to provide continuing strong support for these agencies in the form of technical assistance and funds for capital works. A third autonomous agency, the Southern Central Highlands Rural Development Agency, was formed in late 1985 with the support of the World Bank and other donors, and its activities are scheduled to commence in early 1986.

The Directorate of Irrigation was the first agency given responsibility to manage YAR's water resources. It was supposed to carry out comprehensive surveys of ground and surface water resources in the country and implement projects and legislation to optimize the beneficial exploitation of water resources. DOI's role, however, has been preempted within the areas under the jurisdiction of the TDA and SURDU. Thus, DOI's main geographic areas of responsibility have been in the country's central section, the northern highlands, and eastern valleys.

The DOI has been unable to build up a staff with a high level of technical expertise. Ostensibly, the DOI's responsibilities include supervising consultants' work on the Ma'rib Dam and Wadi irrigation development projects, surveying and designing small irrigation dams and improvements in existing facilities, collecting meteorological data from a limited network of stations, coordinating activities regarding the work of the TDA and SURDU, and supervising Wadi studies in the Tihama regions which have not been turned over to TDA. The DOI, however, is greatly dependent on expatriate assistance, and most of their activities are concerned with providing limited coordination and tracking of projects being performed with donor assistance.

One of the major projects under the DOI's purview is a program to construct some 14 to 22 small irrigation dams throughout the country. The individual projects were said to involve impoundments of surface run-off for groundwater recharge and provision of irrigation supplies. Several attempts were made through the MAF, the CPO, and AID/Yemen contractors to obtain data/information

on this project, with no tangible results. The MAF has, in effect, kept all such information and data within its Ministry, and the details will probably surface if funding is obtained for one or more of these projects.

The research conducted for this project led to the following observations on the activities of the MAF and DOI. The MAF's program is not based upon an established set of objectives. Rather, the Ministry's separate entities appear to function in a loosely coordinated fashion, each pursuing its own goals. This situation is, for the most part, caused by the enormous level of donor assistance which the MAF is absorbing. In 1984, some 16 donors sponsored 51 technical assistance projects and 12 projects concerning capital works. The total donor aid involved (loans and grants) is about $360 million (US$), about one quarter of which was for the construction of the Ma'rib Dam.(52) Many of the technical assistance projects are under negotiation for extension. In effect, the MAF's program is donor driven, and the Ministry appears to be expending most of its energy and limited staff in tracking the status of these projects.

2.7.2 Activities Affecting the Sana'a Basin

The MAF's past activities in the water sector, generally described above, are in regions almost totally outside of the Sana'a Basin. Notwithstanding this lack of activity, the MAF is the counterpart Ministry for the comprehensive study of the Sana'a Basin being carried out under sponsorship of the USSR. This study has been under way since early 1983 and is scheduled for completion in the Fall of 1986. The scope of work and the overall area covered in the study are by far greater than any of the many studies previously conducted in the basin. As such, the study is expected to provide an extremely comprehensive database for the basin, suitable to provide, with little additional detailed work, the basis for developing the Water Management Plan for the Sana'a Basin. The World Bank's Action Plan for the Sana'a Basin has in fact assumed that this will be the case (see Appendices B and D). This study is discussed further in Chapter 3 of this report.

The MAF will have input to the Water Management Plan for the Sana'a Basin, because the Deputy Minister of the MAF sits as a member of the High Water Council. As outlined in the World Bank's Action Plan, a Water Management Department or similar agency is to be established to act as the HWC's technical arm. Thus, the Deputy Minister of the MAF will have input regarding the Water Management Plan for the Sana'a Basin.

Chapter 3

WATER RESOURCES

3.1 Introduction

Water has always been a precious commodity in the Middle East, for water supply, agriculture, and in recent years, growth and development. As observed in nearly all other arid regions of the planet, the Yemeni have evolved highly ingenious methods of capturing, allocating, and efficiently conserving the scant water resources available to them. Historically, reliance on the sayl (seasonal flood), ghayl (spring flow) system of allocations, and shallow, hand-dug wells was prevalent.(59) Using complex traditional systems for managing its use, the Yemeni achieved a tenuous equilibrium that balanced scarce water availability with the needs of the community.

Aggravated by a lack of effective national water policy and the capabilities needed to make informed planning and management decisions, Yemen is now experiencing difficulties in the water sector. The Sana'a Basin exemplifies these difficulties.

This section of the report examines the geologic and hydrologic setting of the basin as well as the technical aspects of the current water shortage. Using available information, the regional and then local hydrologic conditions and system are described to provide the reader with a technical perspective on the current and future water resource situation in the Sana'a Basin. Readers wishing to focus on the Sana'a Basin resources potential are referred to Sections 3.4 through 3.6.

3.2 Regional Setting

3.2.1 Physiography

YARG is located on the southwestern portion of the Arabian Peninsula. It is bounded on the west by the Red Sea, the Kingdom of Saudi Arabia to the north and east, and the People's Democratic Republic (PDR) of Yemen to the south. YARG's physical geography is diverse and exerts a strong influence on the hydrology of the region through its effects on climate and meteorological conditions.

The YARG can be divided into three major hydrographic regions (43); the Western, Eastern, and Southern Escarpments. As shown in Figure 3-1 on the following page, the Western and Eastern Escarpments are separated by a mountain chain extending roughly north-south and bisecting the Yeman Arab Republic. Near Dhamar, this divide splits to form the Southern Escarpment in the PDR. To the west of this divide, all watersheds drain toward the Red Sea. To the east, the area drains generally toward the Rub Al Khali, or "Empty Quarter" that Yemen shares with Saudi Arabia. The southern escarpment drains toward the People's Democratic Republic and the Gulf of Aden. Maximum relief between the mountainous uplands and the Red Sea is as much as 3,000 meters, and the mountainous highlands (over elevation of 1,500 meters) are within 100

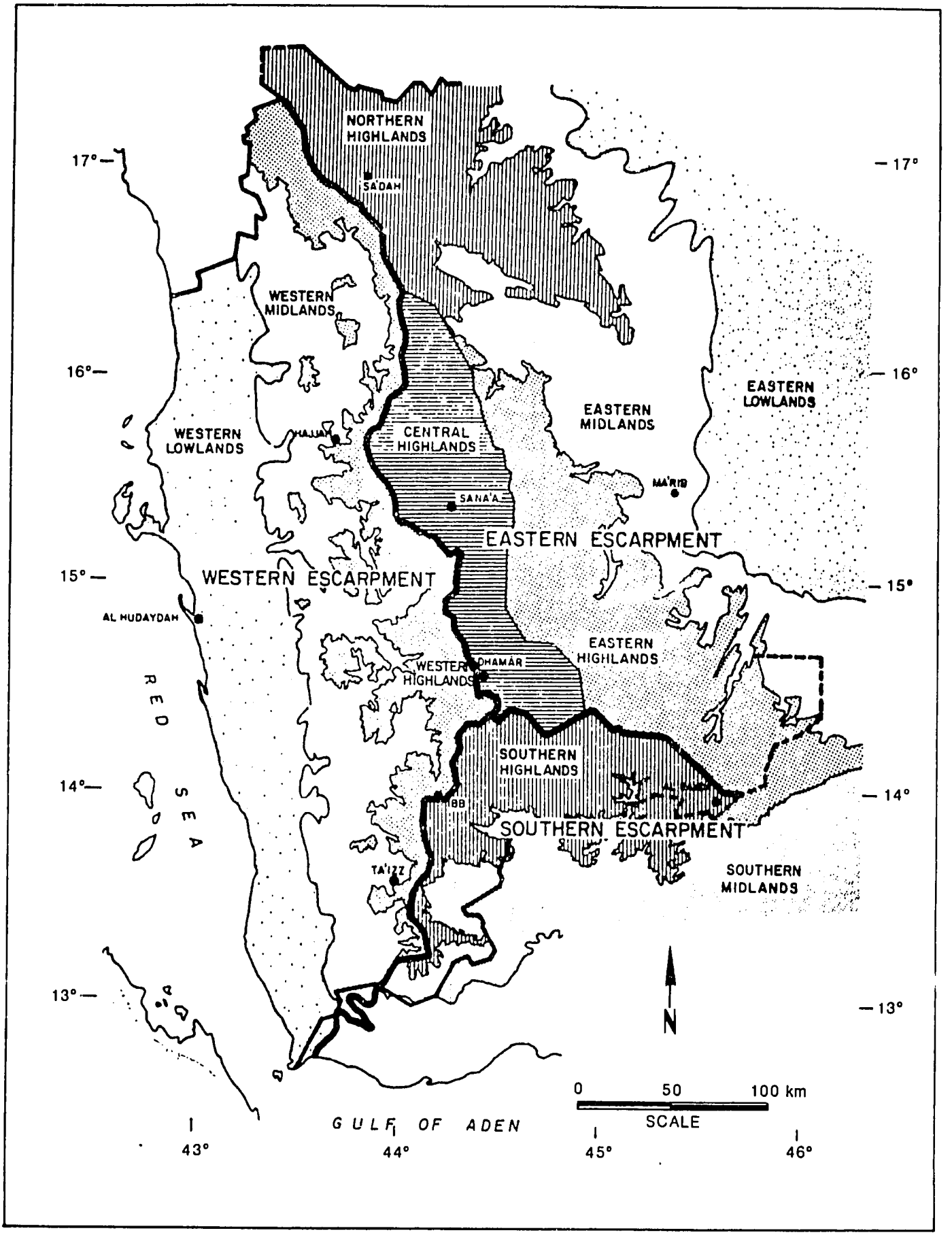


Figure 3-1 Physiographic Regions of Yemen Arab Republic (Adapted from CPO Swiss Report, 1978). (Ref.43)

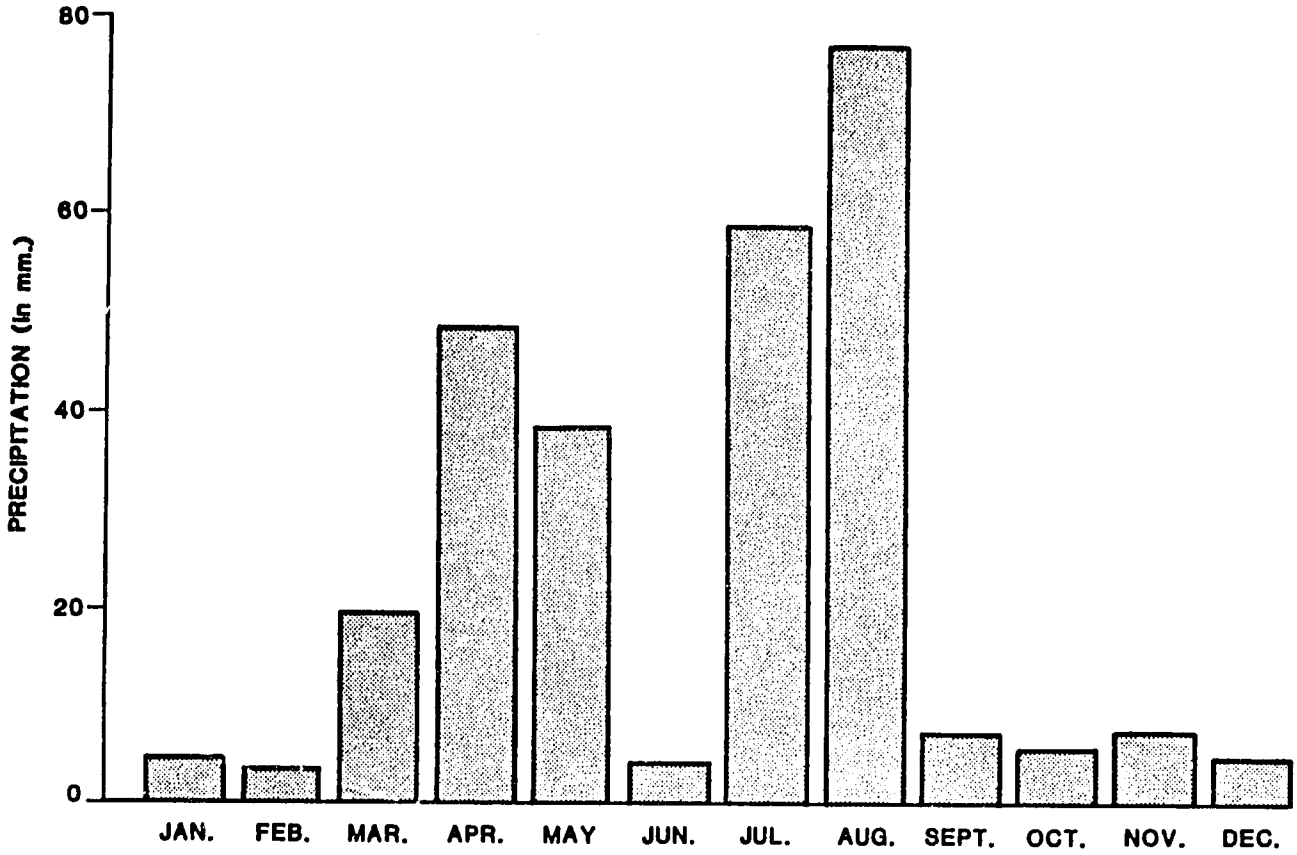


Figure 3-2 Histogram of Mean Monthly Precipitation at Sana'a, Yemen Arab Republic (Ref. 64)

kilometers. Approximately 72 percent of the country's area lies above 1,000 meters of the Red Sea coast.

As indicated in Figure 3-1, the Western Escarpment includes the dissected, mountainous uplands, paralleled by the lowland areas of the Tihama coastal plain. The Eastern Escarpment exhibits less total relief than the Western Escarpment and includes the mountainous zone of the Central Highlands, grading eastward to the lowlands and eolian dunefields of the Empty Quarter. The Sana'a Basin itself includes an area of approximately 3,500 km^2 located primarily within the Central Highlands' physiographic province.

The Central Highlands include a number of alluvial-covered intermountain plains at elevations of 2,100 to 2,700 meters. Some peaks in the surrounding mountain ranges exceed 3,000 meters, including Jebel Nabi Shuayb (3,760 meters), the highest mountain on the Arabian peninsula. Most rainfall occurring in this area evaporates or infiltrates, and, under most conditions, these plains act as zones of internal drainage. Only under intense rainfall conditions does run-off sometimes carry into the drainages to the east. The boundary between the Central and Eastern Highlands is located mainly along drainage divides, but is not well-defined.

3.2.2 Climate and Hydrometeorology

Climate

Dry, arid to semiarid climatic conditions are prevalent throughout most of the Yemen Arab Republic. Potential evapotranspiration exceeds rainfall during most of the year, with the exception of selected areas on the Western Escarpment. Regional climate ranges from the hot, tropical conditions of the coastal lowlands, to the temperate character of the mountainous highlands.

Rainfall

YOMINCO-TNO/DGV report (64) that rainfall in Yemen is generally caused by three primary meteorological mechanisms: (1) the Mediterranean "effects;" (2) the Red Sea Convergence Zone effect; and (3) the Intertropical Convergence Zone effect. The first of two rainy seasons occurs during April or May, resulting from the weather effects of the Red Sea. By July, the Intertropical Convergence Zone lies in the latitudes of Yemen. Warm, dry air from the north converges with the moist southerlies from the Indian Ocean. This second and main rainy season prevails by August and typically lasts until September (Figure 3-2). The rain-producing conditions are most pronounced along the Western Escarpment due to orographic effects. During the remainder of the year (October to March or April), dry conditions prevail, although light rainfalls may occur as a result of weather patterns generated in the Mediterranean during December or January.

An isohyetal map showing the distribution of mean annual precipitation in the YAR is presented in Figure 3-3. Although the database is incomplete, the relationship between topography and precipitation is clear. Average rainfall typically ranges from less than 50 mm, to more than 900 mm annually. In the Sana'a Basin, average annual precipitation is between 200-300 mm.

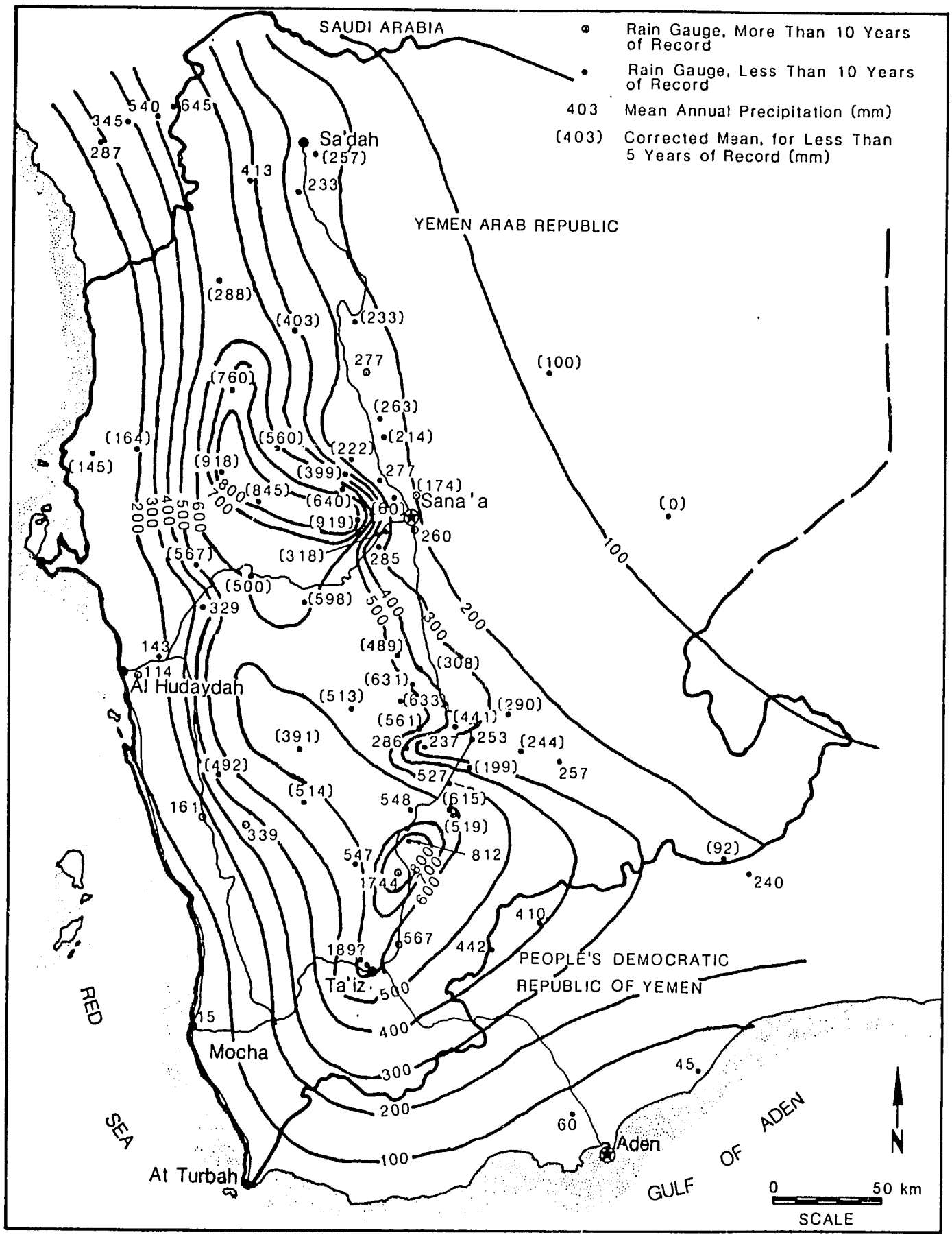


Figure 3-3 Mean Annual Precipitation Distribution in the Yemen Arab Republic (After Yominco-TNO/DGV, 1983)

Many authors who have studied the hydrology of areas within the Sana'a Basin have noted the below average precipitation period starting in the mid-1960s (64). Italconsult's 1973 report on the Sana'a Basin states "...the present cumulative conditions are the worst within the 20-year sample for which factual record is available, the worst for half a century at least."(29) The WRAY 1 report (64) noted that this drought period is still continuing, interrupted by only two "wet" years in 1975 and 1977. The importance of this drought period relative to the basin is that it further reduces the amount of recharge available to the groundwater system.

Temperature

Average temperatures in the YAR are a function of elevation. Above 200 meters (AMSL), temperature decreases linearly with increasing elevation at a rate of about 0.6°C/100 meters. At the lower elevations (that is, along the Tihama coastal plain), mean annual temperature is about 30°C with monthly averages ranging from ?6° to 33°C. In the Central Highlands, conditions are more temperate, with average temperatures of 15-19°C (64). Diurnal (day/night) temperature fluctuations are also greater at the higher elevations.

Evaporation-Evapotranspiration

Yemen is characterized by a net moisture deficit in which evaporation typically exceeds rainfall, for more areas of the country. Reported values for free water surface evaporation rates along the Tihama plain range from 1,900 to 3,400 mm/year, with calculated values of about 2,400 mm/year. Estimates of 1,650 mm/year are reported for zones at about 2,500 meters, such as the Central Highlands.

3.2.3 Geology -- Regional Setting

It is not possible to understand the groundwater hydrology of an area without having a clear and complete understanding of the geology. Rock type, stratigraphy, and geologic structure each play a key role in determining the occurrence, quantity, and movement of groundwater.

The complex geologic setting of the Yemen Arab Republic is the result of regional tectonic (continental drift) forces and events that not only controlled the deposition of sedimentary strata over geologic time, but also by the character of the present day landscape in the YAR. These same forces are also responsible for the complicated geologic and hydrogeologic conditions in the Sana'a Basin. A detailed discussion regarding the geologic conditions in the Sana'a Basin is provided below so that the nature and occurrence of groundwater (virtually the only basin source) in this area may be better understood.

Regional Setting

The Arabian Peninsula comprises part of the East African Shield, an extensive region of Precambrian basement rocks. These rocks were leveled by erosion to a broad peneplain, and subsequently covered by younger marine and continental sediments during the Ordovician, Jurassic, and Cretaceous periods. During the

late Cretaceous and early Tertiary, the present day Arabian Peninsula and East Africa were uplifted by regional plate tectonic forces exposing the previously deposited sediments. The continental plates began to break into separate blocks by a process known as rifting. Faults and other zones of weakness in the plates allowed the upwelling and eruption of lavas and volcanic pyroclastics that covered the now-exposed sediments and basement rocks.

During the Tertiary, the rifting process continued causing the Arabian Peninsula to drift northeastward, pulling away from the East African Plate. The rift valleys of the present day Red Sea and Gulf of Aden opened between Ethiopia and Yemen. This same process also created the Kenyan Rift Valley and caused extensive block faulting of the mountains of Yemen and Ethiopia. The resulting Horst (upthrown) and Graben (downthrown) block structure exhibits displacements of as much as 2,000 meters (64). This faulting not only placed outcrops of the various basement and sedimentary rocks at different elevations in each mountain range, but also created the regional topographic features in Yemen. To further complicate the geologic setting of the YAR, granite and granodiorite intrusions occurred during the Late Tertiary, causing additional deformation and faulting of the surrounding country rock (Grolier, et al., 1984).

Finally, a new phase of volcanism occurred during the Quaternary, forming volcanic cones, tuff layers, and lava flows that are still visible in the Yeman countryside. As the Quarternary proceeded, these volcanic features were modified somewhat as erosive processes formed the principal drainages, creating terraces and alluvial plains. In the lowlands and eastern plateau areas, eolian forces created vast dune fields and mobile sheets of sand that cover the Mesozoic sediments, granite intrusives, and basement rocks (Grolier and Overstreet, 1978).

3.3 Sana'a Basin Hydrology

3.3.1 Overview

The advent of drill rigs and diesel powered pumps during the early 1970s has caused a nearly complete dependence on groundwater for almost all water requirements in the Sana'a Basin. Drilling and groundwater withdrawals from the sandstone aquifer over the last ten years have increased at a phenomenal pace, thereby causing over-exploitation of the finite groundwater resource. Groundwater levels have rapidly declined, many wells have gone dry, and the City's water supply wellfields are no exception.

Although various studies have been conducted over the last 12 years regarding the Sana'a Basin, fundamental information on its hydrologic nature is still lacking. Although the available information has been assembled for the purpose of this analysis, it is clear that additional work is needed before the hydrology of the basin can be clearly understood.

3.3.2 Geology

Although various maps and reports have been published for the Sana'a Basin, the subsurface geology is not well known. A 1:100,000 scale geologic map

prepared by Italconsult in 1973 remains the primary source of information, although more recent, smaller-scale maps have been developed by Grolier and Overstreet (1978)(16), and the FGR Institute for Geosciences and Natural Resources (1983). These maps provide information on the surface (outcrop) distribution of the various geologic units, but are unable to provide us with a complete picture of what's happening in the subsurface. It is similarly unfortunate that although there are thousands of private boreholes within the Sana'a Basin, only a handful of them have geologic logs. Thus, the structure and detailed stratigraphy of the basin remains largely unknown, and the groundwater system of the basin is also poorly understood.

A generalized geologic map of the Sana'a Basin is presented in Figure 3-4. The basin consists of a series of Mesozoic sediments overlain by a complex group of Tertiary and Quaternary extrusive volcanic units. These, in turn, are overlain by Quaternary to Recent deposits of alluvium and eolian material. The central portion of the basin is occupied by extensive deposits of alluvial material up to 400 meters thick. The materials underlying these alluvial deposits vary depending on location within the basin.

In the eastern portion of the basin, Mesozoic sediments predominate. The oldest sediments exposed are the marine to transitional limestones, marls and shales of the Jurassic Amran Series. These units are up to 600 meters thick. Although the Amran may be underlain by a yet older unit, the Triassic-Jurassic Kohlan Series, it does not outcrop within the Sana'a Basin itself. The Kohlan is of significant interest in that it consists of sandstones, conglomerates, and shales that are potentially water-bearing. Comparatively narrow exposures of the Kohlan Series have been mapped to the east and southeast of the Sana'a Basin by the FGR Federal Institute for Geosciences (1983).

These exposures appear to pinch out to the north and south beneath the Amran limestone. Since their depositional pattern is not known, however, there is no information regarding the possible presence of Kohlan units at depth beneath the Sana'a Basin. The upper portions of the Amran limestone are transitional, grading into evaporitic deposits and shales. (To the east of Sana'a, gypsum is mined by the Yemenis to make plaster used for, among other things, the elaborate stained glass window frames found in Sana'a.) These units are overlain by 80 to 100 meters of lagoonal shales, black limestones, and bedded sandstones.

The overlying sandstones and sandy conglomerates of the Cretaceous-Tertiary Tawilah Sandstone represent the primary aquifer in the Sana'a Basin. This unit underlies most of the basin, achieving a thickness of up to 400 meters. Although the Tawilah appears to have been initially deposited throughout most of the YAR, subsequent erosion has removed much of it. Outcrops of the Tawilah are present east and north of Sana'a, but the northwesternmost extent is not known due to the overlying volcanics that may obscure its presence. Resistivity surveys performed by Italconsult suggest that it wedges out at depth immediately north of Rawdah. To the south, the Tawilah is inferred to be at increasing depths up to approximately 700 meters 10 kilometers south of Sana'a beneath thick layers of volcanics.

Overlying the Tawilah Sandstone are the neritic claystones, sandstones, shales and conglomerates of the Medj-Zir Formation. The first (oldest) evidence of volcanic activity is also present in the form of tuffaceous units in the

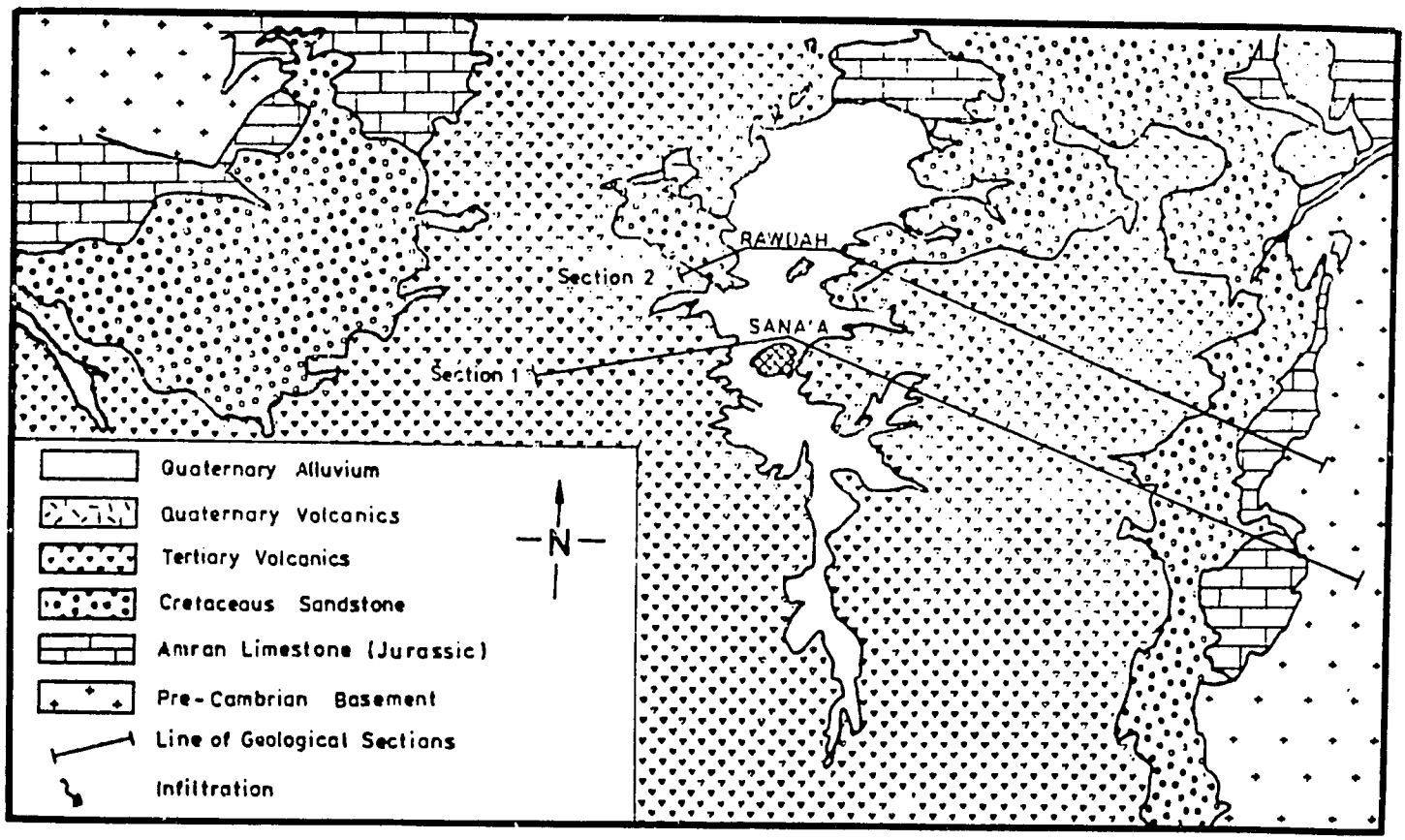


Figure 3-4 Generalized Geologic Map of the Sana'a Basin (After Charalambous, 1982)

Mejd-Zir. The estimated thickness of the Mejd-Zir is approximately 100 to 200 meters. Unlike the Tawilah sandstone, the sediments of the Mejd-Zir are more clayey and thus have less groundwater bearing potential. (29/30)

Tertiary volcanic rocks overlie many of the Paleocene and Mesozoic sedimentary units. Described in detail by Italconsult (29/30), these units are sometimes referred to as the Trap Series. They consist of basalt flows, tuffs and ignimbrites, rhyolies, and other volcanics. Basic intrusive rocks are also present throughout the areas in the form of volcanic necks or plugs, dikes, sills, and other features. The dikes typically trend NNW-SSE and NNE-SSW, and tend to occur in zones of more intense fracturing within the Cretaceous Sandstone units. The thickness of the extrusive volcanic units is variable, with greater thicknesses typically occurring near the eruptive centers. Groundwater does occur within the Tertiary volcanic units, primarily in fracture zones or in weathered zones present between some lava flows. Younger Quaternary volcanic rocks are also present in the Sana'a Basin. They consist of extensive basalt flows and dikes that flank the west and northwest portions of the basin.

Geologic Structure

Geologic cross sections developed by Charalambous (13) suggest that the general structure of the Sana'a Basin is characterized by broad anticlinal and synclinal folds that have been disrupted by intrusions and faulting (Figure 3-5). Howard Humphreys (20) suggests that these sections may be simplistic, and that the actual geologic structure of the region is more complex. Indeed, it is still uncertain as to whether the Sana'a plain was formed by breaching and partial erosion of a broad, north-south trending anticlinal fold, or if it is actually a down-faulted graben in which Quarternary alluvial and lacustrine sediments have accumulated.

The lack of subsurface geologic data is a direct impediment to adequate understanding of the basin's groundwater system. Until deep drilling, regional geophysical, and other studies can be conducted, it will continue to be difficult to:

- Resolve questions regarding the basin's groundwater flow system.
- Determine the actual recharge mechanisms and rates.
- Develop meaningful groundwater management approaches.
- Assess the presence and groundwater potential of the deeper geologic units (such as the Kohlan Sandstone).

The presence of faulting and fracturing in the Sana'a Basin plays an important role in the occurrence and movement of groundwater. Italconsult (1973) has suggested that the Sana'a Basin has not been subject to much disruption, at least not as compared to the much larger displacements that occurred along the Western Escarpments paralleling the Red Sea. Although major faulting may not predominate within the Sana'a Basin, extensive jointing and fracturing is evident. Fracture trace studies conducted by Italconsult (1973) indicate two predominant trends of NNW-SSE (primary) and NNE-SSW (secondary). It is these fracture systems and intersections that impart a "secondary permeability" for

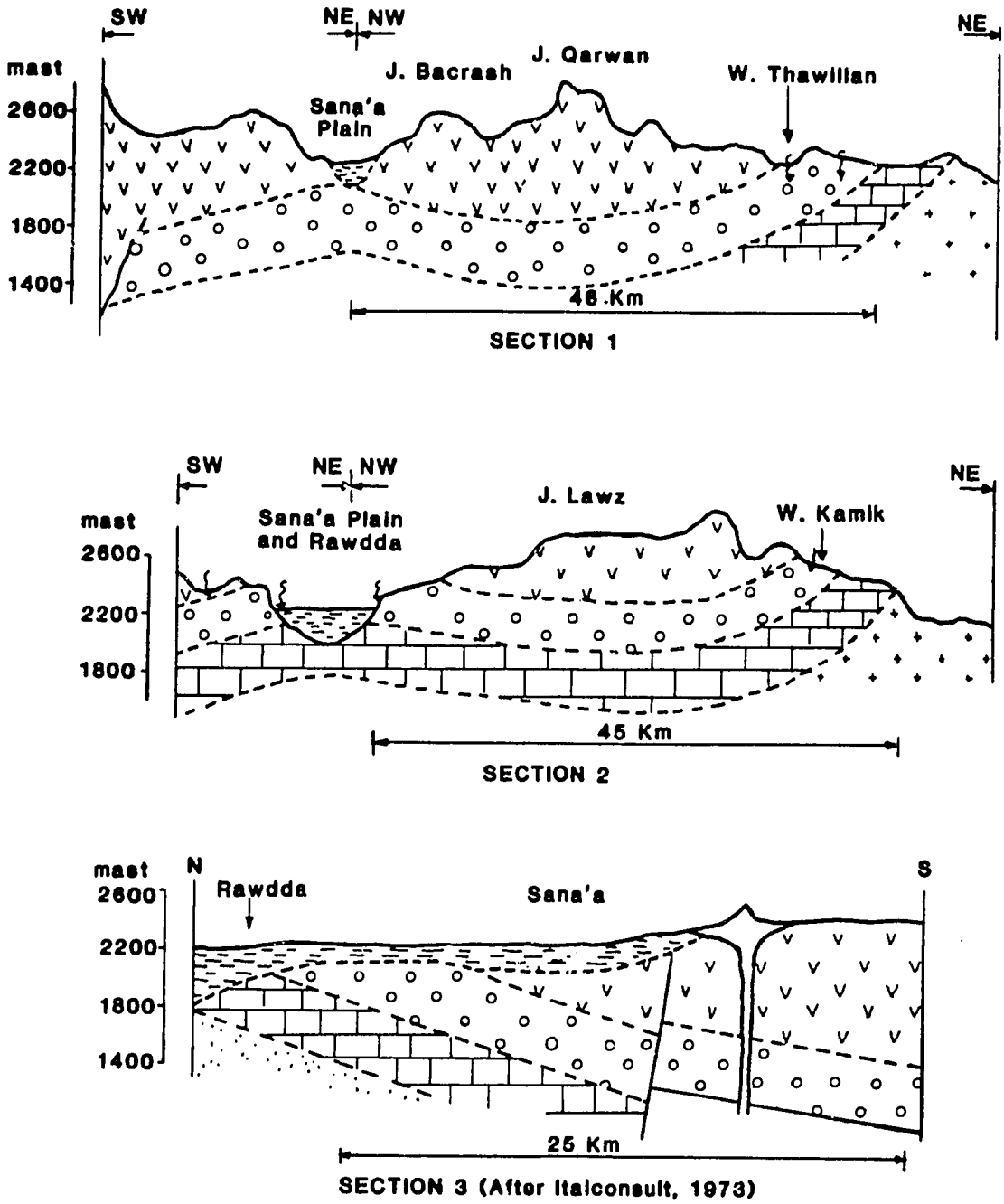


Figure 3-5 Interpretive Geologic Cross Sections of the Sana'a Basin (After Charalambous, 1982)

example, to the Tawilah Sandstone. As a result, wells extracting groundwater from fracture zones in this formation can have production levels two orders of magnitude higher than those producing from unfractured zones. Similarly, fracturing or dike intrusions in relatively low permeability formations such as the Amran Limestone can also create zones of groundwater movement and springs with observed discharges up to 200 l/s.(15)

Extensive fracturing is also evident in the Tertiary and Quaternary extrusive volcanics and lava flows. Again, the secondary permeability imparted by these features creates zones of higher yield in geologic units that otherwise have low to moderate groundwater potential.

3.3.3 Surface Water Hydrology

Watersheds

Figure 3-6, on the following page, presents the major watersheds in the YAR and the Sana'a Basin. The watersheds in the Sana'a Basin are mostly tributaries of the Wadi Al Jawf, which drains toward the Rub Al Khali. In the area of Sana'a, these watersheds become vague and ill-defined within a broad expanse of alluvial materials. This area is known as the Sana'a Plain. The Sana'a Basin is bounded on the west by the major north-south trending watershed divide that bisects Yemen. To the east, the Sana'a Plain drops off gently at first toward the Wadi Al Jawf. Stream gradients then steepen as they descend the Eastern Escarpment. Catchments within the Sana'a Plain typically do not have well-defined channels, and some areas are drained internally (that is, they have no discharge point outside of the plain). Stream gradients are very low, and run-off escapes the Sana'a Plain only during extremely intense rainfall events.

Previous investigations have variously defined the Sana'a Basin either as the alluvial plain itself, or in some areas, described it in general terms only. For the purpose of this Sector Analysis, the surface watershed boundaries have been used as there is insufficient piezometric information to define the groundwater divides adequately.

Run-off

Most streams in Yemen are ephemeral, because run-off occurs only as a result of intense rainfall. In a few cases, wadis may exhibit some intermittent or perennial flow resulting from groundwater spring or seep discharges. Run-off in the ephemeral streams usually infiltrates the channel bed and banks before traveling far, thereby resulting in recharge to the alluvial groundwater system.

In many areas of the Sana'a Basin, the Yemenis have terraced the hillslopes in an effort to capture the sparse rainfall and run-off. Despite these efforts, soil moisture levels seldom approach field capacity, and it is likely that crops on these terraced slopes probably consume most of the retained moisture, with little left for groundwater recharge.

YOMINCO-TNO/DGV, (1983) have attempted to subdivide the YAR on the basis of runoff producing and absorbing zones (Figure 3-7). Run-off-producing areas are

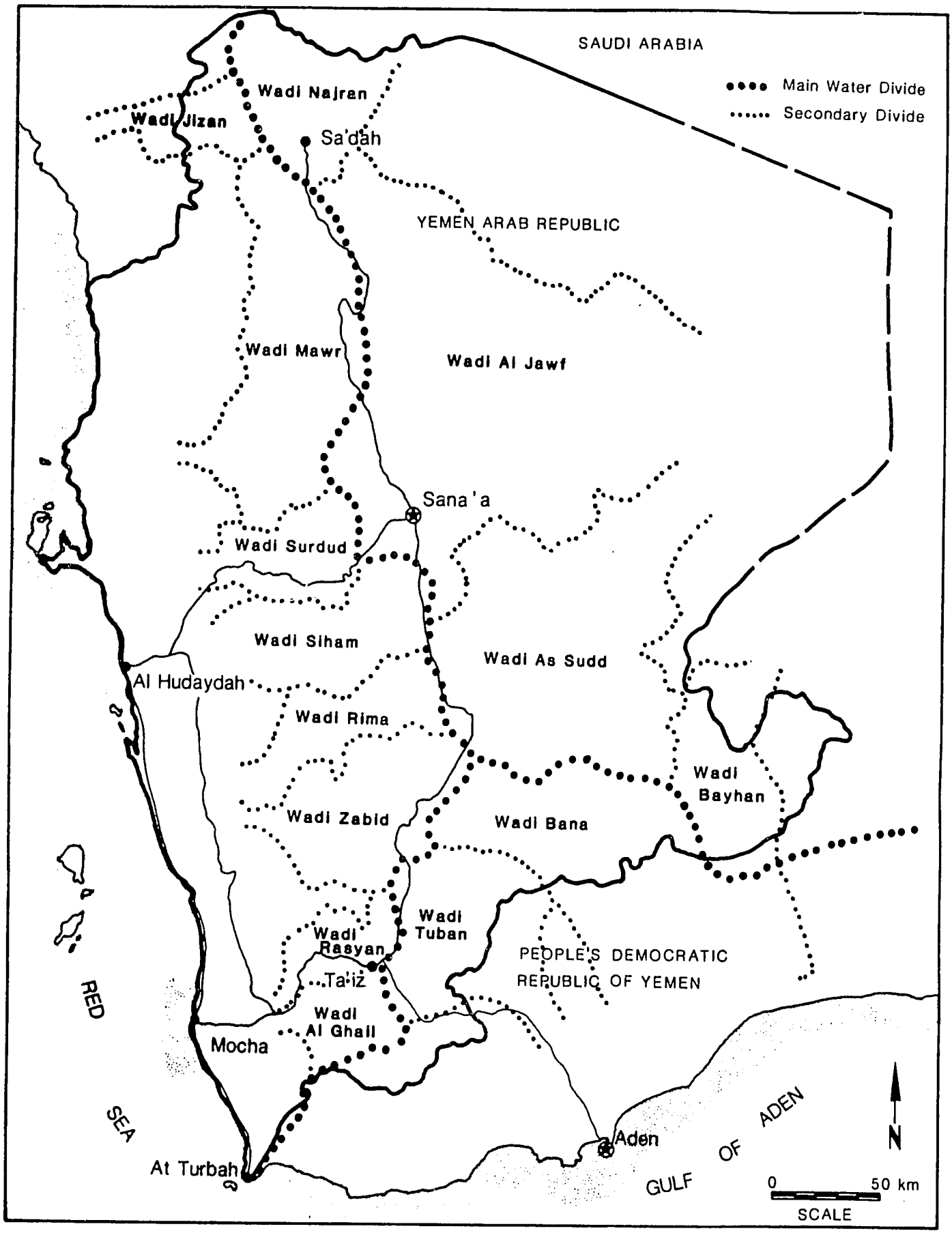


Figure 3-6 Principal Watersheds, Yemen Arab Republic (After Yominco-TNO/DGV, 1983)

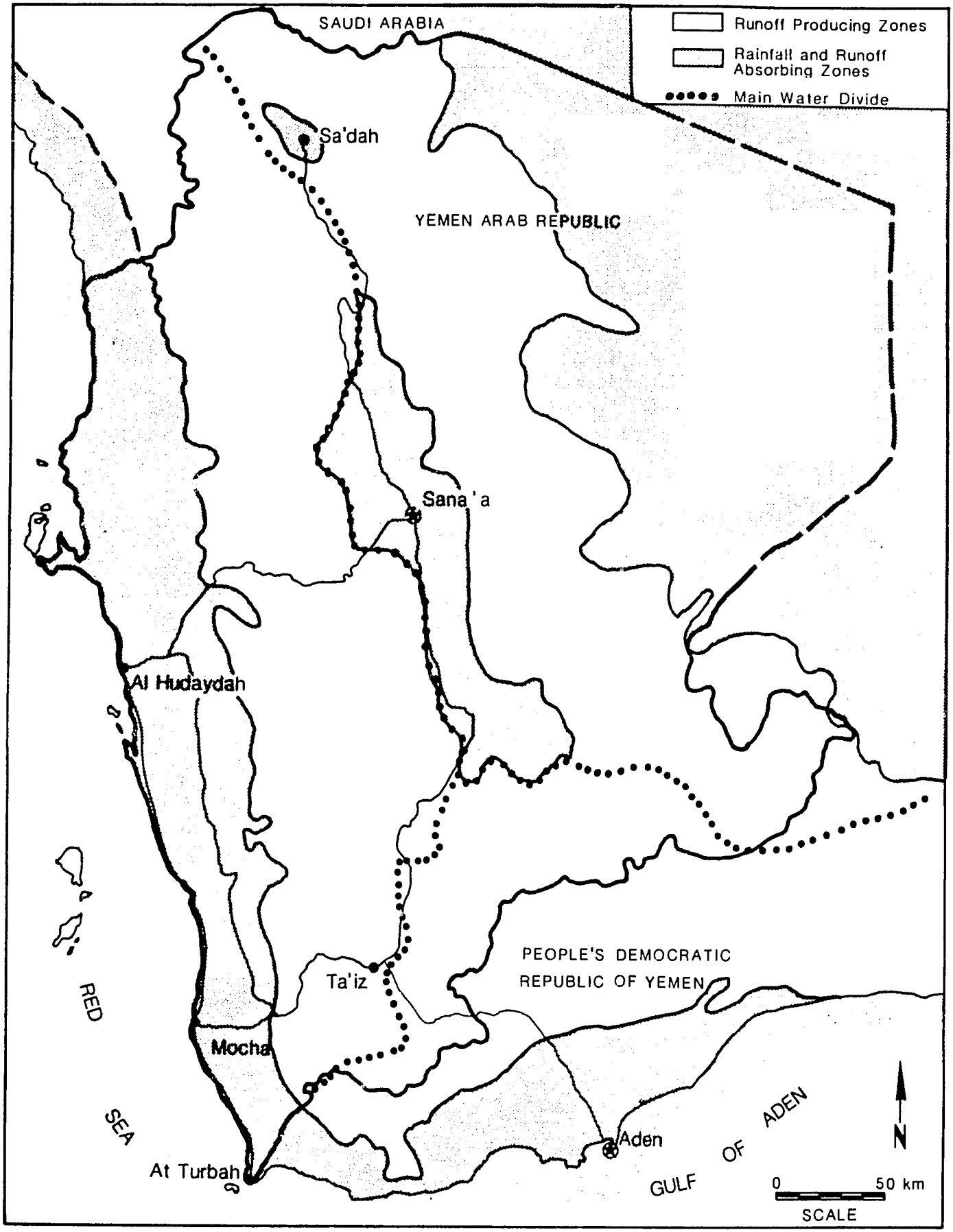


Figure 3-7 Runoff Producing and Absorbing Zones of the YAR (After Yominco-TNO/DGV, 1983)

exemplified by those areas which typically receive the highest amount of rainfall (that is, the south and west facing slopes of the highlands in the Western and Southern Escarpment). Those areas receiving relatively little precipitation and that are topographically lower, such as the Tihama Coastal Plain and the Sana'a Alluvial Plain, tend to be run-off absorbing areas where infiltration predominates. If there is anything less frequent in the Sana'a Basin than wadi run-off, it is the availability of streamflow discharge records. Checks with the WRAY-1,2 Dutch project team at YOMINCO indicate that there are essentially no monitoring or gauging records for wadis in the area.

The USSR investigation of water resources in the basin reportedly included assessment of surface water impoundment schemes in Wadi Al Kharid and seven other catchments. It was reported that 22 possible impounding sites were identified and that detailed surveys were carried out on 8 sites.(15) Unfortunately, the USSR study was unavailable and it was impossible either to ascertain directly from the USSR team the scope of their surface water studies or to review its data.

As is common for all arid regions, wadis in the YAR have a "torrential" regime and are prone to flash flooding. This is a result of intense rainfall events and the physical watershed characteristics. Steep watershed slopes and lack of vegetation for cover are common. As a result, run-off-retarding factors are few, and time of concentration or peak flow is extremely short. Streamflow hydrographs for most wadis in the YAR are thus typically characterized by remarkably abrupt rising limbs, with short-lived peaks that are often several orders of magnitude greater than low flows, and steep recession limbs. This type of flashflood character, combined with the lack of cover and limited soil profile development, results in extremely large sediment loads, and the flood characteristics in the Wadis.

The opportunity for groundwater recharge is not as great as compared to streams with an established baseflow. Nevertheless, some recharge to the alluvial groundwater system does occur through stream channel infiltration. In areas where the wadis cross outcrops of Tawilah sandstone or other bedrock aquifers, some infiltration and recharge is also gained.

3.3.4 Groundwater

Hydrostratigraphy

Groundwater occurs in several geologic units within the Sana'a Basin, which may be grouped accordingly:

- Alluvial deposits
- Volcanic units (including tertiary and Quaternary Deposits)
- Mesozoic sediments (including the Mejd-Zir, Tawilah, Amran, and Kohlan strata).

The following discussion summarizes the available information regarding the hydrostratigraphy and hydraulic characteristics of each groundwater bearing unit in the Sana'a Basin.

Alluvial Deposits

Alluvial materials in the central portions of the Sana'a Plain have been investigated in some detail by Italconsult.(29/30) According to these investigations, the alluvial materials in the central portion of the plain cover an area of approximately 152km^2, and achieve a maximum thickness of approximately 400 meters just north of Rawdda. (The maximum extent of these deposits within the Sana'a Plain is actually greater than the area studied in detail by Italconsult.)

The alluvial deposits in the Sana'a Plain represented the principal source of groundwater used in the basin until the 1970s. Access to this water table aquifer was via "shallow" dug wells and tubewells. In ancient times, qanatys and drainage galleries were also constructed in the alluvium south of the city to transport water. These are now defunct and dry due to lowering of the groundwater table. There are now thousands of wells in the valley alluvium, and the degree of reliance on and exploitation of the alluvial aquifer has been overshadowed by groundwater exploitation from the underlying Tawilah Sandstone.

The character of the valley fill deposits appears to be variable, although Italconsult(29) reports that these materials are typically of low permeability due to their generally clayey nature. Field observations made for this study indicate that there are also more, coarse grained sandy to gravely zones within the alluvium. Although groundwater conditions in the alluvium are typically unconfined (that is, "water table"), Italconsult(29) notes that layering (and therefore textural variability) of these deposits may also create semiconfined (and perhaps perched) hydraulic conditions.

Isopach maps and geologic cross-sections of the Quaternary alluvial deposits show a typical valley fill geometry that tends to thicken toward the north of the Sana'a Plain. The aforementioned maximum thickness of approximately 400 meters is achieved near the airport, just north of Rawdda. From this point, the alluvial deposits thin toward the north and east, until the underlying Tawilah and Amran bedrock units are exposed.

Italconsult(29) and Howard Humphreys(20) report that the alluvial deposits of the Sana'a Plain are generally considered to be poor aquifers. Because of their generally fine-grained texture, the alluvial sediments tend to have transmissivity values on the order of 100 m^2 per day. The reported permeability is 0.9 m per day, which is also indicative of silty to clayey, low permeability aquifer materials. As a result, individual well yields are low, and drawdowns are typically large. Pumping from the large number of alluvial wells in the basin has caused a lowering of the water table at approximately 2m per year.(20)

The investigations performed by Italconsult also addressed piezometric conditions in the alluvial deposits. Information obtained from their study suggests: (1) that groundwater flow in the alluvium is northward along the major axis of the Sana'a valley, and (2) that there may be a single groundwater system that includes both the alluvial and Cretaceous sandstone aquifers. Hydraulic interconnection between the alluvial deposits and the underlying sandstone aquifer is an important factor. Simply stated, it means that groundwater may flow between the two units. The direction (that is,

recharge or discharge) and amount of groundwater exchange between the two units is a function of their permeability and hydraulic head relationships. (An analysis of current piezometric data should be performed for the alluvial deposits and the underlying sandstone. This would help determine what, if any, effect pumping and groundwater extraction in one unit has on the other.)

Within the context of the present groundwater situation in Sana'a, the following considerations should be noted relating to groundwater movement in the alluvial deposits:

- Alluvial groundwater levels in the Sana'a Basin were declining rapidly as early as 1972 as a combined result of excessive pumpage and drought conditions.(29/30)

- The alluvial deposits are influenced more by short-term changes in rainfall or run-off-related recharge than the deeper bedrock aquifers.

- The alluvial deposits probably provide at least some degree of recharge to the underlying Tawilah sandstone.

Given these factors, extensive pumping of the alluvial units within the Sana'a Basin may be at the expense of recharge to the Tawilah Sandstone.

Volcanic Units

As described in Section 3.3.2 the Tertiary and Quaternary volcanic units within the Sana'a Basin are diverse and represent a variety of rock types and water bearing characteristics. These units consist of lava flows, ignimbrites, and intrusive volcanic features. The primary or intrinsic permeability of these units is typically low to nil. Extensive fracturing and jointing of these rocks has, however, provided varying degrees of secondary permeability, thus enhancing their water bearing characteristics and ability to receive recharge.

In the Sana'a Basin, local wells often tap the Tertiary Yemen Volcanics or "Trap" series as well as the younger Quaternary basalt flows. When water is encountered, yields are reportedly low, and drawdowns are high. Like the alluvial deposits, reported transmissivities are also low (100 m^2 per day), with corresponding permeabilities of less than 0.5 meters per day.(20) Specific capacities are similarly low, on the order of 0.1 l/s/m. Aubel(6) notes that groundwater occurs not only within some fracture systems in the volcanics, but also along weathered zones between individual lava flows. Drilling conditions in the volcanics are reportedly difficult, as a result of the fractured nature of the rocks and occasional presence of large void spaces.

Information regarding head relationships and groundwater movement through the various volcanic units is lacking. Italconsult(29) reports that the basal unit of the Trap Series is from a few meters to more than 300 meters thick. Depth to groundwater is quite variable, tends to parallel surface topography, and is typically found under unconfined conditions. Perched zones in the upper Trap basalts are also reported by Italconsult, in one case forming a series of springs near Hadda, southwest of Sana'a.

An extensive series of Quaternary basalt flows is present west-northwest of Sana'a. As a result of the irregular topographic surface on which these flows were deposited, their thickness varies from tens to hundreds of meters. These units are also extensively fractured, and appear to be the source of groundwater springs discharging in the areas of Wadi Dhahr, Wadi Lulua, and Wadi Assr.(29)

Although piezometric data are lacking for the volcanic units, the presence of extensive fracture systems and discontinuities, and the observed presence of groundwater accumulations, suggests that they may also serve a role in recharging the Tawilah Sandstone.

Mejd-Zir Formation

The Paleocene Mefd-Zir formation consists of 100 to 120 meters of sandstone, siltstone, and claystone beds which overlay the Cretaceous Tawilah Sandstone. In the Sana'a Basin, the Mejd-Zir is always present above the more uniform sandstones of the Tawilah. Tuffaceous beds and other indications of volcanic activity are present in the upper, finer-grained portions of the Mejd-Zir.

For hydrogeological purposes, the Mejd-Zir and Tawilah Sandstone are often grouped together. The generally finer-grained character of the Mejd-Zir formation makes it less permeable, however, and its importance as a groundwater aquifer is low as compared to the Tawilah Sandstone. No quantitative data are available for this report regarding the hydraulic parameters for the Mejd-Zir, although Italconsult (1973a) reports that the two formations are "hydraulically inseparable."

Tawilah Sandstone

The Cretaceous Tawilah Sandstone is the primary source of groundwater in the Sana'a Basin and is relied upon by nearly all areas of water use, including agriculture, rural supply, the city's wellfields, industry, and commerce. Through the availability of drilling rigs and pumps, the Tawilah has become accessible to nearly everyone, and as a result, this aquifer has become overtaxed and conflicts between users are becoming more frequent.

The Tawilah Sandstone outcrops extensively north of Sana'a, but is buried beneath a thick (400 to 900 meters) cover of volcanic units in the central and southern areas of the highlands. To the east of the Sana'a Plain, the Tawilah has been eroded, thereby exposing the underlying Amran limestone. Geophysical data obtained by Italconsult (1973a) suggest that the Tawilah thins and ultimately pinches out north of Rawdda. To the west of Sana'a, the Tawilah is covered by tertiary pyroclastic units and quaternary basalt flows until it is again exposed on the Western Escarpment near Dafir and Shibam. The thickness of the Tawilah aquifer is typically between 300 to 400 meters. Erosion in the northern part of the Sana'a Plain has removed a substantial part of the formation (Howard Humphreys, 1983). Tertiary volcanic plugs and other intrusives have also disrupted the Tawilah at selected locations within the Sana'a Basin.

As discussed in Section 3.2.3, the geologic structure of the Tawilah is not well-defined. Geologic interpretation by Charalambous (13) suggests that the Tawilah forms a broad, southerly-plunging, eroded anticline in the Sana'a

Basin area (refer to Figures 3-4 and 3-5). The basin has alternately been described as a graben (down-faulted) structure, although this possibility is not obvious from inspection of the available geologic mapping. Structurally, the Tawilah has also been displaced by faulting at various locations within the basin, with observed offsets up to 200 meters. As discussed in Section 3.2.3, fracturing and jointing within the unit is extensive, thereby providing in some locations, a high degree of secondary permeability.

The permeability of the Tawilah Sandstone varies by about two orders of magnitude as a result of fracturing, faulting, and jointing. The intrinsic or primary permeability of the sandstone itself is low, on the order of 0.05 to 0.5 meters per day. This low permeability is most likely a result of the arkosic nature of the sandstone in which finer-grained matrix materials reduce the intergranular porosity of the rock. Local fracturing of the sandstone has increased the permeability to approximately 1 meter per day. Although the fracturing has increased the water bearing potential of the Tawilah, it has also resulted in a highly anisotropic aquifer with an irregular distribution of transmissivities, ranging from 10 to 1,000 m^2/day.(20) This means that individual well yields will vary significantly depending on their location, depth, and degree of fracturing encountered in the sandstone. This variability is depicted in Figure 3-8, which shows the variability in transmissivity as a function of penetrated aquifer thickness for the Tawilah Sandstone.

Howard Humphreys (20) also reports areal variability in the range of observed permeabilities within the city's wellfields, most likely a result of the pattern of fracturing within the sandstone. Although available data are incomplete, it appears that permeability may decrease with depth. If true, this condition may partially offset the increased yields that could otherwise be achieved by deepening wells to penetrate the full thickness of Tawilah Sandstone at some locations. Storage coefficients in the Tawilah Sandstone range from 10^{-2} to 10^{-4}. Both are considered typical values for unconfined (water table) and confined (artesian) aquifers, respectively.

Italconsult (19) states that the Tawilah aquifer is hydraulically "open" to the overlying volcanics and alluvial units, presumably by virtue of its fracture-induced secondary permeability. The underlying shales and limestones of the Amran Series are reported to be much less permeable, and thus create a hydraulic boundary below the Tawilah. The sandstone therefore would represent the major groundwater "collector" in the basin, receiving recharge from all overlying units as well as its outcrop areas. The degree to which this situation exists is the focus of much speculation by previous studies.

Charalambous (13) reports that groundwater in the Tawilah occurs under unconfined conditions near its outcrop or where it is shallow. In the southern portion of the basin where the Tawilah is overlain by a considerable thickness of less permeable alluvium and/or volcanic rocks, the aquifer is confined, with water levels rising as much as 100 meters above the top of the sandstone.

For the area north of Sana'a, groundwater movement within the sandstone appears to be generally from the southwest and southeast periphery of the Sana'a Plain, to the north (Figure 3-9). Geologic data presented by Charalambous (13) and Italconsult (29/30) suggest also, however, that this trend may converge with a southerly flow direction originating from the subcrop of the Tawilah north of Rawdda. It is likely that local faults and

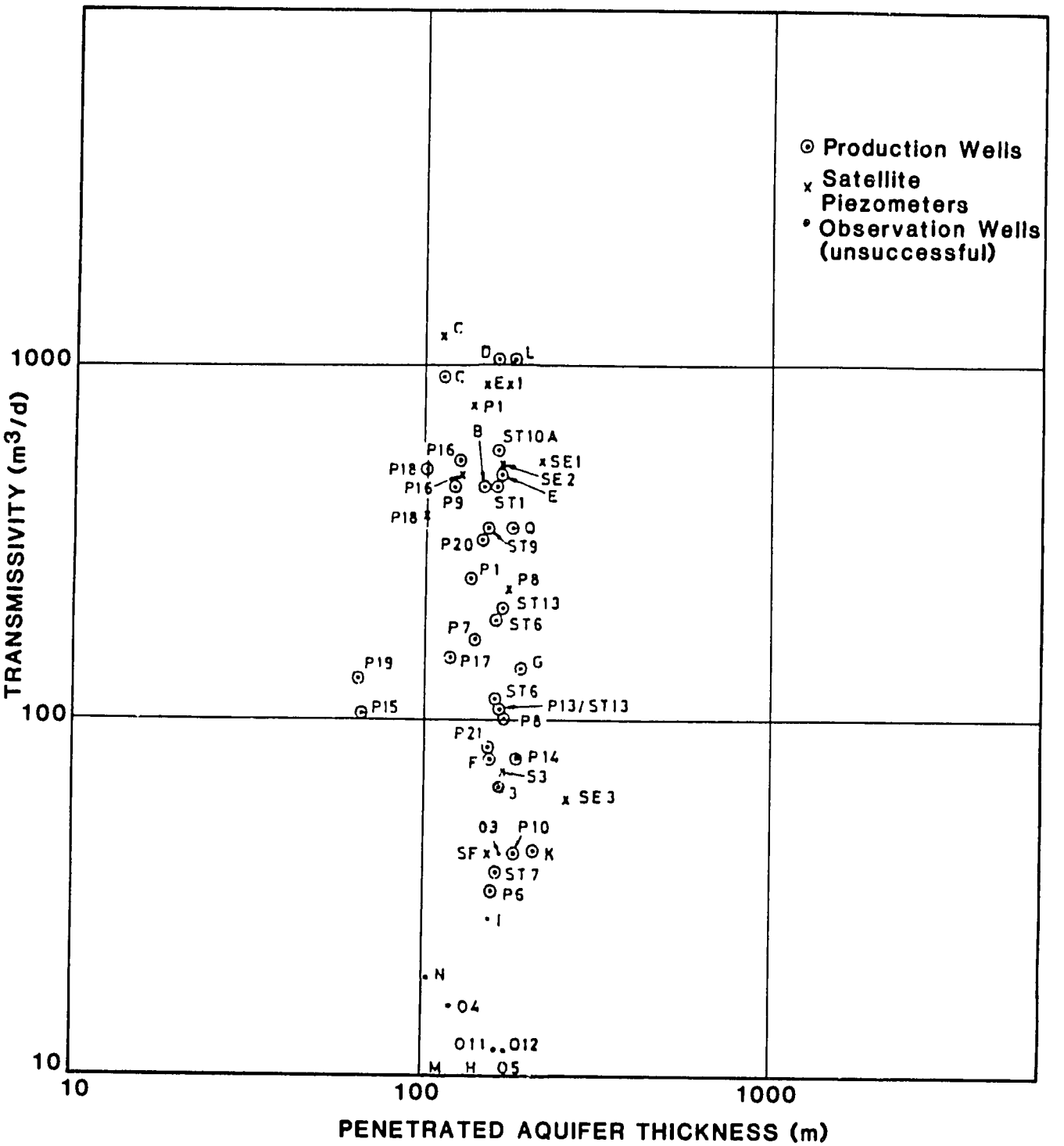


Figure 3-8 Variation of Transmissivity with Penetrated Aquifer Thickness for the Tawilah Sandstone , NWSA Wellfield (After H. Humphreys, 1983)

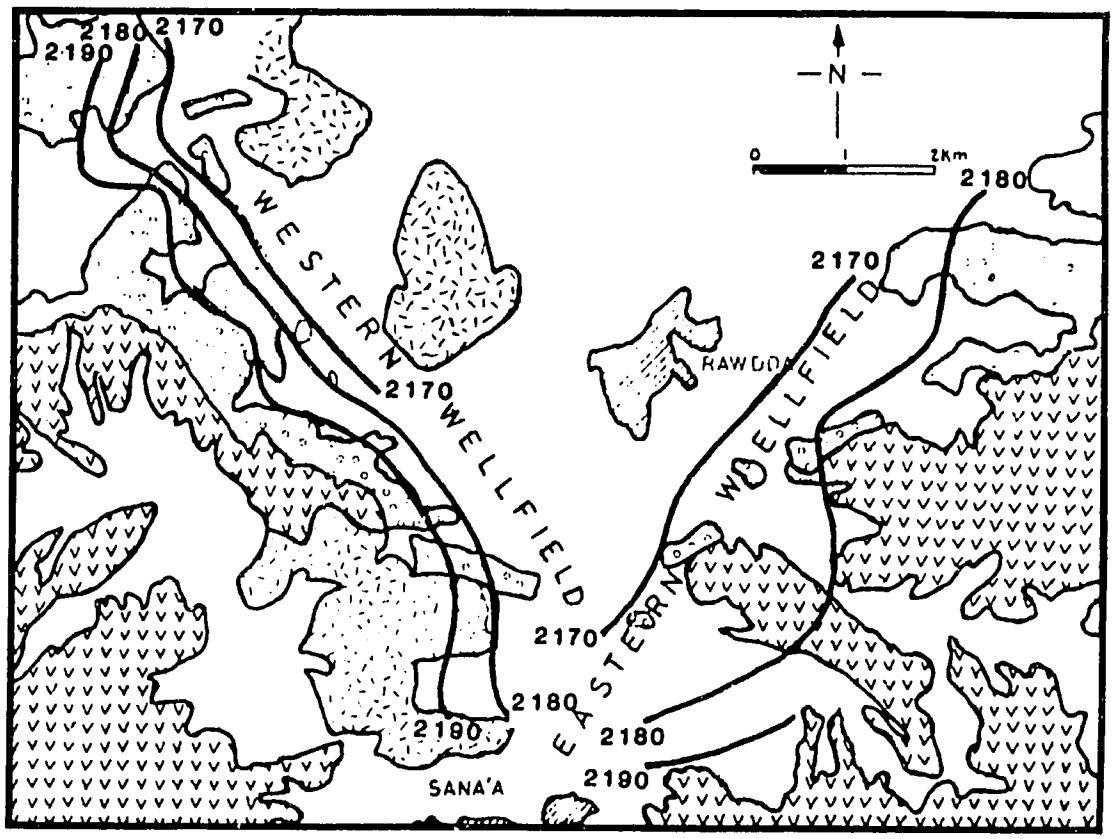


Figure 3-9 General Piezometry of the Tawilah Sandstone in the Sana'a Plain (After Charalambous, 1982)

volcanic intrusives further complicate the local pattern of groundwater flow. Currently available information regarding the basinwide piezometry of the Tawilah Sandstone is lacking. Further data and analysis will be required to properly understand the specifics of groundwater movement in this aquifer.

Specific zones or points of naturally occurring groundwater discharge from the sandstone have been identified by previous studies. To the west of the basin, springs and groundwater seeps from the sandstone occur along the Western Escarpment near Shibam at Wadi Ahjar.(15) Other small springs are present to the east of Sana'a at the base of the Tawilah Sandstone.

Amran Series

The Amran Series consists of 350 to 450 meters of limestones, shales, and evaporitic units that underly the Tawilah Sandstone. All available information suggests that the Amran is generally not water-bearing and that it tends to function as an aquitard or aquiclude. The Amran thus forms a less permeable boundary layer below the Tawilah that is hydraulically connected primarily through the presence of faults, fractures, or other structural discontinuities.

Howard Humphreys (20) reports that boreholes in the Amran limestones have been found to be poorly productive, with well yields of a few liters per second and large drawdowns. In the vicinity of Wadi Kharid, thermal springs are reported to emanate from the Amran where it has been intruded by basalt dikes.(15) It is not clear as to whether these springs are an expression of groundwater discharge from a deeper unit, or if they are a result of downward percolation of groundwater from the overlying Tawilah Sandstone through a complex system of fractures.

Kohlan Sandstone

The Traissic to Jurassic Kohlan Sandstone represents a significant unknown in terms of its groundwater potential. As discussed in Section 3.3.3, relatively little is known about the geologic extent of the Kohlan Sandstone within the Sana'a Basin. The predominant sandstone lithology of the Kohlan suggests that it may be a potential aquifer. Neither exploration nor evaluation of the Kohlan has been undertaken, however.

Italconsult (29) reports that a number of high yield springs are present in the Kohlan to the north-northwest of the Sana'a Basin. Within the basin itself, they estimate that the Kohlan may be present at depths of 300 to 700 meters.

3.4 Existing Water Resources

3.4.1 Groundwater Availability

Sana'a Basin water use is predominantly from the groundwater resources of the Tawilah Sandstone. (Although groundwater is also present in the alluvial deposits, these supplies are dwindling and have been subject to contamination in some areas. They are also sensitive to annual fluctuations in rainfall and recharge).

The estimated quantity of groundwater available from the Cretaceous sandstones of the Tawilah has been the subject of debate since Italconsult's first investigation in 1972 to 1974. These differences stem primarily from the fact that the aquifer dynamics, and in particular recharge mechanisms, for the Tawilah are poorly understood. Two trends are apparent in this regard. First, over the years subsequent investigators, with few exceptions, have reduced the estimates of available groundwater resources and recharge. Second, regardless of what the true level of groundwater recharge and available extractable quantity, the recharge is probably insufficient in terms of supporting the drilling and pumping that the Sana'a Basin has experienced over the last ten years.

Table 3-1, on the following page, summarizes the various estimates of groundwater quantity and recharge that have been calculated for the Sana'a Basin's sandstone aquifer. As indicated, there are considerable differences in the estimates for inflow and recharge, the general trend being toward reduced availability of groundwater reserves. The USSR study was an exception to this trend but reported preliminary results(15) indicated that the serious situation in the basin is due primarily to excessive pumpage.

The basinwide study by the USSR represents the most recent estimate of available groundwater resources in the Tawilah aquifer. Its 1984 preliminary report estimates a total of 63 x 106 m^3 annually of available groundwater, 49 x 10^6 m^3 annually of which are now being consumed. Under one scenario, it was estimated that demand will exceed the remaining reserve of 15 x 10^6 m^3 in the year 1991.

If 48 x 10^6 m^3 annually is an accurate estimate of total groundwater consumption, then by the other estimates of aquifer recharge in Table 3-1 (that is, Charalambous or Howard Humphreys), groundwater mining has been continuing for quite some time in the basin. Given the general nature and similar magnitudes of groundwater level declines observed at various locations in the basin, this seems to be a reasonable hypothesis. Additional evidence to support this contention has been gathered by Jungfer (32), who conducted isotopic dating on groundwater samples from the Sana'a Basin. His results indicate that groundwater within the Tawilah Sandstone is fossil, with sample ages ranging from 2,000 to 20,000 years before present.

Jungfer concluded that except for isolated areas in the southern and western portions of the basin, the Tawilah aquifer has received little or no recent recharge. Past estimates of aquifer inflow and recharge Jungfer claims are invalid because they assumed that recharge rates have been constant over geologic time. Plainly stated, the aquifer received significant recharge in the past, but now it receives much less due to long-term global climatic changes.

Perhaps the best summary on groundwater availability in the basin has been provided by Dubay (15): "It is not feasible to aspire both for a metropolis of one million people as well as full scale irrigated agriculture at 2,400 meters above sea level in one of the arid zones of our world." "...arguments about the exact amount of groundwater resources have become academic. For irrespective of how much water is available...the present abstraction exceeds the figure being recharged..."

Table 3-1

Reported Values of Inflow and Recharge for the Tawilah Sandstone Aquifer, Sana'a Basin, Yemen Arab Republic

Source	Estimated Inflow	Extractable Quantity	Estimated Recharge	Comments
Italconsult, 1983	67 x 10^6 m^3/yr	57.5 x 10^6 m^3/yr	59 x 10^6 m^3/yr	Assumes 9.5 x 10^6 m^3/yr current level of use, and 100% of remaining quantity available for extraction.
Howard Humphreys, 1977	44.8 x 10^6 m^3/yr	31.9 x 10^6 m^3/yr	31.9 x 10^6 m^3/yr(?)	N/A
Howard Humphreys, 1979	58.9 x 10^6 m^3/yr	34.9 x 10^6 m^3/yr	Not specified	Estimates pertain to Eastern and Western wellfields only.
Charalambous, 1982	Unspecified	Not specified	27.25 x 10^6 m^3/yr	Contends prior estimates incorrectly assumed steady state conditions.
Jungfer, 1983	Unspecified	Not specified	Minimal	Isotopic data indicate fossil groundwater. Only minor recent recharge in south and west portions of Basin.
Howard Humphreys, 1983	Unspecified (Total estimate storage = 2700m^3)	Not specified (Total estimate extractable = 675m^3	3.15 x 10^6 m^3/yr near Sana'a 25.23 x 10^6 m^3/yr along NE outcrop.	Assumes recharge through outcrop only.
USSR, 1984 (*Preliminary*)	Unspecified	63 x 10^6 m^3/yr	63 x 10^6 m^3/yr	Usable groundwater quantity shown constant until 2,006, thus assumed to be equal to annual recharge.
Dubay, et al., 1984	63.1 x 10^6 m^3/yr	31.5 x 10^6 m^3/yr maximum	63 x 10^6 m^3/yr	Reiteration of USSR numbers.

3.4.2 Current Problems

The current concerns over groundwater shortage in the Sana'a Basin have a certain element of déjà vu. In 1973, based upon the depletion rate of groundwater in the alluvial aquifer caused by the problems similar to those now being encountered, Italconsult concluded that development of the Tawilah Sandstone aquifer was necessary. It is now 12 years later, and the same situation has evolved for the water levels in the Tawilah aquifer.

The patterns and trends of growth and water use that have led to the present situation are discussed in Chapter 4. The result of these trends has been manifested in the form of rapidly declining water levels, abandoned wells, and the city's water supply wellfields, which are suffering a similar fate. As the water table declines, new and deeper wells are drilled at an increasing rate, thereby continuing the downward spiral.

Groundwater problems in the Sana'a Basin are epitomized by the plight of the city's western and eastern wellfields. Victimized by the encroachment of numerous private irrigation wells tapping the same aquifer, water levels have been declining rapidly, in some cases dropping below the present pump intake levels. Figure 3-10, on the following page, summarizes the situation by graphically comparing the number of new wells drilled, the increasing rate of abstraction, and the rate of water-level decline in the city's wellfields.

An analysis of water level declines in the basin has been conducted for the city's wellfields by Howard Humphreys (20) and, on a more general basis, by Dubay et al.(15) for the Sana'a Basin. In NWSA's wellfields, the rate of decline exceeds six meters annually in some wells, with abandonment an imminent reality. Example well hydrographs depicting these declines are presented in Figure 3-11. Cumulative water level declines for some wells are between 16 to 38 meters. A similar analysis performed for a broader area by Dubay et al.(15) identifies two distinct periods of water level decline, one attributed to drought, the other to pumping from the hundreds of new private wells. All parties admit, however, that there has been such a rapid and continuous increase in the number of new wells in the Tawilah that it is difficult to determine the status of declining water levels and the specific response of the aquifer.

3.5 Future Water Sources

3.5.1 Tawilah Sandstone

As the water levels drop in the Tawilah aquifer, the wells get deeper. In the northern portion of the Sana'a Plain, the Tawilah is thinner and more shallow. As a result, many wells penetrate the full thickness of the aquifer. Additional drilling in these areas does not appear to be a good option in that it would simply accelerate the already rapid rate of depletion.

To the south of the basin, the Tawilah is deeper and it is estimated that approximately 60 percent of the wells do not fully penetrate the aquifer. As such, there is additional groundwater storage that may be tapped by drilling deeper. This of course would mean greater expense, and greater distances over

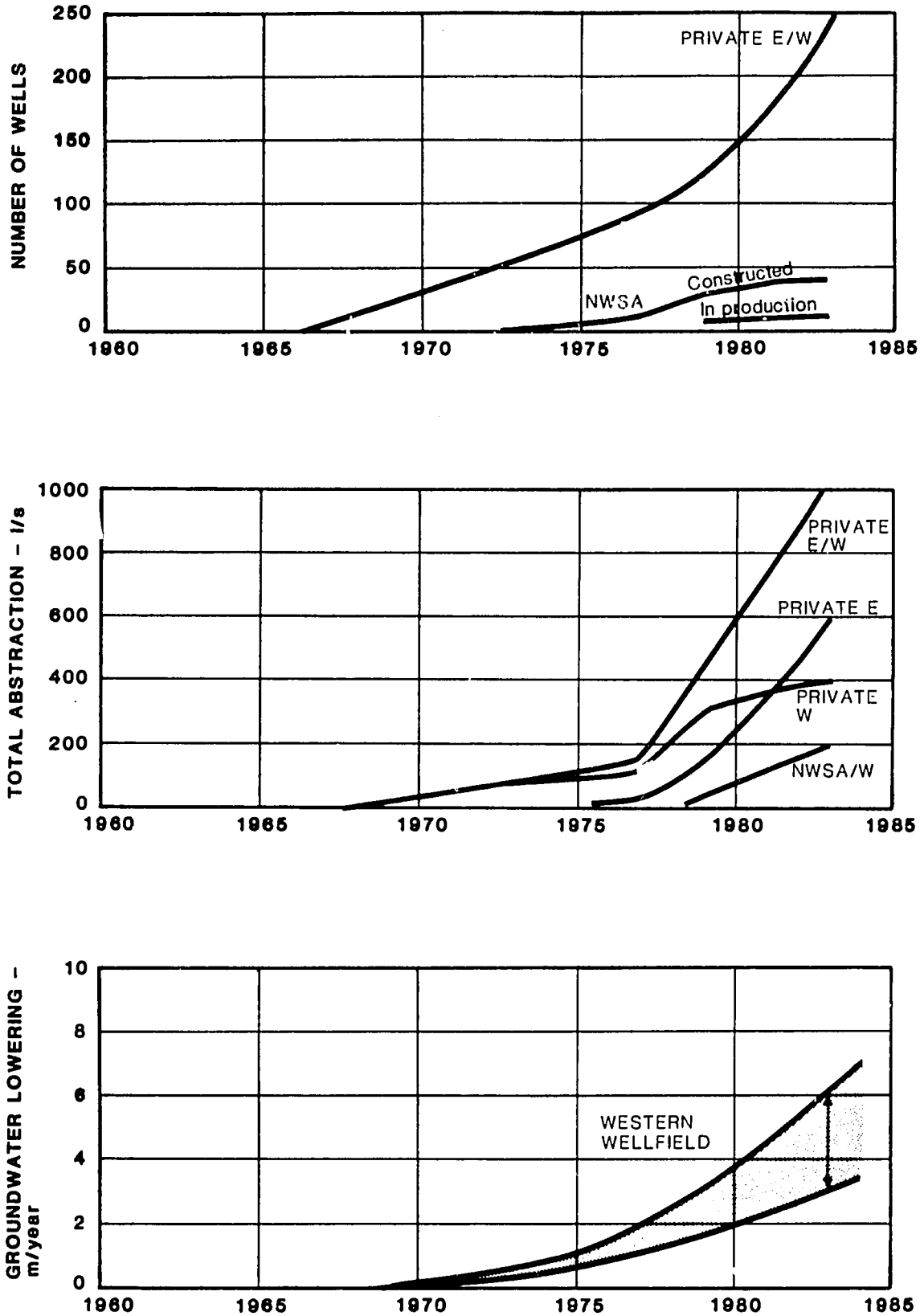


Figure 3-10 New Wells Drilled, Total Abstractions and Ground Water Lowering in the Sana'a Basin (After H. Humphreys, 1984)

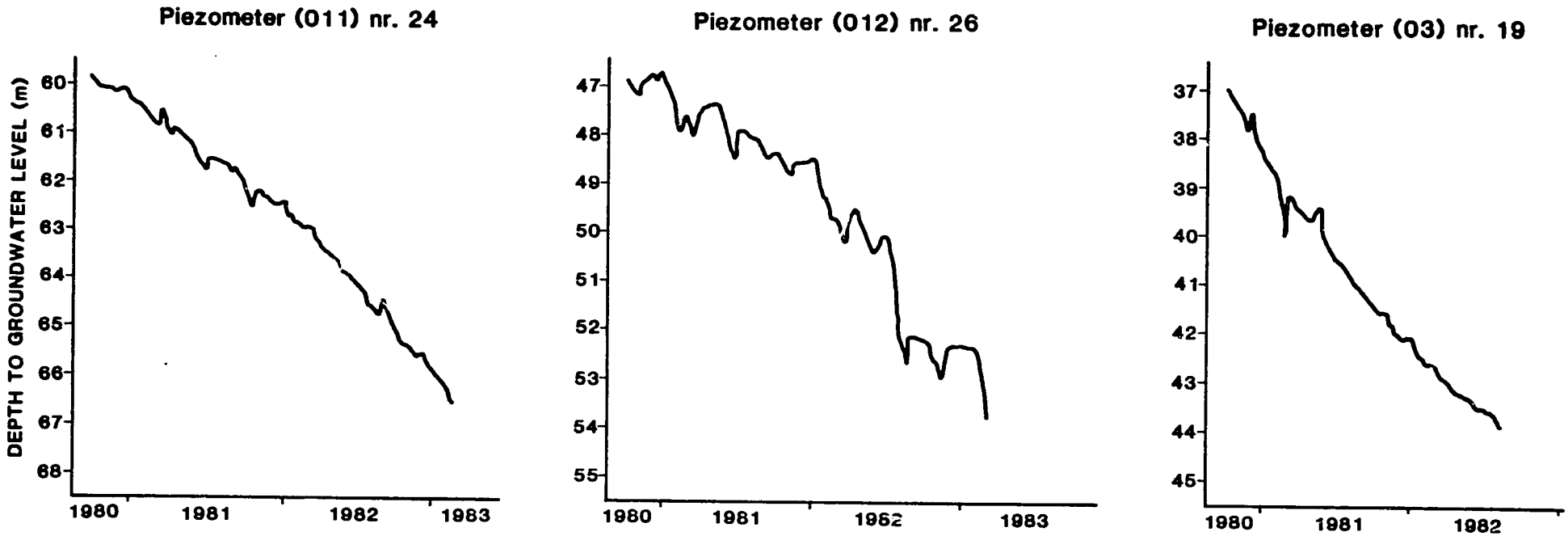


Figure 3-11 Selected Hydrographs of Wells on the Sana'a Plain (After Jungfer, 1984)

which to transport water. In addition, the thick cover of volcanic units to the south of Sana'a would represent further difficulties.

The Tawilah Sandstone appears to be present over a broad area, perhaps as large as 6,500 km^2. As such, there is probably additional groundwater that may be tapped depending on the practical constraints of cost, access, logistics, land ownership, and so forth. If additional exploitation of groundwater from the Tawilah aquifer is unavoidable, then it would be logical to first identify those areas that do receive significant recharge(32) and to ensure that withdrawals do not exceed a sustainable safe yield rate. Unless this is done, withdrawal from storage and eventual depletion will occur. The fundamental guidelines should be: (1) acquisition of sufficient data to first understand the hydrologic system, and (2) management of groundwater exploitation and development on a finite resource basis.

3.5.2 Kohlan Sandstone

As discussed in Section 3.3, the Kohlan Sandstone represents a significant unknown in terms of its groundwater resources. Extensive investigation and exploration would be required to assess its potential.

3.5.3 Surface Water

Little data are available with which to speculate about the potential for surface water development in the Sana'a Basin. Rainfall is sparse, and run-off is infrequent. Most wadis are ephemeral, although some (that is, Wadi Al Kharid) are noted as having a spring-fed base flow. When run-off does occur, it is typically characterized by torrential flows with high sediment loads. In addition, data are lacking regarding mean annual flows, peak-flow characteristics, and firm yields, on which to base sound feasibility or engineering analyses.

Although the current USSR study of the Sana'a Basin is said to have evaluated various reservoir storage sites, no data were readily available regarding these findings. Additional assessment of the potential for conjunctive use or groundwater supply augmentation by way of surface water development schemes would require review of their information.

3.6 Conclusions

The Sana'a Basin is now facing a situation not unlike that described by Italconsult approximately 12 years ago for the alluvial aquifer. This time, however, it is the Tawilah aquifer that is experiencing over-drafting and alarmingly rapid water level declines. The following factors have combined to create the present water resource difficulties:

- An arid climatic setting compounded by drought conditions
- Dependence on a complex groundwater system that receives limited recharge

- Population growth and uncontrolled drilling and pumpage by private landowners

- Inability to either protect or manage existing groundwater resources

- Lack of knowledge regarding the basin's groundwater system.

The water resources evaluation of this assessment has relied primarily on available published data information from YAR representatives, donors, local contractors, and limited field reconnaissance. The conclusions drawn from these data sources are presented below.

3.6.1 Hydrologic Setting

The Sana'a Basin is located in an arid region where annual precipitation is typically 200 to 300 meters or less, and where evapotranspiration far exceeds available moisture. Available climatic records also indicate extended drought conditions in this region. Run-off is correspondingly infrequent, and most wadis are ephemeral. When run-off does occur, it is often torrential, of short duration, and carries high sediment loads. All prevailing hydrometeorological conditions combine to limit the amount of recharge available for groundwater replenishment.

3.6.2 Hydrogeology

Hydrogeologic conditions in the Sana'a Basin are complex, incompletely known, and reflect a geologic history characterized by structural disruption and volcanism. Water-bearing hydrostratigraphic units include the basin's alluvial deposits, various volcanic units, and Mesozoic sedimentary strata. Traditionally acting as the area's primary source of groundwater, the alluvial units were subject to agricultural-related overpumpage during the early 1970s. As water levels in the alluvium rapidly declined, attention focused on the deeper bedrock units for new sources of groundwater. Serious exploitation of the Cretaceous Tawilah Sandstone aquifer resulted. Some 300 meters to 400 meters thick, groundwater in the Tawilah occurs under unconfined and artesian conditions, and is controlled primarily by the presence of fracturing. Transmissivities thus vary with location as much as two orders of magnitude (10 to 1,000 m^2/day), with permeabilities of 0.05 to 1.0 meters daily. Well yields and specific capacities exhibit similar variability. Fracturing may also hydraulically connect the Tawilah to the overlying alluvium and volcanics.

Groundwater in the Tawilah appears to move from the southwestern and southeastern flanks of the basin toward the north. Structural discontinuities and volcanic intrusives may disrupt the pattern, although the available subsurface geologic data is not adequate to define the aquifer system.

Tertiary and Quaternary volcanics in the basin also contain some groundwater, again as a result of fracturing and weathered zones between lava flows. The thickness of these units is variable ranging up to hundreds of meters. Depth to groundwater is variable, tends to parallel topography, and is found under

unconfined and perched conditions. Springs discharge from the volcanics at selected locations in the basin. Fracture systems in the volcanics may allow recharge to the underlying Tawilah Sandstone in some locations. No information exists for areas within the Sana'a Basin regarding the hydrogeology or groundwater potential of deeper geologic units, such as the Kohlan Sandstone, within the Sana'a Basin.

3.6.3 Water Resource Availability

The Tawilah Sandstone serves as the primary source of groundwater in the Sana'a Basin. Due primarily to overexploitation, water levels in this aquifer have been dropping rapidly, in some cases up to six meters annually, with cumulative declines of 18 meters to 38 meters reported. Estimates of groundwater availability in the Tawilah, and inflow to the Sana'a Basin vary widely. The differences result primarily from disagreement over the amount of recharge the aquifer receives and the methods used for calculation of the estimates. Recent isotopic dating results for Sana'a Basin aquifer samples suggest that the groundwater is fossil (2,000 to 20,000 years old) and that little or no recharge has occurred. Pumping from the aquifer is, therefore, thought to be water "mining," withdrawal from groundwater storage without replenishment.

Two basic conclusions may be drawn regarding the extent of groundwater resources in the Sana'a Basin. First, there are insufficient hydrogeologic data to allow a full understanding of the aquifer system(s). Second, regardless of what the resource is, it is finite and insufficient in terms of sustaining indefinite growth and unmanaged exploitation.

3.6.4 Future Water Sources

There is probably additional groundwater in the Tawilah aquifer that may be tapped, depending on the practical constraints of cost, access, logistics, and land ownership that result from deeper and more distant drilling and development. If additional exploitation of the aquifer is unavoidable, it would be helpful to evolve and implement policy that assigns priority to water use allocations and enforces conservation and management of the limited resources available. The focus of new development in the Tawilah should be on areas that receive significant recharge and to develop withdrawals on a sustained (safe) yield basis. Guidelines for additional exploration and development should be to: (1) acquire sufficient data to understand the hydrologic system, and (2) monitor and manage groundwater exploitation on a finite resource basis.

Information on the groundwater potential of deeper units such as the Kohlan Sandstone is lacking, and should be obtained by way of a phased program of investigation and exploration. Streamflow monitoring data and information on which to assess the feasibility of augmentation by way of surface water impoundment schemes are unavailable. Mean annual flow, peak discharge, and other information with which to assess firm yield should be obtained. Although the USSR study has reportedly evaluated various watersheds in the basin, the results of these efforts were unavailable for review.

Chapter 4

WATER USES

4.1 Introduction

This chapter describes historical and current water use and discusses how a continuation of present trends will affect the water supply situation in the basin. Reuse of treated sewage for irrigation is also discussed.

4.2 Historical Background

Until the advent (ca 1970) of the drilled well and the diesel-driven pump (paid for by sheikhs, Local Development Authorities (LDAs) and farmers with remittances from the oil fields), the average Yemeni family, especially in rural areas, treated water with religious respect, using relatively minute quantities in the household. Ansell (4) describes water consumption patterns of villagers living in Mahweit Province having an average consumption of 17 liters per capita per day (lcd).

Varisco (58) describes the various irrigation methods farmers used to obtain the most benefit from a scarce resource. Entire mountainsides were terraced and elaborate systems of furrows and bunds were built to manage the water produced from springs and from rain. Floodwaters from spring rains were diverted from intermittent streams into adjacent fields under cultivation. The tradition of careful water use is centuries old in Yemen. In less than a generation, however, the drilled well and the motor-driven pump have, in many areas in the country, removed the age-old constraint of extremely limited availabilities and are now beginning to threaten the delicate water balance of the nation.

4.3 Status of Present Water Use

4.3.1 Domestic, Municipal, and Industrial

In terms of domestic water use, the Yemeni are no different from any other group. As piped systems make water more accessible and convenient, the per capita consumption of water starts to rise. From the meager consumption levels described by Ansell (4), rural water supplies are now designed to provide a minimum of 60 lcd in Project No. 279-0044. The 1976 World Bank report on the Sana'a Second Water Supply and Sewerage Project (26) gave an estimate of 48 lcd of domestic consumption in Sana'a. The Sana'a water system was designed to provide 137 lcd in 1985.

Prior to the installation and expansion of the city water supply system, Sana'a population was served by hundreds of dug wells. Most of these wells were abandoned as the groundwater level fell. It was reported that some dug wells have been deepened periodically and are still in use. One well on the outskirts of Sana'a off Hadda Road is reported to be 120 meters deep and is used for irrigation.

Within the city of Sana'a, the tradition of spartan use of water still seems to be more or less intact. Little evidence exists of green space, and lawns are a luxury that, fortunately, only a few can afford. The ubiquitous eucalyptus is used to line some streets, and also for forestation. But taken as a whole, Sana'a is a dry and dusty city. One does not see water overflowing into the streets in Sana'a. Although we were unable to obtain any hard data on nondomestic municipal water use (that is, street cleaning, plant irrigation, and so forth), it is safe to assume that these uses are not a significant part of water consumption in the city.

The sole reference found on industrial water use was contained in a reference to the Italconsult study (29/30). Industrial use was estimated to be 0.66 Mm^3 annually as compared to 1.31 Mm^3 annually for domestic use and 0.09 Mm^3 annually for commercial use. Industry is in its infancy in Sana'a. At present there are no heavy industries (that is, refineries, petrochemicals, steel mills, and so forth) in operation. There are several textile mills and soft drink bottling plants. At present, the industrial sector is a minor user of city supplied water. The major water bottling plants are supplied by their own drilled wells.

NWSA's quarterly reports covering the first six months of 1985 show the gross water production for Sana'a as 1.74 Mm^3 for the first quarter and 2.79 Mm^3 for the second quarter, giving a total of approximately 4.53 Mm^3 for the six-month period. Assuming that the same amount of water is pumped during the second half of 1985, the total municipal water use for the year will be approximately 9.1 Mm^3 annually (including losses). (This converts to a consumption rate of around 100 lcd. While being almost double the design figure for rural water systems, this falls at the low end of the consumption curve for urban centers). Compared with the estimated municipal water use by Italconsult in 1973 (2.06 Mm^3 annually) the current water production levels indicate that in 12 years, water supply requirements have just about quadrupled. This rate of increase in water supply requirements obviously cannot be sustained in the long run.

4.3.2 Irrigation

Traditionally, approximately 90 percent of all cultivated land in the Sana'a Basin was rainfed. The use of stored groundwater tapped through hand-dug wells constituted an almost negligible demand. Most dug wells penetrated only the alluvial aquifer and did not draw water from the sandstone aquifer, the source of water for deeper drilled wells. The proliferation of drilled wells with motor-driven pumps has changed farming practices dramatically. Lands formerly rainfed have been placed under irrigation and certain crops are now cycled two and even three times a year. From a negligible user in the past, irrigation has now become the single largest user of stored groundwater in the Sana'a Basin and the actual amount being pumped is unknown.

During the 1970s and early 1980s various groups, such as Italconsult (29/30), Howard Humphreys (20/23), Charalambous (13), and Jungfer (32), attempted to estimate the amount of water being pumped for irrigation. The USSR study team is said to have developed its own estimate. Although there appears to be little or no agreement among the study groups on the level of groundwater used

for irrigation, there was general agreement that irrigation use was growing at the greatest rate of all groundwater uses in the Sana'a Basin.

The 1979 Howard Humphreys report (21) estimated that, while NWSA was pumping 45 liters per second (l/s) (1.42 Mm^3 per annual rate) from the western wellfield, a total of 465 lps (14.66Mm^3/per annual rate) was being pumped from the western and eastern wellfields, mostly for irrigation.

Using the number of hectares of crops irrigated from wells given by the MAF for 1984 and the estimates of irrigation requirements as presented in the IFP project paper for conditions of normal rain (55), a total irrigation requirement for the Sana'a Basin can be calculated.

If the MAF 1984 values are reliable, and the district of Hamdan is included in the Sana'a Basin, the total estimated irrigation requirement for the basin is estimated at approximately 78 Mm^3 annually. (This total includes irrigation for the 5,592 hectares of qat reported for Hamdan district. The Hamdan district's qat irrigation requirement accounts for about 31 Mm^3 annually (or approximately 40 percent of the basin's estimated total irrigation requirement). Although existing water requirement records and estimates for municipal and irrigation uses vary widely, it is clear that the major use of groundwater in the Sana'a Basin is irrigation. As noted earlier, irrigation is also growing much faster than municipal use.

4.3.3 Reuse of Sewage

The idea of sewage reuse brings along with it a host of technical, social, and, ultimately, political problems. Even in Yemen, where it has been reported that dried human feces is used as fuel to heat water in public bath houses, there is little indication of a general acceptance of either the practice or the idea of sewage reuse. (On the other hand, during an earlier visit to Yemen, one of the WASH team members observed farmers using raw sewage effluent from the city of Taiz to irrigate vegetables and row crops. On the basis of this observation, it can be assumed that the idea of treated sewage reuse may be acceptable under certain environmental and social conditions by certain segments of the population.

A USAID-sponsored study in September 1982 (10) concluded that the use of primary, secondary, or tertiary effluent is technically and economically feasible. They also concluded that tertiary treated effluent is the best choice from a public health and economic point of view. Their Table 1, which has been reproduced in this report as Table 4-1, describes the degrees of effluent treatment and types of crops they considered in their study.

Even if sewage reuse turns out to be totally acceptable by farmers in the Sana'a Basin, any USAID-funded project will have to be designed to meet stringent EPA guidelines. Therefore, it may be advisable for AID/Yemen to focus its attention on other less problematic project options related to the Sana'a Basin water resources sector. If, however, AID/Yemen were to become involved in a sewage reuse project, some controversy may be avoided by cutting any linkage with the food supply chain, with the project objectives being improved pastures, forestation, wood or wood pulp production, instead of food crops.

Table 4-1

Effluent Treatments and Cropping Systems
Considered for the Sana'a Sewage Effluent Distribution Project

Treatment Alternative (a)	Crop (b)	Net Return to Farmer YR/Year/Farm Unit
Alternative 1: Primary Treatment	Sorghum	8,452 (c)
Alternative 2: Secondary Treatment	Sorghum Alfalfa Grapes	23,761
Alternative 3: Tertiary Treatment	Sorghum Alfalfa Grapes Tomatoes	39,994

(a) Primary Treatment: Anaerobic ponds for settlement of solids and anaerobic degradation of organic matter.

Secondary Treatment: Aerobic (oxidation) ponds which receive outflow from anaerobic ponds.

Tertiary Treatment: Chlorination of the outflow from the aerobic ponds; equal quality could be provided by a system of many ponds.

(b) Cropping systems were selected which include crops which are representative of those which can be grown with the given type of effluent and minimize any potential public health problems associated with application of the effluent as irrigation water.

(c) Two crops of sorghum annually were assumed.

4.4 Trends in Water Use

4.4.1 Municipal Use

Using NWSA's second quarter report for 1985 as the base, and a population-served figure of 250,000, per capita consumption, including all system losses and industrial and commercial uses, comes to approximately 130 liters per person served. While this falls in the minimum consumption range recommended by WHO for urban systems around the world, it may also be at the upper consumption limits for a water-scarce area such as the Sana'a Basin. (Certainly, domestic water consumption values appropriate to urban areas in Europe and the United States, ranging from 250 to 500 lcd, would be inappropriate here). It is probable, however, that consumers will continue to install more sanitary fixtures in their homes, thus continuing the upward pressure on consumption rates. While consumption rates are expected to increase, by far the driving force behind increasing municipal water demands has been the rapid population growth Sana'a is experiencing.

Table 4-2, on the following page, presents a range of population estimates. NWSA is concerned with increasing production of its wellfields. Depending on the projection used, the totals vary widely. The population of Sana'a in each set of projections, is, however, expected to increase by 100 percent by 1995 and probability indications are that NWSA will accomplish this goal in the next few years and be able to temporarily meet Sana'a's increasing water requirements within the limits of its distribution system. In the long run, after NWSA has fully penetrated the aquifers in Sana'a Basin, its production curve will turn flat and then begin to fall. When that point is reached, NWSA will have to embark on an expensive program of finding and developing alternate water sources and also possibly consider rationing its supply.

The municipal demands and population growth rates give strong argument that NWSA must begin to look beyond the immediate problem of its shallower wells going dry. A long-range plan of action to address the much more serious problem of extreme scarcity of water resources must be formulated. At the very least, NWSA must determine what options are available to it.

4.4.2 Irrigation

No firm values are available on the number of new wells drilled in the Sana'a Basin each year. If it is assumed that there are now approximately 6,000 drilled wells in the basin and that 75 percent of these wells were drilled after 1970, then the average number of new wells drilled annually would be 300. (The 6,000 value and "one new well per day" are values mentioned by several persons interviewed during this study.)

The total area in the basin irrigated by well water is estimated at approximately 35,000 hectares. Thus, on the average each well irrigates approximately 6 hectares, which means that for 300 new wells about 1,800 additional hectares annually would be put under irrigation. Using an estimated annual irrigation requirement for all crops of 6,000 m^3/hectare, 300 new wells would represent an additional abstraction of about 11.0 Mm^3 annually. This marginal value alone is greater than NWSA's expected supply levels for Sana'a for all of 1985.

Table 4-2

Sana'a - Population

Year	Swiss Technical Cooperation Service		CYDA	CPO*	
1975	138,625		---	(138,625)	
	Growth Rates			Growth Rates	
	4%	6%	High	Medium	Low
1981	175,400	196,640	277,818	239,650	228,760	218,078
1985	205,200	248,250		325,000	301,088	278,496
1986	213,400	263,150		350,680	322,665	296,183
1996	315,900	471,264		743,040	639,035	546,690
2000	384,333	595,000		997,790	840,090	698,306
2006	467,600	844,000		---	---	---

*CPO used 83.2% of total urban population as the factor for Sana'a city population.

Governmental, commercial, and light industrial installations are expected to continue to grow, and along with them a steady growth in water demand. Probably the largest industrial and commercial growth during the next several years will be related to the recent discovery of oil reserves in the Ma'rib area. Most of the facilities are expected to be centered in the Ma'rib area, although several office installations will be centered in Sana'a. These latter installations will not, however, require large amounts of water. Overall, the outlook on increased water demands for nondomestic uses appears to be moderate.

4.5 Conclusions

4.5.1 Water Resource Limitations

In spite of the nondefinitive hydrogeological database available, it can safely be assumed that there is a finite volume of water underlying the Sana'a Basin. Every indication is that present withdrawal rates by far exceed the natural recharge rates. Even if treated sewage were to be used to irrigate farm crops, it does not necessarily follow that an equivalent number of irrigation wells will be put out of service to compensate for this supply. It is more likely that additional lands will be put into production using treated sewage.

4.5.2 Continuation of Present Trends

The two main causes of the Sana'a Basin groundwater problem are the uncontrolled growth of Sana'a city and the uncontrolled withdrawal of water for irrigation. Unless both of these phenomena are controlled, it is certain that NWSA will be able to do little more than supply water to a dwindling population and Sana'a could be lost as a city of vital importance to the country.

A conservative projection of Sana'a's population in the year 2000 is around 385,000, using the 1975 census figure of approximately 138,000 and a growth rate of four percent annually. The CPO, using the same base but higher growth rates, figures a year 2,000 population ranging from 700,000 to just under one million. With a constant consumption rate, say at (130 lcd), a population of 385,000 would require 50,000 cubic meters per day, or 18.25 Mm^3 annually. If the CPO projections are borne out, the demand would be about twice as much.

Even larger increases in demand may be attributable to the agricultural sector in the basin. The ten districts which roughly fall within the alluvial outline of Sana'a Basin, cover an area of approximately 1,500 km^2 and have approximately 13,000 hectares under irrigation. As discussed in Section 4.3.2, irrigation water requirements are estimated at 78 Mm^3 annually. This abstraction rate alone far exceeds all of the estimated rates presented in prior studies and as discussed in Section 4.3.2 could increase at 11 Mm^3 annually or 15 percent annually.

It is obvious from the discussion of the last several sections that the increasing demand rates indicated cannot continue unabated. The challenge for YARG is to control the groundwater abstractions while at the same time

developing new sources for the needed supplies, and developing the policy and mechanisms to optimize the use of whatever the volume of total supply may be.

Chapter 5

RECOMMENDATIONS

5.1 Introduction

This final chapter presents the recommended water resources sector project options for AID/Yemen to consider in their future programs. The options are a mix of specific projects and conceptual descriptions relating to key issues in the water resources sector concentrating on the Sana'a Basin. Many key variables are still poorly defined, including YARG's inaction in establishing a Water Management Division, the unavailability of the USSR's draft report study, and the many recommendations for changes to the World Bank Action Plan, as presented in Appendix D. The remainder of this section will present recommended actions on program strategy project options, cost estimates, and conclusions drawn from the overall work effort.

The recommended options were reviewed with AID/Yemen staff to determine their overall feasibility under the AID umbrella. No attempt was made to recommend which AID programs should be used as vehicles for the project options. AID would be the best judge of where the prospective projects would fit. The project cycle process (PID's and PP's) would allow the final determination of program applicability and definitive cost estimates to be made.

The recommendations presented herein should be examined in view of the social and political overview presented in Chapter 1, the technical data in Chapters 3 and 4, and the recommendations of Appendix D.

5.2 Program Strategy

USAID/Yemen should fully support the overall thrust of the World Bank's Action Plan. USAID should not, however, tie itself to the preconditions set forth in the Action Plan and should allow itself enough flexibility to be able to respond to specific requests for assistance which, in USAID's view, require timely action and do not run counter to the Action Plan's goal.

USAID/Yemen should not become involved in projects on the basis of the inadequate technical data available to date. Thus, USAID should stipulate, as a condition for its participation in major programs, that YARG make available the results of the USSR's preliminary draft study. USAID/Yemen may, after consultation with the World Bank and other donors (Dutch and German), decide to undertake or contribute to one or more of the water resource investigations and studies listed in Sections 4.2.1 through 4.2.4 of the World Bank Action Plan and the educational and training activities described in Section 4.4 and 4.5. AID/Yemen should use the conclusions presented in Chapter 3 as guidelines for evaluating the technical aspects of any requests for assistance or program formulation.

In addition to the activities listed in the Action Plan, USAID/Yemen may wish to further explore project options which are related to the Sana'a Basin and the national water resources sector but not specifically mentioned in the

Action Plan. These are low-risk activities which would fit within the Mission's overall development strategy.

5.3 Project Options

The projects recommended in this subsection are considered low-risk options. The projects will be beneficial to the short- and long-term solutions for the Sana'a Basin's water resources problems, while at the same time having definite end products beneficial in themselves. These projects all fit the framework of the World Bank Action plan, and several can be substituted for various work elements of the plan. In effect, these low-risk options can be undertaken as components of the larger World Bank project, because they are beneficial in themselves and their success is not contingent upon the success of the larger project.

Training:

Training is an obvious option for AID/Yemen interventions. Many such programs in almost every sector have been implemented over the past dozen years. The training option recommended herein has, as its basis, the following features:

- Training would be, for the most part, on shore.

- The trainees will be selected to fill positions in particular organizations. As a condition to receiving the training, the trainees will be expected to formally agree to work for a particular organization for several years (details to be worked out later). Thus, the trainee would be guaranteed a job, and the organization would receive a person specifically trained in its activities.

- The training will be geared toward the particular organization's activities.

- The trainees need not be from the organizations they will agree to work for. The focus will be on recruiting recent returnees from abroad and other qualified candidates in and out of the public sector.

This training option has been designated the "institute model." The following examples pertinent to the World Bank's Action Plan illustrate its key features.

The World Bank Action Plan indicates that a Water Management Department (WMD) should be established, with NWSA's Hydrogeological unit transferred to WMD to act as its core unit for monitoring and enforcement activities (see Appendix B). In Appendix D of this report, it is recommended that the Department of Hydrology in YOMINCO be transferred to act as the WMD's technical cadre for water resources planning. Because the DOH, under sponsorship of the Dutch Government, is principally engaged in the WRAY-2 Project, it is recommended (Appendix D) that additional personnel be added to DOH, so that the DOH's work for WMD would not impair the WRAY-2 effort.

The "institute model" of training would work as follows: WMD and DOH's senior managers would determine the number of new positions needed. Engineers and geologists would be recruited (some may come from DOH's present staff) and given 9 to 12 months of intensive training in hydrology. Once the program ended, they would receive at least a certificate and return to or start work with DOH.

The training program offered (actually higher level education and field work equal to a master's degree) would be given in Sana'a. Expatriate or local trainers would present the classroom work. The course would be designed based upon WMD's program and how the DOH would function under WMD in its short- and long-term program. A similar program could be established for WMD's technical staff (engineers, water resource planners, and so forth). This program would probably be geared to 12 to 20 trainees and the curriculum geared to high level hydraulic engineering and water resources.

This option for training would support the World Bank's Action Plan directly and would solve the often critical problem of finding adequate staff or counterparts. It would allow expatriates to fill the various WMD work slots early in the program and have these expatriates replaced as the trained Yemenis come on board. Further, it could be used to complement the programs which sponsor off-shore training. (Note that the institute model is not intended to replace off-shore training for B.S. and M.S. degree candidates.)

The institute model is not without drawbacks. It is quite different from most of the continuing higher-level degree training programs, and in a country which is "degree conscious" offers high prestige employment with a special certificate but no degree. To obviate this problem, by agreement with the WMD, salary scales for holders of the "institute's" certificate could be pegged equal to those of holders of M.S. degrees. Further, an attempt could be made to attach the "institute" program to Sana'a University or overseas colleges, so that a degree would be awarded. Or, if this cannot be effected, Sana'a University or overseas colleges perhaps would agree to allowing the one year of "institute" instruction to fulfill a substantial portion of the credits needed to obtain an advanced degree. Some delicate negotiations may be necessary. The approach, however, appears quite applicable to the World Bank's Action Plan and the sector in general.

Similar training interventions designed along the lines of the "institute model" could be devised for technicians. NWSA is the institution with prominent activities in the Sana'a Basin. While rapidly maturing as a service delivery institution, their need to train technicians in water supply and wastewater maintenance is great (See Section 2.4). The availability of vocational training opportunities in Sana'a may obviate the need for special programs to be created. If AID/Yemen believes sponsoring a technician training program would be beneficial, it would be best to confer with the GTZ sponsored training team working in NWSA prior to completing the program design.

5.3.1 Multi-objective Technical Assistance Projects

The serious water supply problems in the Sana'a Basin in large part require specific engineering solutions. The engineering project's objectives should be: defining the water supply needs of the basin, determining the water

resources available to meet the projected needs, determining the feasibility of developing additional supplies (in or out of the basin), and initiating programs which will allow the basin's water resources to be monitored and, as necessary, regulated. This approach has been recognized in the World Bank Action Plan, and many work elements of the Action Plan are directed towards these objectives.

Thus, within the framework of the Action Plan, several projects, accomplished separately or combined in single or several technical assistance package(s), appear feasible for consideration by AID/Yemen. These include:

a. A comprehensive master planning study of the water supply needs in the Sana'a Basin. The project would be basinwide but concentrate on Sana'a city, and its environs, and would include the study of feasible interbasin transfers of surface and/or groundwater and alternatives for groundwater augmentation.

b. Technical assistance to NWSA for provision of short-term relief in the existing Sana'a well fields. The city's wells will require deepening within the next five to six years and the project referred to here would provide the technical assistance only, to implement the needed improvements, and includes program design, project award, and monitoring and supervision of the contractors' activities.

c. Implementation of an exploration program to estimate the potential groundwater reserves in the Tawilah Sandstone aquifer. This program will include the technical assistance for program design, geographical data interpretation, project award and monitoring, and supervision of the contractor's activities.

d. Implementation of a program that tests the potential of the Kohlan Sandstone aquifer. The technical assistance will include the program design, (deep well-drilling, aquifer testing and geophysical investigations), project award, and monitoring and supervising the contractor's activities.

e. The technical assistance and advisor services required to design and implement a hydrologic monitoring network for the Sana'a Basin. The network would use the USSR study as the basis for the program design. Selected existing wells, new wells, meteorological and surface water monitoring stations (existing and new) would be incorporated into the network. The program would include continued sampling and analyses for use in technical support for water management decisions and to provide hands-on training for Yemenis.

   (This program was based upon establishing a unit inside YOMINICO's DOH with U.S. technical assistance complementing the assistance now being provided DOH through Dutch Aid. It would represent the first two years of a long-term program described in Section 5.3.3 and Appendix E.

The rough cost estimates for these five projects are shown in Table 5-1. It must be noted that the basis for all programs discussed above is the draft

Table 5-1

Cost Estimates of Potential Technical Assistance Projects

Section Reference	Project	Overall Duration Months	Man-Months Expatriate	Man-Months Yemeni	Estimated Cost of Technical Assist.(1) $US Component (million)	Estimated Cost of Technical Assist.(1) YR Component (million)
5.3.1a	Master Planning Study	15	43	200	1.1	4.0
5.3.1b	NWSA Short Term Assist.	15	24	84	0.6	1.5
5.3.1c	Tawilah Aquifer	18	27	108	0.7	1.7
5.3.1d	Kohlan Aquifer	18	24	84	0.6	1.4
5.3.1e	GW/Hydrology Network	24	48	192	1.2	3.3
			166	668	4.2 (2)	11.9

(1)Cost estimates were prepared based upon all work being prepared by U.S. consultant firms executing the projects as single entities unto themselves, with Yemeni staff and an office; thus, they include the usual allowance overheads, and profit margins for such projects (see Section 5.4.).

(2)Combining (a+b) and (c+d) into two distinct projects would reduce the costs of these as individual projects by approximately 20 percent. Providing all services for the five projects under a single project would also reduce the total costs by approximately 20 percent.

report prepared by the USSR. The report should be reviewed thoroughly prior to any commitments by USAID. (In fact, its availability from YARG should be made a prerequisite for any action to commence.)

5.3.2 Additional Low-risk Interventions

Additional low-risk interventions include AID/Yemen's Irrigated Farm practices Project (IFP) (55) and a communications project, as recommended in the World Bank Action Plan.

a. IFP Project

The IFP Project (in the Project Paper Stage as of October 1985) will provide data on more efficient irrigation practices and increased crop yields per hectare and is beneficial to the entire agriculture sector and the Sana'a Basin. It would be a sound project to implement, even if the water resources condition of the Sana'a Basin were not in a crisis state. This project could be used as a substitute for the similar work element in the World Bank Action Plan.

b. Communications Project

A communications project, as described in the World Bank Action Plan, could play a vital role in conserving the water resources of the Sana'a Basin. The project's objectives would be to increase the awareness of all citizens concerning the water resources situation in the Sana'a Basin and the need to reduce waste and use all water as efficiently as possible throughout YAR. The characteristics of such a "campaign" would have to be developed by experts in communications who also have an appreciation of the social structure of Yemeni society. The program can be envisioned on three levels:

- Governmental (to make all ministries aware of the problem)
- Urban users (to make them aware of the problem and the need to conserve water during everyday use)
- Peri-urban and rural (probably the most important, because these users, through uncontrolled pumping of private irrigation wells, are stressing the groundwater aquifer most). The campaign must be directed at the population-at-large, with special programs directed toward religious leaders, sheikhs, and farmers with large land holdings. The program emphasis would be conservation and more efficient use of irrigation water, and cooperation so that water could be used to benefit the entire community.

The communications project could be an entity of its own. It could also be combined with the recommendation made in Appendix D for the World Bank Action Plan to include a work element to foster voluntary compliance with the recent legislation aimed at controlling groundwater extractions.

5.3.3 Other Potential AID Interventions

The work accomplished for this assignment led the team to recognize two additional potential long-term interventions that would be beneficial to the national water resources sector. These interventions pertain to ground and surface water monitoring and a "farm club" system of training. These interventions have more national than Sana'a Basin specific significance and thus are actually outside the scope of this assignment. Thus, these are briefly mentioned below and described in detail in Appendix E. Because projects are basic to these potential national water resources.

A groundwater and surface water and data-collection program will provide the foundation for all water resources planning in Yemen. This has been recognized by AID in their several attempts to provide institution building for the DOH (See Chapter 2) and has been further recognized in the World Bank Action Plan for the Sana'a Basin.

Briefly stated, past efforts have produced an inadequate water resources database, both nationally and in the Sana'a Basin. Indications are that the USSR study will produce a more comprehensive set of data, but even this will provide only a detailed "snapshot," one that is frozen in time, of the water resources situation. This type of static view, while valuable in the short run, must be implemented by a long-term, continuing program which will provide a dynamic view of what is happening in the aquifers and watersheds. Further the program must be such as to keep the database continually updated.

The two-year monitoring project described in Section 5.3.1e, combined with the ongoing Dutch assistance for DOH would offer YARG a solid foundation for such a nationwide program. Appendix E describes in detail the type of long-range program required for the Sana'a Basin.

The "farm club" program addresses the lack of a trained talent pool in many national sectors. Its objectives would be to produce a larger talent pool than now exists, rather than to provide training for a specific sector, and it is modeled after the system used by many U.S. professional sports organizations which use minor leagues or farm teams to groom and prepare players for the top or major leagues.

The basic idea of the program is to recruit secondary school-level students, train them in a wide range of construction and mechanical trades, and place them as apprentices to gain experience. The more advanced trainees could go on to gain advanced training or university degrees. Those less advanced will have marketable skills enabling them to enter the national labor market. The program is discussed in further detail in Appendix E.

5.4 Estimated Cost of Recommended Interventions

The information in this subsection is presented to provide AID with an indication of the rough order of magnitude costs for many of the projects discussed in Section 5.3. The estimates were based upon the incomplete data available and have purposely been estimated conservatively high. In all cases, the estimates assumed the projects would be implemented by U.S. consulting firms. (This assumption allows overheads and profit margins to be included in

the total cost and cuts down the risk potential of estimates which essentially have been prepared with incomplete data.) Thus, the costs include allowances for expatriate and Yemeni labor, housing, travel and other normal allowances for long-term expatriate experts, office space, materials, supplies, vehicles, equipment, and miscellaneous costs. AID's project evaluation process (PID and/or Project Papers) will allow a better definition of costs and schedules to be prepared.

Rough cost estimates have been presented for:

- An institute model training project whose objective would be to provide a cadre of water resources experts for the Water Management Division to be formed as part of the World Bank Action Plan
- The five projects described as multiobjective technical assistance projects
- The communications project.

Costs for the long-term hydrologic monitoring program and the "farm club" training program have not been presented. The costs for the IFP project have been presented in the AID/Sana'a Project Paper (55).

5.4.1 "Institute Model" Training Project

The "institute model" training project described in Section 5.3 was roughly estimated at $2.1 million (US$) plus $8 million (YR). The rough estimates were based upon providing advanced water resources and hydraulic engineering instruction to approximately 30 Yemenis. The overall project duration would be 18 months and provide for the furnishing of 88 expatriate man-months, plus approximately 160 Yemeni man-months (all for administration and other miscellaneous support).

As envisioned, four expatriate experts would be provided for 18 months (in Yemen) to plan the program and make provisions necessary to carry out the project. An allowance for 12 man-months for visiting experts to participate in the actual instruction plus four man-months to help plan the program is also provided. The estimated costs also include allowances for travel, living allowances and establishment of a hydraulic/hydrology laboratory, special equipment, vehicles, materials, commodities, and miscellaneous costs.

5.4.2 Multiobjective Technical Assistance Package

The cost estimates for the five technical assistance projects described in Subsection 5.3.1(a) through 5.3.1(e) are shown in Table 5.1. As described in Section 5.3.1, these costs cover the technical assistance elements of the projects. The capital costs associated with the projects are not included. (These costs are estimated at $9 million to $12 million for improvements to NWSA well fields, approximately $3 million for well-drilling for the Tawilah Sandstone exploration and approximately $2 million for the Kohlan exploration plus about $300,000 for the hydrology network). These capital investment requirements are expected to be furnished through YARG and/or other donors.

5.4.3 Communications Project

The communications project briefly discussed in Section 5.3.2 and Appendix D is difficult to estimate as many of the work elements are very long-term in nature. The approach recommended herein is that AID/Yemen limit their intervention level to a specific dollar amount. The actual level could be determined through preparation of an AID Project Paper. Proceeding in this manner would allow the Mission to maximize its investment in that it could execute the project directly through its own contractors, or could participate, with other donors, in executing the work by way of the World Bank Action Plan.

From brief discussions held with AID/Yemen and other expatriates with a background in Yemeni sociology, it is recommended that AID/Yemen make provision for a Project Paper to be prepared (approximately $40,000 to 50,000 (US$)) investment). The investment for the communications project (or contribution toward a joint project) is in the order of magnitude of $250,000 (US$) over a two-year period.

5.5 World Bank Action Plan

Appendix D presents a detailed discussion of the World Bank Action Plan.

A summary of the recommendations in Appendix D is repeated here for the convenience of the reader. These recommendations are as follows:

- A Water Management Division should immediately be established and the High Water Council reorganized under the Prime Minister's office.
- YOMINCO's Department of Hydrology should be transferred en toto to WMD, to act as the core cadre for water resources planning.
- Training should be provided to new Department of Hydrology employees and others who will be assigned to WMD.
- USAID/Yemen's IFP project should replace the irrigation study mentioned in the Action Plan.
- The Action Plan should include a work element designed to foster voluntary compliance with YARG's groundwater control legislation.
- The project should fund at least two senior advisors for its duration, with one being an expert in groundwater hydrology.
- The overall number of senior expatriate advisors to be funded by the project should be increased.
- The project should be revalued, based upon the data available in the USSR study and the most recent developments.

Inherent in these recommendations is the belief that for the WMD to be established, a much greater component donor assistance for several years will

be required. Further, even with the DOH transferred to WMD to act as its technical cadre, a large number of Yemeni water resources specialists must be trained to assume positions in this new agency.

Cost estimates were prepared for such an expanded program. These estimates were based upon a six-year program, with two expatriates furnished for six years, and four more for four years (that is, 338 man-months of expatriate time) and from 3,000 to 4,500 man-months of Yemeni time for all administrative and technical activities including contingencies with a mid-1986 start and 6 percent inflation annually. The overall program estimates were approximately $12 (US$) plus $122 million (YR) (equivalent to approximately $27 million (US$)). Training of 30 Yemeni water resources and hydrology specialists (See Sections 5.3.1 and 5.4.1) would add approximately $2.1 million (US$) plus $8 million (YR), for a combined total equivalent of approximately $30 million (US$) for the six-year period.

(Note that to be conservative, the cost estimates were based upon a private company providing all services. Thus, the costs include allowances for complete overheads and profit. The program costs for the Action Plan also include a portion of the costs previously discussed for the technical assistance projects (See Section 5.3 and 5.4.1).

More accurate cost levels for the Action Plan can be developed only through discussion and agreement between the YARG, the World Bank and the several interested donors. For purposes of this report and as a basis for discussion by AID/Yemen with potential donors, a level of $US (equivalent) approximately $5 million annually for six years is recommended. This cost level should be adequate to, in effect, finance the total operation of the WMD while providing training of 30 water resources specialists and providing some 338 man-months of senior expatriate specialists.

5.6 Donor Coordination

It is recommended that AID/Yemen take a lead role in fostering donor coordination regarding the World Bank Action Plan and for other efforts aimed at improving the water supply situation in the Sana'a Basin. AID/Yemen should designate a specific staff member with responsibility to act as AID's "in-house expert" on the content and progress of the Action Plan, and other basin efforts. The staff member named should also act as contact person with other interested donors and YARG officials. The donors which have expressed interest in the Action Plan (UNDP, the Government of the Netherlands, and possibly Germany) should be contacted and a method of tracking progress of the Action Plan devised. The interested donors should be sure to contact the World Bank on their coordinated efforts and be active members in the World Bank's appraisal mission scheduled for early 1986.

5.7 Conclusions

The World Bank Action Plan presents, a framework for needed action in the Sana'a Basin. As vividly illustrated in the Conclusions of Chapter 3, short-term solutions are becoming fewer and fewer. Limiting use of the aquifer buys only more time for a diminishing resource to be depleted. Action on all

fronts is required. AID/Yemen is wise, however, in taking a cautious approach in providing interventions until the overall picture becomes clearer. Until, however, the action by all parties, not least of all that of YARG, becomes clearer, there are several low-risk options worth pursuing. These are discussed in the previous subsections of this chapter.

APPENDIX A

List of Persons Interviewed

LIST OF PERSONS INTERVIEWED:

USAID:

Charles F. Weden, Jr.	Director
Bobby Allen	Controller
Howard Thomas	General Development Officer
Robert Rose	General Development
Rufus Long	General Development
Lee Feller	General Development - Health
Tracy Atwood	Agricultural Development Officer
Ray Renfro	Agricultural Development Office
Geraldine Donnelly	Program Officer
Karl Schwartz	Education/Human Resources Development Officer
Daniel M. Varisco	Consultant

CONSORTIUM FOR INTERNATIONAL DEVELOPMENT (CID):

Dr. Royal H. Brooks	C.O.P. Agricultural Development, Core Subproject
Richard Griffin	Water Use and Management Advisor
Victor Amann	Agricultural Planning/Economist
Audrey Dibble	Advisor, Librarian - MOA Documentation Center

NATIONAL WATER AND SEWERAGE AUTHORITY (NWSA):

Mohamed A. Fusail	Director General
Abdul Rahman Saeed Nadji	Technical Manager
Hamood Hamran	Operations Manager
Mohamed Al-Muayud	Manager, Financial Department
Mohamed Al-Silwi	Asst. Manager, Hydrology Dept.
Yahya Zabara	Manager, Data Processing Dept.
Abdul El-Dayim	Planning Department
Yasin Ismael	Training Officer
Abas Al Mutawakil	Sana'a Branch Manager
James Ziegler	Consultant, Data Processing Dept.
Peter Riehlmann	Consultant, Technical Branch

CENTRAL PLANNING ORGANIZATION (CPO) - YARG:

Fatih Salim Ali	Deputy Chairman
Abdul Karim Al Kustaban	Manager, Technical Assistance
Anwar Harazi	Manager, General Projects
Dr. Anton Wirth	German Advisory Team to CPO

MINISTRY OF PUBLIC WORKS--Rural Water Supply Division (RWSD)

Abdul Bari Saleh	Director General
Abrahim Abdul Shami	Deputy Director General for Bilateral Programs
Mohamed Sharafi	Deputy Director General for Administration
Mahdi Mohamed Mahdi	Deputy Director General for Projects

MINISTRY OF AGRICULTURE:

Ahmed Moqbil Ahmed	Deputy Minister

YOMINCO:

Mohamed Ahmed Al-Saidi	Director General, Geological Survey & Dept. of Hydrology
J. A. M. Van Der Gun	Dutch Team - Former Co-Project Manager, WRAY 1 Project
F. Charles DuFour	Dutch Team - Co-Project Manager, WRAY 1-2 Project
P. Nota	Dutch Team - Hydrologist, Data Base Manager
Ahmed Wahib	Co-Project Manager, WRAY 1-2 Project
Jamal Zaifallel	Geophysical Technician, Department of Hydrology
Noory Gamal	Hydrogeologist, Dept. of Hydrology

YEMENI JOINT PROJECT FOR NATURAL RESOURCES:

Vladimir Skvor	Economic Geologist, Acting Officer-in-Charge

UNDP:

Christine Abel	Assistant Resident Representative
Abdul Wahed	Project Officer - Yemeni Joint Project for Natural Resources

FAO:

Abdul Latif Tabet	Consultant

WHO:

Julian Kozinski	Advisor to RWSD

GOVERNMENT OF NETHERLANDS:

Hon. M. A. Poolman	First Secretary
Theo Haagsma	Project Manager - RWSD

GOVERNMENT OF USSR:

A. Prokopovich	Head of Soviet Specialists, Sana'a Basin Water Resources Study Team

GOVERNMENT OF UNITED KINGDOM:

Jeremy McCaidy	ODA

GOVERNMENT OF SAUDI ARABIA:

Mohamed Moosa	Director, Saudi Projects Fund

PRIVATE SECTOR:

M. M. Sediq	Vice President, New Transcentury Foundation (NTCF)

(USAID - RWS Project)

Douglas Craig	(NTCF)
Susan Hoops	Sanitary Engineer (NTCF)
Michael Cullen	Sanitary Engineer (NTCF)
George Scott	O & M/Mechanical (NCTF)
James Aubel	Hydrogeologist, Associate Manager, Dar El Yemen Hydro-Consultants
Joseph C. Lysonski	Geophysicist, Dar El-Yemen HydroDConsultants
Graham Cummings	McConnel Dowell Drilling Co.
David Laird	Howard Humphries Consulting Engineers

APPENDIX B

World Bank Action Plan

REVISED VERSION
OBTAINED FROM BANK ON 30 Aug 1985
(Daniel Cayaud)

Sanaa, February 1985

YAR
WATER RESOURCES MANAGEMENT
SANAA BASIN

ACTION PLAN

At the request of the Ministry of Development, a World Bank mission visited Sanaa in February 1985 to assist the Government in preparing an Action Plan for improving water resources management in the Sanaa Basin.

To prepare the Action Plan, a Working Team was established with the mission and representatives of the Ministries involved in water resources management. The working team (list attached in page 3) held five meetings (February 11, 13, 16, 18 and 23, 1985). The attached report and the Action Plan proposed below reflect the information, proposals and comments provided by the working team during the meetings.

Interim Actions	Proposed Completion Date
1. Provision Additional Support to NWSA (Para. 3.2.1.) *	May 31, 1985
2. Extension of existing Protection Zone to new Protection Zone (Report para. 3.1.1)	July 31, 1985
3. Licensing of Abstractions within new Protection Zone (Para. 3.1.2.)	July 31, 1985
4. Licensing of Drilling Companies (Para. 3.1.3.)	July 31, 1985
5. Educational Programme for Population in Sanaa Basin (Para. 3.2.3)	July 31, 1985
6. Charges for Abstracting Water from Aquifer (Para. 3.1.5.)	February 28, 1986
Passing the Law	
Application to Commerce, Industry	February 28, 1986
Application to Irrigation	July 31, 1986

* Note: The paragraphs refer to the report for the detailed action plan.

Interim Action	Proposed Completion Date
7. Establishment of Water Management Department (Para. 3.2.2)	February 28, 1986
Long Term Actions (dependant on Technical Assistance Programme)	
8. Secure Financing for Technical Assistance Programme (Section 6)	December 31, 1985
9. Start Implementation Technical Assistance Programme	February 28, 1986
10. Arrival of the two resident experts (Para. 4.1)	February 28, 1986
11. Final Terms of Reference of Water Resources Investigation and Studies (Para 4.1 & 4.2)	October 31, 1986
12. Award contract for Implementation Water Resources Investigations and Studies (Section 5)	February 28, 1986
Establish Sanaa Basin Water Commission (Para. 3.2.2)	
13. Complete Technical Assistance Programme	October 31, 1989

Sanaa, February 1985

YAR
WATER RESOURCES MANAGEMENT
SANAA BASIN

TABLE OF CONTENTS

YAR WATER RESOURCES MANAGEMENT

LIST OF WORKING TEAM MEMBERS

YAR

High Water Council - Member*	Mohamed Al-Fusail DG of NWSA
High Water Council - General Secretary	Abdul Karim Al-Fusail (Key person)
Central Planning Office	Hisham Abdalla
NWSA Hydrogeological Section	Mohammed Al Selwi
YOMINCO Director Dept. of Hydrology	Ahmed Wahib
Ministry of Public Works	
Dr. Drilling and Hydrogeology	Abdulla A. Malik
Ministry of Agriculture	
Chief Groundwater Section	Abdulla Althary
Planning	Mohammed Al-Thamary
Planning*	Adel Al Kherbash
Irrigation Department	Ali M. Alzumeir

World Bank

Water Supply and Sewerage Chief*	Peter Ware
Water Supply and Sewerage Financial Analyst*	Paul Bowron
Water Supply and Sewerage Sanitary Engineer	Daniel Coyaud
Short-term Consultant*	Andreas Charalambous

Note * - Partially attended the meetings

YEMEN ARAB REPUBLIC
WATER RESOURCES MANAGEMENT
(SANA'A BASIN)

1. Existing Information On Water Resources Management

1.1. Legislation And Documents Related To Water Resources Law

1.1.1. Legislation

Islamic Water Law

The rules of water law in YAR have been described by Maktari (1971) and Caponera (1973) and summarized by the Consortium of International Development (CID) in their report on Water Policy Initiatives for Yemen, 1980.

According to the CID's report the legal doctrine in Yemen is as follows. The system of water rights is based upon a mixture of Islamic legal principles and local customary practice. The rules of groundwater law approximate common law in other countries i.e., the land owner owns the water underlying his land. However within Islamic legal doctrine there is also an interpretation which is that groundwater is common in ownership. Caponera's conclusions on codified Water Law in Moslem countries is that "modern tendencies in water legislation aim at institutionalizing in one form or another, the concept of community interest which in fact constitutes the traditional basis of Moslem Customary Water Law".

Constitution of the Republic

Within the constitution of the Republic there is no direct reference to water but there is a general provision which require that natural resources, above and below ground, should be utilized to the benefit of the whole community. (Clause 16 of the Constitution)

Law No. 14 (1973)

The introduction of Law No. 14 in 1973 results from proposals by Italconsult (Consultants to NWSA on the Water Resources of Sana'a and Hodeida) to protect the groundwater sources of Sana'a from over exploitation. The law stipulates three small areas totalling less than 200 km^2 around NWSA's western wellfield where borehole drilling and abstraction should be regulated and provides for the obtaining of licenses by persons who may wish to drill boreholes for the purpose of abstracting water. Although Law No. 14 refers specifically to areas around NWSA western wellfield, NWSA has "unofficially" applied the same law to other areas around its eastern wellfield constructed in 1981-82.

1.1.2. Publications and Reports

Caponera, D. A., 1973 The author describes the Islamic water law in different Moslem countries (including YAR) and the development of water legislation in modern times.

Johnson, R. J., 1980 In a report submitted to the Ministry of Municipalities under the auspices of U.S. AID Mission in Sana'a, the author recommends:

- The establishment of a Water Resources Council
- Licensing of Drilling Companies
- Licensing of Abstractions
- Preparation of national principles and standards for the planning and development of water resources

* Consortium for International Development (CID), 1980

The report prepared by CID under U.S. AID auspices gives an overview of the water resources in the country and general guidance for water planning, policies for national water resources and groundwater, and a program for implementing the recommendations. A US AID financial assistance was proposed to support the program, but no agreement was reached.

1.2. Organizational Set Up

The following institutions, ministries or authorities currently deal with water:

1.2.1. High Water Council

In 1981, in an effort to coordinate all activities concerned with water resources and prepare a general policy and plans for their development, the High Water Council was formed by the same law that provided for the formation of the Ministry of Electricity, Water and Sewerage. Article 3, Law No. 28 (1981) defines the aims, tasks and membership of the High Water Council as follows:

Aims: (i) Coordination between all authorities and ministries concerned with water.

(ii) Coordination of all studies of water resources for the purpose of drinking, irrigation and power.

(iii) Preparation of a general policy and plan for the development of water resources.

Tasks: (i) Proposals for and coordination of water resources studies.

(ii) Proposals for legislation and for "decrees" for coordinating uses of water resources,

preparing programmes for water use and for exploitation within the framework of a national policy and approved plans.

(iii) Study and evaluation of all information, reports, statistics, maps etc., which the General Secretary obtains from all authorities, ministries, agencies, etc.

(iv) The "following-up with action" of the useful development of water resources in the interest of the community.

(v) The organization of and collaboration in symposiums, conferences, meetings, etc., nationally and internationally.

Membership of High Water Council:

(1) Minister of Electricity, Water and Sewerage: Chairman

(2) Deputy Minister of Ministry of Electricity, Water and sewerage Deputy Chairman.

(3) Deputy Minister of Ministry of Agriculture and Fisheries: Member

(4) Deputy Minister of Ministry of Public Works: Member

(5) Deputy Minister of Ministry of Municipality and Housing: Member

(6) Deputy Minister of Ministry of Al Awkaf (Islamic Affairs): Member

(7) Deputy Minister of Ministry of Central Planning Organization: Member

(8) Deputy General Manager of Cooperative Organization (CYDA): Member

(9) Director General of NWSA: Member

(10) Director General of Geological Survey: Member

(11) Director General Rural Water Supply Office, Ministry of Public Works: Member

(12) Director General of Meteorology and Civil Aviation: Member

(13) General Manager of Tihama Development Authority: Member

(14) Water Resources Specialist: General Secretary

1.2.2. The National Water and Sewerage Authority (NWSA)

NWSA was established in 1973 (Law No. 13) under the Ministry of Public Works. In 1981 (Law No. 26) the Ministry of Electricity, Water and Sewerage was formed and NWSA was "transferred" into the new Ministry. Since approximately 1977, a NWSA hydrogeological section has been responsible for monitoring and protecting water resources in the urban centers served by NWSA. (six presently).

1.2.3. The Department of Hydrology (DOH) (Geological Survey)

Under the wing of the Geological Survey Board which is part of the National Authority for Petroleum and Mineral Resources (Yominco) the DOH was formed in 1981. The Department deals with the collection and processing of hydrological data, and with geophysical groundwater and surface water studies. A computerized hydrologic and hydrogeologic data bank system is being developed in DOH with assistance from the Netherlands under the first phase of a cooperation programme. The second phase of the cooperation programme is scheduled to start in

August 1985. Its objectives are to assist DOH in being the water resources research and information center of the YAR.

1.2.4. The Irrigation Department of the Ministry of Agriculture is concerned with Rural Development Projects (Central Highlands Project, Southern Uplands Project, etc.) and includes staff with knowledge of rural water supply.

1.2.5. The Rural Water Supply Department under the Ministry of Public Works includes a Water Well Drilling Division managed by a hydrogeologist. The staff of the division includes 2-3 other hydrogeologists.

1.2.6. CYDA (Cooperative Organization)

CYDA's department of General Services which deals with drilling wells for local cooperatives has on its staff one hydrogeologist.

1.3. Studies and Data Base

1.3.1. List of Studies and Publications

In the last 15 years a considerable number of studies and investigations have been carried out for the Sana'a Basin. A complete bibliography was prepared by Mrs. Babcock in 1980 for DOH. The main studies are listed below:

(1) Italconsult, 1973b, Sana'a Basin Groundwater Studies, UNDP YEM WHO Yemen 3202 (Volume I Report, Volume II Figures, Volume III Annexes, Drawing 1 Hydrogeological Map of the Sana'a Basin).

(2) Leggette, Brashears and Graham, 1976, Observations and Evaluation of Sana'a Wellfield.

(3) Howard Humphreys, Reports to the National Water and Sewerage Authority, YAR:

- 1977, Sana'a Water Supply, Interim Report.
- 1979, Monitoring Report Sana'a Basin
- 1980, Recommendations for the Development of the Sandstone Aquifers and other sources in the Sana'a Basin
- 1981, Report on Western Wellfield
- 1983, Hydrogeology and Development of the Tawilah-Mejd Zir Sandstone and other sources.

(4) Dar El Handasah, 1978, Report on Western Wellfield

(5) Charalambous, A. N., 1982, Some Problems of Development of the groundwater resources of the Sana'a Basin, YAR, IAHS Publ. No. 136, Proceedings of the Exeter Symposium.

(6) Jungfer, E., 1984, Das Wasserproblem im Becken von Sana'a, Sonderdruck aus: "Entwicklungsprozesse in der Arabischen Republik Jemen, Dr. R.R. Verlag, Wiesbaden.

(7) TNO-DGV, Institute of Applied Geosciences, Delft, 1984, Hydrology and Hydrogeology of the Yemen Arab Republic, Report WRAY-1, YOMINCO, Department of Hydrology.

(8) Dubay L., Garabedian S., and Thiele J., 1984, Sana'a Water Resources, Reappraisal, Report to the National Water and Sewerage Authority.

(9) USSR Study Group, 1984, Sana'a Basin Water Resources Scheme, Brief Review prepared for the Ministry of Agriculture and Fisheries (study and investigations still in progress to be completed in August 1986). In order to implement the scheme, the USSR granted the YAR a loan of $2.5 million.

1.3.2. Conclusions from Studies

Groundwater Sources

(i) The Tawilah Sandstone is the major aquifer of the Sana'a Basin, an area of approximately 3,500 km^2. It outcrops north of Sana'a but underlies the entire Basin at depths of 400-500m south of Sana'a and more than 1000m in the Highlands. Other aquifers may be the Kohlan sandstone outcropping outside the Sana'a Basin.

(ii) The Tawilah sandstone in the Sana'a Basin is now exploited north of Sana'a through a total of about 1000 boreholes by:

- NWSA (Water Supply of Sana'a)
- Commerce and Industry (Hotels, bottled drinks, factories, etc.)
- Farmers (irrigation and local domestic use)

Private abstraction exceeds by far that of NWSA. Irrigation abstractions amount to 80-90 per cent of private abstraction. In 1984, estimated abstractions were approximately:

	l/s	Mm^3/a
Government(NWSA)	250	8.0
Private	1000	31.5
Total	1250	39.5

(iii) Recharge to the Tawilah sandstone has been variously estimated to be between 27 and 60 Mm^3/a. Recent isotopic studies suggest groundwater ages between 3000, 8000 and up to 20000 years. Current thinking

is that replenishment may not be greater than 27 Mm^3/a.

(iv) Tentatively, the present estimate of the Tawilah sandstone groundwater budget is:

	l/s	Mm^3/a
Replenishment	860 or less	27 or less
Abstraction	1250	39.5
Deficit:	390 or more	12.5 or more

According to this estimate, 30% or more of the present abstraction is not being replenished.

(v) Because of over-exploitation of the aquifer, water levels in the last 13 years (1972-84) have fallen by 16 to 38m - corresponding to average decline of 1.2 to 3m per year. The fall in water levels has placed NWSA wellfields at a serious risk of depletion. NWSA pumps in the Western Wellfield already need to be lowered. According to some investigators, if the present level of private abstraction continues, the life of service of government wellfields (at production rates of 400 l/s) may only be 15 years, even if boreholes were deepened to fully penetrate the aquifer.

Surface Water Sources

(i) Present indications are that there are no major surface water sources in the Sana'a Basin.

(ii) Preliminary studies (USSR 1984) suggest possible impounding schemes by dams on the western slopes of the Central Highlands (Wadi Surdud) but conveyance of water from there to Sana'a would involve distances of 100 km and pumping lifts of 1000-2000m.

(iii) Other impoundment sites at Wadi Kharid, 50 km north of Sana'a, would involve pumping lifts of 500-800 m. Intakes to exploit spring flow (approximately 200 l/s) in the same wadi are now being designed for irrigation.

1.3.3. Data Base

Water Resources data are now being collected by various authorities (NWSA, Public Works, Ministry of Agriculture (TDA), and YOMINCO). The Department of Hydrology in YOMINCO has begun a nationwide data collection programme with a view to forming a central computer data base. TDA collect data in the Tihama, and NWSA mainly groundwater data in Sana'a, Ibb, Dhamar and Hodeida and Taiz.

2. Needs for Water Resources Management

2.1. Legislation, Policy and Institutions

(a) Legislation

- Groundwater abstractions are to be controlled in only a small area of approximately 200 km^2 (5% of the total Sana'a Basin) (Law No. 14, 1973).
- Existing law does not provide for penalties to offenders.
- There is no scheme of charges for water abstraction by private users or of control of quantities used.
- There is no provision for licensing of drilling companies.

(b) Policy Related Directly or Indirectly To Water

- There is no national policy for the management of water resources.
- There is no public education program to explain the realities of the water resources situation and the necessity of legislative and enforcement actions to preserve the resources.
- There is no policy regarding population and industrial growth in Sana'a.

(c) Institutions and Organizati[illegible]

- There is no single department, or agency or unit responsible for the management of water resources either nationally or locally.
- Organizational support to implement the existing legislation (NWSA Hydrological Department) is weak.

- The High Water Council does not have staff.

2.2. Data and Information on Water Resources and Their Use in Sana'a Basin

(a) Hydrogeology

- Data derived from field investigations are limited to a geographically small area, north of Sana'a.
- Groundwater abstractions are not known accurately.
- Groundwater levels are only monitored in the Government wellfield areas. There is no regional water-level network.
- There is little hydrogeological information from private boreholes.
- Except for a small area north of Sana'a there is very little knowledge of:
  - (i) Water/table/piezometry of aquifers
  - (ii) Groundwater movement
  - (iii) Extent, thickness and properties of aquifers
  - (iv) Recharge, storage and age of groundwaters
  - (v) Chemical quality of groundwaters
- Consistent, agreed estimates on the status of aquifers do not exist.

(b) Hydrometeorology

- The rainfall measuring network is inadequate.
- There are no measurements of wadi runoff.
- There is very little hydrometeorological data.

(c) Water Use

- There are little data on water use for domestic,

industrial/commercial and irrigation purposes.

- Water conserving irrigation and other practices have not been studied.
- There are no reliable estimates of current and future water use in the Sana'a Basin.

(d) Future Sources for Water Supply of Sana'a

- Present knowledge on future water sources is poor.
- There are no plans for the development on possible additional sources.

2.3. Problems Arising from Existing Situation

As a result of the above deficiencies in water resources management, the following problems were identified:

- Depletion of groundwater resources, particularly of the Tawilah Sandstone aquifer which is supplying the city of Sana'a.
- Dramatic fall of water levels north of Sana'a.
- Shortening of useful life to 10-15 years of Government wellfields north of Sana'a which provide water to the city.

Should the present situation of over-exploitation of the Tawilah sandstone supplying Sana'a continue, the implications are:

(a) Lowering of pumps and deepening of boreholes.

(b) Partial and eventually total abandonment of the existing Government wellfields north of Sana'a.

(c) Conveyance of water to Sana'a at greater cost from sources farther afield:

Either, groundwater from deep boreholes outside the

present wellfields but in the Sana'a Basin;

OR, surface water from impoundment schemes outside the Sana'a Basin;

OR, a combination of groundwater and surface water sources.

3. Interim Actions Recommended

The following interim actions are recommended to be taken prior to longer term actions which would be based on results of additional investigation with technical and financial assistance. The interim actions are proposed in order to control further increase in the rate of groundwater abstraction in the Protection Zone. The implementing authority should be instructed by the High Water Council to deliver licenses for new abstraction schemes only to public water supply or for public interest schemes especially approved by the High Water Council.

3.1. Legislative Actions

3.1.1. Extension of existing Protection Zones to new Protection Zone

It is proposed to extend the protection zone to an area of about 3000 km^2 around Sana'a, according to the boundary Indicated in a report prepared in November 1984 by three experts commissioned by NWSA.

3.1.2. Licensing of abstractions within new Protection Zone

(i) New wells or boreholes

Unless authorized by a license, no person shall:

(a) construct any well, borehole or other work for the purpose of abstracting water from underground strata;

(b) extend any well, borehole or other work;

(c) install or modify any machinery for the purpose of abstracting water from underground strata.

(ii) Existing boreholes

Owners of unlicensed boreholes of depth greater than 50 metres used for abstraction of water are required to obtain a license within six months from the date of enactment of the law.

3.1.3. Licensing of Drilling Companies

(i) Drilling companies in YAR must have a license which should be obtained two months from the date of enactment of the law.

(ii) Drilling machines should be licensed on importation.

(iii) Only licensed companies in possession of licensed drilling machines shall be permitted to drill within the new Protection Zone.

(iv) Drilling companies constructing boreholes within the Protected Zone shall be required to provide:

(a) a location plan

(b) a drilling and lithology log

(c) an as constructed drawing of the borehole

(d) data of discharge and drawdown from a 24-hour pumping test

(e) static water levels

3.1.4. Enforcement of Legislation

(i) Any person contravening the laws on licensing of abstractions within the Protection Zone shall be guilty of an offense and shall be liable to a fine.

(ii) Any drilling company contravening the licensing laws shall be guilty of an offense and shall be

liable to a fine and withdrawal of license to operate for a period of 12 months.

3.1.5. Charges for Abstracting Water from Aquifer

(Applicable to licensed boreholes in Protection Zone)

(i) Licensing fee payable on granting the license and annually thereafter.

(ii) Charging scheme in addition to licensing fee. Levying of charges at different rates for:

(a) Commercial use (Hotels, etc...) (charges based on consumption)

(b) Industrial use (Textile factory, Bottle water and Soft drinks industry, Private water supplies, etc...) (charges based on consumption)

(c) Irrigation use (charges either based on pump-size)
(or irrigated area)
(or usage (requires metering)).

Suggest: special low charges for farmers who install drip or spray irrigation. This will reduce groundwater usage.

3.2 Actions Related To Implementation of Legislation in Protection Zone

3.2.1. Provision of additional support to NWSA. Pending the establishment of a Water Management Department directly under the High Water Council, NWSA will act as the implementing agency for the new legislation. During

the interim period NWSA's Hydrogeological Department would need to be strengthened in terms of staff (2 to 4 technicians), equipment (unit of air lifting and pumping test, water and electric tapes, conductivity meters), transport (2 four-wheel drive vehicles), and should be supported by a police or military contingent (2 groups with 6 people in each group).

3.2.7 Establishment of a Water Management Department under the High Water Council within 12 months. This may involve the transfer of part of the staff and facilities of the NWSA Hydrogeological Section to the newly established Department. The duties of the Water Management Department would be to:

- prepare information for the meetings of the High Water council;
- develop national standards for water planning;
- prepare or oversee the preparation of water resources master plan in the different catchment basins;
- conduct or commission studies as directed by the High Water Council;
- promulgate and enforce Water Resources policy and legislation, through licensing and monitoring, first in the Sana'a Basin and later in other hydrologic basins through regional offices;
- stimulate changes in water management practices to achieve greater economic productivity;
- levy charges for abstraction of water from aquifer where there is a need to restrict abstractions;

- develop a policy to protect aquifers against pollution;
- establish in each catchment basin a Regional Water Commission which would include representatives of Water Users: local development authorities, ministerial regional offices, municipalities, villages, agricultural cooperatives. The regional offices of the Water Management Department would have to consult the Regional Water Commissions during the preparation of water resources master plan.

It would be more appropriate that the above duties be carried out by a Water Management Department under the High Water Council, and not by NWSA because of the several important national interests involved, principally agricultural and industrial/commercial in addition to domestic water consumption, the highly political nature of policymaking in this area, and the need for authority at the highest possible level in order to implement the policies.

3.2.3 Educational Programme for Population in Sana'a Basin

The legislative actions recommended in 3.1 should be accompanied by an educational programme which would inform the population in the Sana'a Basin, through the news media, on the rapid lowering of the water level in the main aquifer of the Sana'a Basin and on the actions that the Government is taking to balance water resources and demands.

4. Long Term Actions Dependant on Technical Assistance Programme

4.1. Operational Support to W.M.D.

In order to assist Government in developing further and implementing a legislative, institutional and organizational framework for the management of water resources, it is proposed that two resident experts be provided for a period of 2 years each to assist in implementing the tasks of the W.M.D. (3-2(2)).

- A Water Resources Planning Expert with experience in water supply and water legislation.
- A Water Resources Planning Expert with experience in irrigation.

The two experts will be attached to the Water Management Department and, together with Yemeni staff, will initially develop the water policy for the Sana'a Basin and extend the policy to other critical areas of the country. It would be necessary for at least one of the experts to have a good knowledge of the Arabic language, both spoken and written.

The water resources of the Sana'a Basin are now being investigated and studied by an USSR team who will be reporting on its results in September 1986. The USSR team envisages to complete field investigations in November 1985 by which time it would be in a position to report on these aspects of its work.

The Water Resources Assessment in Yemen W.R.A.Y. - 2 Project (1985-1988) expected to be financed by the Netherlands and the YAR Government includes funds for a continuation of studies in Wadi Surdud (Under W.R.A.Y. - 1) and, in addition, hydrogeological/ hydrological studies in the upper reaches of the Wadi. Although outside the Sana'a Basin, the study of water resources of Wadi Surdud Basin is useful since if resources in the

Sana'a Basin prove to be insufficient, Wadi Surdud appears to be the best alternative resource to supplement the Sana'a Basin resources for the supply of Sana'a.

Finally, under a UNDP Project, irrigation techniques in selected areas in the Sana'a Basin are being studied to improve present methods and introduce new methods of irrigation. The project is implemented by FAO. FAO contribution of U.S. $80,000.

It would be the responsibility of the resident experts in co-operation with the staff of the Water Management Depa: tment and . taking account of the above studies in the Sana'a Basin and peripheral areas to assist the Department in preparing detailed Terms of Reference for further engineering, hydrological and hydrogeological studies required for formulating a definitive Water Resources Management Plan for the Sana'a Basin and an updated version of the Water Supply Master Plan for Sana'a.

In this task the Water Management Department will be assisted by two visiting experts:

- An Hydrogeologist (6 weeks) to assist the W.M.D. in establishing a programme of drilling exploratory boreholes and testing in the Tawilah Sandstone of the Sana'a Basin.

The exploratory drilling programme should be designed such that it can provide maximum information to determine within practicable limits the regional hydrogeological setting of the Tawilah Aquifer and to enable the development of future wellfields for the supply of Sana'a.

- An Irrigation Technician (6 weeks) to assist in supervising the studies indicated in 4.2.4.

4.2. Water Resources Investigations and Studies for the Sana'a Basin and Water Supply Study for Sana'a

The proposed Technical Assistance Programme would include the following field investigations and studies:

4.2.1. Water Resources Investigations and Studies

(a) Review of Studies (USSR and WRAY - 2) Reports Data and Information. On the basis of this review, an appraisal of existing knowledge on the geology, hydrogeology, groundwater exploration, and hydrology will be made and detailed plan of activities be drawn which should include the delineation of the most productive aquifers and their investigation.

(b) Abstractions and Monitoring Networks

(i) Assessment of groundwater abstraction from the various aquifers, with special attention to the Tawilah Sandstone. Monitoring of private abstractions on routine basis.

(ii) Extension of the water-level measurement network of the aquifers to cover the whole of the Sana'a Basin.

(c) Geophysical Surveys to determine with more accuracy the distribution and thickness of the Tawilah and Kohlan sandstones.

(i) Borehole geophysical logs (gamma, neutron and caliper) to be run in about 60 deep private boreholes.

(ii) Resistivity, and if required, seismic surveys.

(d) Hydrogeological Surveys in the Tawilah Sandstone

Examination to the possibility of hydraulic connection of the Tawilah aquifer in the west (Wadi Surdud catchment) and east (Wadi Jawf catchment) and the Sana'a plain.

(e) Exploratory drilling and testing of about four boreholes penetrating the Tawilah Sandstone in the Sana'a Basin according to the programme established by the Water Management Department. This programme will complement the 4 shallow boreholes ($\sim$ 60m) and the three deep boreholes ($\geq$ 300m) in order to fully establish the piezometry of the aquifer over a large area, its hydraulic extent and catchment area and its variation in thickness.

(f) Hydrochemical Survey

Chemical analyses of major ions and trace elements to be carried out on about 50 groundwater samples from boreholes and springs in the Tawilah Sandstone, Volcanic and alluvial aquifers to study the hydrochemical facies of the aquifers and their relationship.

(g) Isotopic Analyses

Isotopic analyses of about 50 groundwater samples from Tawilah Sandstone, Volcanic and Alluvial aquifers which should include: thermonuclear tritium, stable isotopes and carbon-14 to determine the likely origin and ages of groundwaters.

(h) Recharge Studies

(i) Installation of Gauging Stations at suitable locations in two wadi-catchments, one over the Tawilah Sandstone, the other over the volcanic layer to establish rainfall - runoff - infiltration characteristics.

(ii) Estimation of the recharge of the aquifers through the wadis.

(i) Modelling of the Tawilah Aquifer in the Sana'a Basin

Refining of the model prepared by the USSR team with the results of the four complementary exploratory boreholes and the new data on abstractions, water levels, etc. The model will be used for dynamic runs under different options of demand and wellfield patterns to estimate future water availability.

(j) Analysis and Evaluation of Data

As far as possible data analysis should be presented in graphical land map form. The following main maps of the Sana'a Basin should be prepared:

(i) Hydrogeological map

(ii) Water-table/piezometric map of different aquifers

(iii) Geological subsurface maps showing the depth to the Tawilah Sandstone

(iv) Hydrochemical maps of different aquifers

(v) Maps showing the results of the model

(vi) Rainfall maps

(vii) Maps showing the hydrometeorological network

(viii) Maps showing the groundwater monitoring network

(ix) Maps showing groundwater abstractions, and any other maps which will be required for the evaluation and study of water resources

4.2.2. Study of Water Demand up to year 2006

The objective of this study is to update the water demand projections in the Sana'a Basin.

- Sana'a water supply demand (domestic, commercial, industrial, governmental).

- Rural water supply demand in the different center of the Basin.
- Water demand for irrigation.

4.2.3. Engineering Study for additional Water Supply for Sana'a

The objectives of this study are:

(i) To compare alternative schemes for additional water supply to Sana'a if it is proved that the water resources present in the Sana'a Basin are insufficient to supply Sanaa up to 2006.

(ii) To prepare a preliminary design of the best alternative selected as a result of the above comparison.

4.2.4. Further Studies on Irrigation Methods and Varieties of Crops.

The USSR study on irrigation is of general nature and covers the Sana'a plain only. The proposed new study would delineate irrigated areas, and improvements will be proposed. The UNDP - FAO study YEM/84/003 small because of lack of financial resources. It is felt that once the above studies are completed, it will appear that further studies will be needed to:

- Improve the present flood system of irrigation in order to save water (determination of depth of water and irrigation schedules).
- Introduce new methods using sprinklers and drip-fed irrigation.
- Study the introduction of least water consuming varieties of crops.
- Study irrigated crops using sewage effluent.
- Select, design and operate a pilot farm to test the proposals which would result from the above studies.
- Organize regular visits to the pilot farm of local farmers,

give lectures and seminars and assist farmers in adopting the most suitable and least water consuming methods.

4.3. Supply of Facilities and Equipment to the Water Management Department

In order to enable the Water Management Department to function in an efficient and effective manner back-up equipment will be required. Some of the facilities will be provided by the Technical Assistance Programme and the rest by the Yemen Arab Republic Government.

4.3.1. Equipment to be provided by the Technical Assistance Programme

- 4 No. (4-wheel drive) vehicles.
- 1 No. micro-computer with graphic facilities.
- 6 No. water-level borehole dippers.
- 6 No. electrical-conductivity meters.
- 6 No. Chemical Kits.
- 1 No. borehole-geophysical logging unit.
- 12 No. autographic borehole water level recorders.
- 6 No. weir-boxes for measuring flow.
- Textbooks and publications.

4.3.2. Facilities and equipment to be provided by Government

- Office accommodation
- Secretarial and administrative staff
- Typewriters, desks, drawing boards, stationery, etc.
- Communication facilities

4.4. Preparation of Educational Programme for Population

In order to educate local leaders and the population of the YAR on the realities of their local water situation and on the actions the Government is taking to balance water resources and demands,

it is proposed that an intensive programme of seminars, media information and educational services be prepared and implemented.

To this end, it is recommended that a media specialist either from Yemen Arab Republic or overseas, be retained to provide advices, as required, to the Water Management Department as to the most effective methods of presentation of programmes (T.V., Radio, Newspapers, Posters, Pamphlets, Seminars, School Programmes) likely to produce quick results and assist in the preparation and implementation of the programmes.

4.5. Training of Water Management Professionals

The Water Management Department should select for further education and training three or four persons (geologists, engineers, scientists) who are currently involved in water resources management at the various Government Departments. These persons should be sent on scholarships to overseas universities or institutes to attend post-graduate or training courses in water resources.

5. Implementation of the Technical Assistance Programme

The newly established Water Management Department would be the implementing agency of the Technical Assistance Programme.

The two resident experts and the two visiting experts (form 4.1.1.) will be hired directly by the High Water Council.

Facilities and equipment included in the Technical Assistance Programme (form 4.3) will be procured directly by the Water Management Department (WMD).

The carrying out of Water Resources Investigation and studies bill be contracted to a consulting firm after tendering in which the Department of Hydrology of YOMINCO might participate, and to a drilling company with the W.M.D. acting as a supervising agency.

The implementation (Schedule in Figure 1) is expected to start in February 1986 and to end in October 1989. In order to avoid duplication of studies, detailed terms of reference for water resources investigation and studies can only be finalized after the completion of the USSR study (September 1986).

6. Cost Estimates of Technical Assistance Programme

A summary of estimated costs is presented below:

			US$
1)	Resident and Visiting Experts		462,000
2)	Supply of Equipment		120,000
3)	Investigations & Studies:		
	Exploratory Drilling	=	1,300,000
	Instrumentation	=	50,000
	Borehole, Well Levelling	=	50,000
	Chemical/Isotope Analysis	=	50,000
	Geophysical Surveys	=	75,000
	Modelling	=	100,000
	Staff	=	850,000
	Reporting	=	50,000
			2,525,000
4)	Educational Programme		75,000
5)	Training of Water Management Staff		60,000
6)	Base Costs		3,242,000
7)	Contingencies		758,000
8)	TOTAL		4,000,000

YAR-WATER RESOURCES MANAGEMENT
TECHNICAL ASSISTANCE PROGRAMME (SANA'A BASIN)
IMPLEMENTATION SCHEDULE

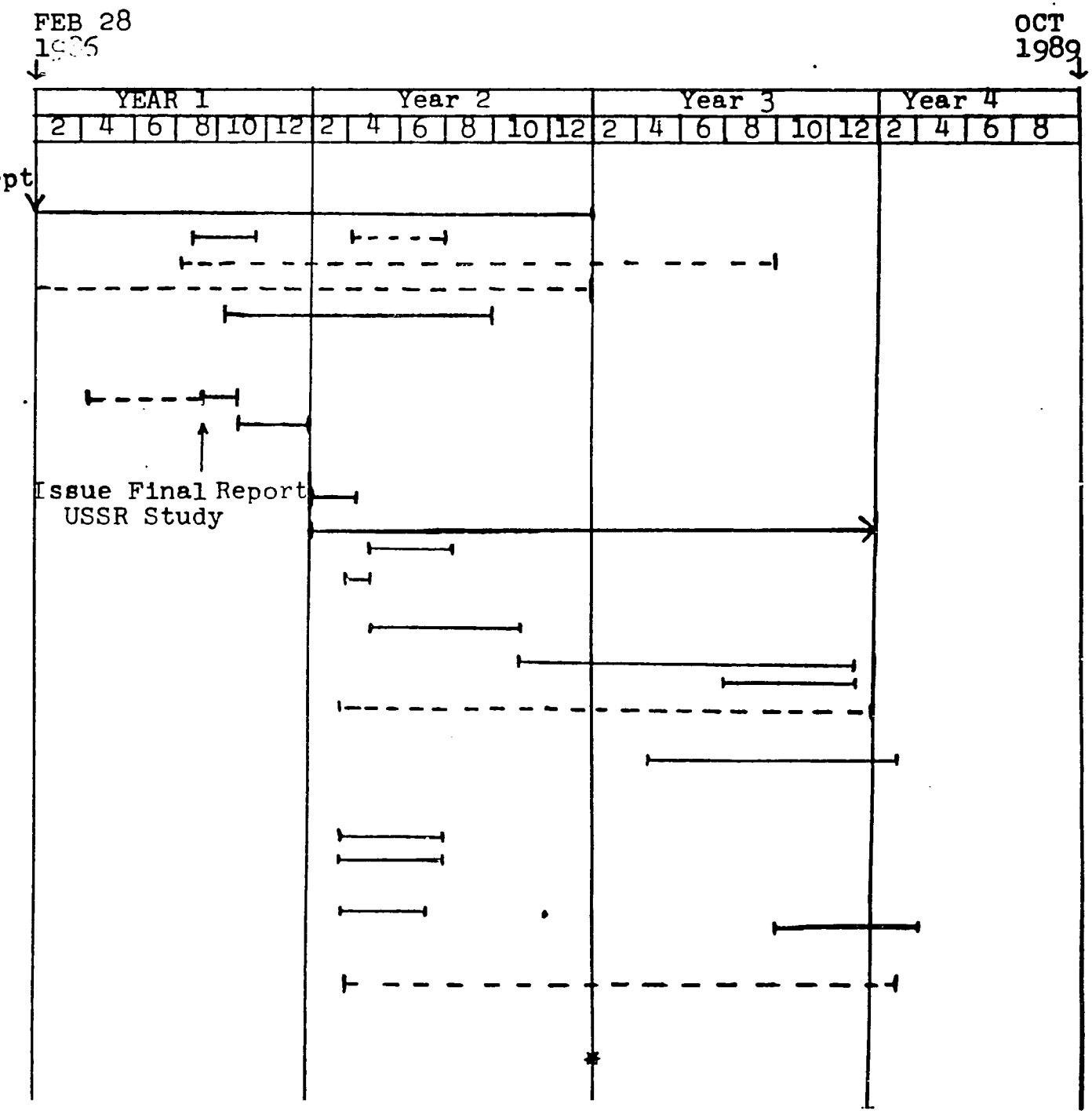


FIGURE 1.

APPENDIX C

Traditional Principles of Resource Use

Traditional Principles of Resource Use

(Excerpted from: A Social and Institutional Profile of the Yemen Arab Republic - Reference No.)

Allocation of land and water in Yemen results from a dynamic interplay between formal Islamic law and customary law. Islamic law is the basis of the Yemeni government, but this does not contain a formal code of water or land law. General resource use principles are provided and these must be applied by judges to varying contexts. The tendency in Yemen has been for Islamic judges to resolve water use problems by resorting to customary practices in a region, as long as this is not antagonistic to Islamic principles. Thus, it is difficult to define water use rights on a national level.

There are three basic principles guiding allocation of land and water in Islamic law:

1. All Muslims share in the resource water. The prophet Muhammad is quoted as saying that water, fire and pasture were given by God for the entire Islamic community. Water is perceived as a shared resource in terms of a priority of needs. Drinking, the most fundamental need, can be denied to no one. It is not hard to see how this principle developed in the arid, pastoral society of the Arabian peninsula. A Muslim denied water to drink or to quench the thirst of his mount has a right to take up arms to obtain what he needs. This concept of sharing is one reason why private wells, inside a walled enclosure, may have an outlet to the street for those passing by. Similarly, no Muslims should be denied access to water for performance of the ablutions in prayer.

   It is with irrigation that access to a shared resource must be limited. For a water source that is more or less unlimited, such as a major river, there is no need to limit access for irrigation. Seasonal flow in a wadi, however, is generally shared between a number of communities along the watercourse. Thus, it is important to reach an arrangement so that the upstream users do not take more water than they need and consequently harm the agriculture of downstream users. Springs are invariably defined as communal access in Yemen. Those who own nearby land share the flow from a spring, usually according to a rotation system of defined turns. A well dug by a man on his own property may be used for his own irrigation needs. However, he is admonished by the prophet Muhammad to allow surplus water to be used by others.

2. Water is essentially an ownerless resource. Since water is shared, it cannot be considered disposal property in Islamic law. Yet there are cases when water is owned in a de facto sense, such as when a person has water in a small container (jar) or digs a well on his own land. In fact, this is not an absolute right of ownership, because the owner cannot dispose of the water as he wishes. For example, he cannot alienate a water right from a land right in inheritance, as part of a bride's dower, as a gift, as

alms, or as a bequest to the religious trust. The owner of a well must provide water for drinking to anyone who asks. Furthermore, Muhammad admonished people not to waste surplus water, but to pass it on to those who need it. To the extent a man withholds water from another, said the prophet, God will withhold his mercy on the day of judgment. Shareholders in a spring system do not own the water;they simply have prior rights. This principle presents a major problem to developing user fees.

3. Water and land are intimately linked resources. In Islamic law of Yemen, the water right is attached to the land right and cannot be alienated. A water right cannot be bought or sold as such, although a turn may be "rented" on a daily or seasonal basis. The guiding principle is that the amount rented be a known or fixed among to protect the rights of other shareholders. This linkage of land and water rights may have evolved out of a pastoral setting on the peninsula.

   Several basic doctrines in Islamic law associate water and land as resources. One of these is the right of pre-emption, which is designed to protect fellow shareholders. If, for example, a group of men build a cistern and channel, the right of pre-emption guarantees that fellow shareholders will have first rights of purchase if one man wishes to sell his land (and thus his attached water right). This is also a principle in tribal customary law, where it is difficult for a man to sell land outside his descent group, because his kin have pre-emptive rights. In the past, and to a certain extent today, this right had tended to keep ownership of land and use of water for irrigation at a local level, especially in tribal areas.

   Another principle linking land and water is the concept of a buffer zone or easement around most water sources. One cannot build a well within so many meters of another well or water source. Similarly, one cannot block access to a shared water source or block travel along a common channel. This principle appears to have worked well in the past,when water was lifted by hand or animal power, but it cannot effectively deal with use of hydraulic pumps. Here is an area of groundwater usage where a national policy must be established to build on the traditional concept of the buffer zone.

APPENDIX D

Review of World Bank Action Plan

Review of World Bank's Action Plan
Water Resources Management - Sana'a Basin

Introduction

The World Bank's Action Plan (AP) is presented in its entirety in Appendix B. This appendix will review the AP's salient points and discuss the key elements in light of the work accomplished by the WASH team for the Sana'a Basin Water Resources Assessment.

Review of the Action Plan

The AP is a combination of institutional (i.e., non-investment) and technical approaches. The institutional approaches include a package of legislation to set the legal basis for YARG to control extractions from the Sana'a Basin ground water aquifer and establishing the Water Management Division (WMD) to act as the technical secretariat arm of the High Water Council.

The legislation

- Extends the boundaries for the protection zone around Sana'a to encompass approximately 3,000 square kilometers.

- Requires licensing of new wells in the protection zone, including all new wells and existing wells over 50 meters in depth.

- Requires the licensing of drilling companies and establishing the content of data logs which must be filed by drilling companies.

- Provides enforcement and penalty provisions for individuals and drilling companies which violate the new laws.

- Establishes a fee schedule for all licensed wells in the protected zone, and a timetable for applying these fees to various classes of users.

NWSA, through its Hydrogeological Department, would implement the new legislation on an interim basis. The WMD, once established, would take over enforcement functions with part or all of NWSA's Hydrogeological Department transferred to the WMD.

NWSA would be strengthened by adding (to its Hydrological Department) two to four technicians, plus equipment to do monitoring. Police/army support would also be provided.

The AP's long-term points include:

- Provision of funds for manpower, equipment, materials and contractors for a 46-month project leading to the establishment of a Water Resources Management Plan for the Sana'a Basin.

- Provision of two experts for two years each to WMD.

- Provision of training overseas for three or four selected Yemenis involved in technical and/or scientific activities in the water resources sector.

- Provision of equipment and outside contractors to define the capacity of the Sana'a's groundwater Basin.

- Performing the necessary hydrological and geological studies necessary to complement the USSR study.

- Performing studies on irrigation methods/needs, and the water supply needs for Sana'a city until 2006. (This would be an update of Sana'a's Water Supply Master Plan.)

- Developing a groundwater model of the Basin.

- Use this study as a prototype for other basins throughout the YAR.

The AP also calls for the establishment, in each catchment basin, of a Regional Water Commission whose members would be drawn from government ministries, local authorities, villages, and agricultural cooperatives. These commissions would give input to WMD on any plans they developed.

Comments on Key Elements

The AP describes a logical program, and provides a framework for long-term action which effectively melds technical and institutional approaches to implement the start of a national water management plan. However, there are some serious drawbacks in the technical and institutional details of the plan. These are discussed in the following sections.

Staffing and Implementation of the Long-Range Plan

Two senior expatriate advisors would be working with NWSA's Hydrogeological Department (now with six members, only two of which have experience in hydrology and geology, the others being technicians).

Short term assistance including six weeks of a hydrogeologist's time to establish an exploratory drilling program, and six weeks of an irrigation technician's time to assist in supervising the recommended "Further Studies on Irrigation Methods and Varieties of Crops" (see AP section 4.2.4, Appendix B).

After twenty-four months, the program will be taken over by Yemenis to complete, including the work necessary to refine the Sana'a Basin ground water computer simulation model developed as part of the USSR study.

Based upon the work accomplished by the WASH team, the conclusions reached on the above areas follow:

- The AP gives no consideration to the database which could be assembled from the many fragmented data sources available, excluding the USSR study.

If the preliminary results of the USSR work--especially their field investigations--become available prior to the finalization of their work, a larger database would be available for use by WMD.

In both instances cited above, analysis and interpretation of the data will be necessary. The only group which appears to have the expertise to prepare such a database is the Dutch team supervising the WRAY-2 work.

- The only institution working in the Yemeni public sector having potential to provide the necessary expertise for WMD is the Department of Hydrology in YOMINCO (working on the WRAY-2 project--see Section 2.6).

- The number of long-term advisors (two recommended) appears too low.

  Further, the only significant water resource in the Sana'a Basin is ground water. Therefore, it is logical to provide at least one senior advisor who is an expert in groundwater hydrology. If after a period of time it becomes necessary to investigate surface water resources outside the Sana'a Basin, an expert in surface water hydrology could be added to the staff.

- The nature of water resources planning in Yemen suggests that providing resident advisors for two years is too short a time frame for the project to then be completely turned over for Yemeni implementation. Further, the overall schedule of 46 months may be too low, considering the institutional constraints (see section C.3.).

The long term project schedule enumerated in the AP is supposed to commence late February, 1986. This schedule should be reevaluated considering the most recent developments. As of the end of October, 1985, no action has been taken to create a WMD, and no support staff or counterparts are available.

Putting two advisors on the ground under these conditions may cause the project to start off so badly that it may never reach the level necessary to achieve its objectives. Further, as stated above, providing only two advisors does not appear to be adequate for the task at hand.

The reevaluation should consider reorganizing the High Water Council under the chairmanship of the Prime Minister. Membership should be the Ministers of Agriculture; Electricity, Water Supply and Sewage; and Public Works (or the Managing Director of RWSD, if it becomes autonomous); the Managing Director of NWSA; and the Deputy Director of Development responsible for the CPO.

Recommendations

The World Bank team should reevaluate the project timetable, staffing levels of expatriate advisors, and overall costs, in light of the above and the following recommendations.

a. YOMINCO's Department of Hydrology should be transferred--en toto--to the WMD to act as the technical core group for analysis and planning. NWSA's Hydrogeological Department should be designated as WMD's monitoring and enforcement arm. The present membership of the HWC is unwieldy and has little political muscle. The four institutions which would remain are the only YARG agencies functioning in the water sector (assuming DOH is moved from YOMINCO).

b. The DOH transferred from YOMINCO should be provided twelve additional staff members (six technical, and six technician level) so that the WRAY-2 work can be unimpeded while the WMD's work goes on and the overall DOH staff should be given training ("Institute Option" described in Section 5). Consideration should be given to having the project fund one or two additional Dutch advisors for two to three years to work exclusively with the WMD.

c. A cadre of engineers and geologists should be identified (fifteen to twenty) and provided training ("Institute Option" described in Section 5). The training would be provided commensurate to the work plan developed by WMD. Specific individuals should be selected from the cadre and assigned as counterparts to expatriates, with the idea of assuming the senior expatriate position in six to twelve months after assignment as counterparts.

d. The project should immediately be reevaluated so that a determination can be made as to the proper number of advisors and senior managers necessary.

e. Two expatriates in WMD (one a senior water resources planner and the other a hydrogeologist) should be provided for the entire term of the project.

f. USAID/Yemen IFP project should be accepted as a substitute for the program element outlined in 4.2.4.

g. A reevaluation of the AP should be made, assuming the USSR study will be one of three levels of quality:

    1. Relatively low addition to information/data on hand.

    2. A large increment of information/data needing moderate amounts of additional field measurements and analyses (this appears to be the alternative upon which the cost estimate presented in the AP was based).

    3. A comprehensive study that allows sufficient data for all analyses for long-term planning to be accomplished with minimal additional work.

The recommended reevaluation should include schedule, budget, staffing needs, and training requirements (as part of the project). Each of these factors should be examined for the alternatives (1-3) above, the recommendations in

sub-sections C.3.1.1(a) through (g) above, plus the institutional requirements discussed in the next section.

Institutional Elements

The AP correctly includes an element of control as part of the long-term water management plan. The thousands of wells operating on an unlimited pumping basis are almost all privately owned. It is logical to attempt to conserve the available ground water by restricting its use through licensing and fees. However, the AP's failure to include the development of an implementation mechanism for the legislation may be its weakest link.

Before any control system can be established, a large data base must be established from the wells operating in the Basin. The licensing system is the first step. However, NWSA, with just a few employees devoted to the task, would probably be unable to implement the recent legislation even with a willing group of well owners. It is safe to say the well owners in the Basin will be extremely reluctant to voluntarily comply with the licensing or fee requirements in the legislation. Resorting to force to implement the legislation would be political suicide, and does not appear to be an alternative the Government would favor.

Voluntary compliance with the legislation is a definite possibility, but one which will take many years to implement. Public opinion must be marshalled to support pumping controls and proper water management practices. The sheikhs, religious leaders, village committees, LDA's, and prominent citizens must all be convinced that controlled pumping is best for the overall community. These points are obvious, but the implementation of a program to actually convince the populace at large is difficult and will take a long time to be fully effective.

Recommendation:

The AP should be reevaluated to include, as a specific work element in the long term project, the establishment of a system to promote voluntary compliance with the new legislative requirements concerning ground water in the Sana'a Basin.

The system should include education campaigns, public meetings, publicity through the media, and discussions with prominent religious leaders, sheikhs, individual large farmers, village committees, and LDA officials. Individuals to be involved could be Peace Corps volunteers, volunteers from other countries, or others whose credibility is high on the village and regional level.

AID/Yemen could help in this process by preparing a work plan for such a project.

APPENDIX E

Other Long-term Options

Two additional AID/Yemen potential interventions mentioned in Chapter 5 were national in character rather than specific to the Sana'a Basin. Because of the significance these projects have to the entire water resources sector, they have been described in detail below.

Ground and Surface Water Monitoring and Data Collection Project Project:

Description of the Problem

Data collected in previous studies may potentially be inadequate to fully describe the ground water dynamics, boundaries, or safe yield of the Sana'a Basin. It is hoped that the current USSR studies will add significantly to the data base. Even if the USSR study produces a comprehensive set of data, they may only provide a detailed snapshot of the ground water conditions, frozen in time--a static view of the situation. What is needed is an on-going data collection and monitoring program that will provide a dynamic view of what is happening in the aquifer(s).

Project Description

Most of the drilled wells in the Sana'a Basin are privately owned. The USSR study is reported to have identified and collected data on over 3,000 wells, presumably of all types. We have little information is available on the methodology or human resources used. But there were strong indications that the study work schedule did not provide time for the development of close personal relations with many well owners. However, the building of trust between farmers and USSR team members was probably not necessary for a short-term data collection program conducted by the USSR team.

The purpose of the project described herein is to collect surface and groundwater data to further expand the present data base. This will be a continuing activity requiring five to ten years of significant inputs by donors. The activity itself is to be operated on a continuing basis by qualified, experienced Yemeni staff after the expatriate staff has left. The interim counterpart YARG institution would be the Department of Hydrology/Ministry of Petroleum and Natural Resources. USAID/Yemen should work in a collaborative mode with the Dutch team now assisting the DOH and support its activities as much as possible.

This project will be a part of a continuing activity that is primarily dependent on getting private well owners to cooperate with the program. A key element for its success will be the building of understanding and trust between the well owners and project field staff. The use of technically qualified expatriates proficient in Arabic is necessary. Thus, USAID/Yemen should examine the possibility of obtaining the cooperation of the Peace Corps, and other agencies willing to provide volunteers fluent in Arabic. The a detailed project description and implementation plan would include determining the collection of information on surface and ground water monitoring and data collection activities being carried on in the Sana'a Basin (or on a national scope including the Sana'a Basin). Project activities would be designed to take advantage of existing monitoring networks and data collected and to support and complement rather than duplicate existing programs.

Without complete knowledge of existing monitoring and data collection programs, it is not possible to estimate the size or cost of this project. At a minimum, the project staffing should include an experienced hydrogeologist capable of designing and managing this activity. The project manager will require support staff to manage an office and interpret and collate the data collected, and technically qualified field supervisor(s) to supervise the work of the volunteers in the field. Anticipated monitoring activities would, at a minimum, include the systematic acquisition of ground water levels, well discharge, and basic field water quality data from each well or discharge point. (The numbers and locations of these monitoring points would be designed by the team hydrogeologists to include an adequate network of representative existing wells. This would allow identification of short and long-term trends or changes in the various aquifers, and provide an information feedback mechanism to support ground water management decisions.) The number of volunteers would be based on the size of the area to be monitored, the number of wells, and the number of field supervisors hired. A group of from six to twelve volunteers is envisioned for the Sana'a Basin. Each professional level staff member and volunteer should work with and train a professional counterpart. (All counterparts should have permanent status in the DOH).

"Farm Club" Training:

Description of the Problem

Practically every person we interviewed, both from the donors' and YARG sides, expressed serious concerns about training. Donor staff uniformly complained about the lack of qualified counterparts and the practically empty applicant pool of qualified candidates for training. On the host government's side, ministry staff complained bitterly about donors not accepting the candidates they nominated, feeling that the standards (e.g. language fluency) were set unrealistically high. Although the two sides view the problem differently, the end result is the same--not enough people are being trained. To address this problem, we recommend instituting a variation of the "farm club" system used by professional sports teams in the US to groom, test, and prepare players for the major leagues in various programs.

Project Description

This training model focuses on building a talent pool rather than on withdrawing candidates from the pool. The basic idea is to recruit students entering the secondary school level, subjecting them to a selection process and then placing them in one of several training/education modules designed to produce well-trained apprentices in a wide range of construction and mechanical trades. In addition to the main focus of providing both theory and practice related to a specific trade, each student will receive instruction in the physical and biological sciences and classes in English during a three to four year program.

A shortened version of this program could be operated in parallel with the above program. In this version, students entering their third year at the secondary level would be recruited, selected, and placed in a "cram" course schedule. These candidates would have had the basic science courses and some level of English fluency to qualify.

Upon graduation, the apprentices would be placed in a wide variety of public- and private-sector jobs to gain practical experience. After one to three years on the job or jobs, the apprentices would become candidates for certificate or university education, thus expanding the now tiny talent pool of candidates qualified for university-level training.

Evaluating the types and numbers of training institutions in Yemen and neighboring countries capable of providing quality skills and basic science training is outside the scope of this assignment. However, the indication is that such institutions do exist. If qualified institutions do not now exist, the project would have to be designed to create adequate training facilities.

Although this training program will take at least two years to produce its first apprentices, and at leas another year for experience, there is no short cut or cut-rate method of producing qualified technicians and university level candidates who have a well documented track records. In the long run, this rigorous selection and training model will weed out the non-performers and reduce the percentage of failures in the more expensive offshore programs. In addition, those who cannot meet the requirements for advanced training will have marketable skills which are in short supply in Yemen, and will be well-positioned to enter the local job market and make a valuable contribution to the country.

APPENDIX F

Bibliography

Bibliography

1. Abu Bakr Ahmed Ba Kader, et al., 1983. Basic Paper on the Islamic Principles for the Conservation of the Natural Environment. International Union for Conservation of Nature and Natural Resources (IUCN) and Kingdom of Saudi Arabia Meteorology and Environmental Protection Administration (MEPA). IUCN Environmental Policy and Law Paper No. 20. Gland, Switzerland.

2. Abel, Christine, 1985. YEM/82/024 - Introduction of Improved Irrigation Methods and Practices in the Sana'a Governorate. Memorandum to File from C. Abel, Assistant Resident Representative, United Nations Development Programme. Sana'a, YAR. April 11, 1985.

3. Althary, M. C., 1983. An Evaluation of Ground Water Potential of the Sana'a Basin, Yemen Arab Republic. Unpublished Master's Thesis. University of Arizona, School of Renewable Natural Resources. Tucson, Arizona.

4. Ansell, Christine, 1980. Domestic Water Use in a Subdistrict of Mahweit Province. Applied Research Report No. 2, ASTC, Yemen. November, 1980.

5. Armstrong, A. T., 1981. End-of-Tour Report, A. T. Armstrong, Journeyman Hydrologist. USAID Project 0025/0043. Contract AID/NE-C-1616. May 16, 1981.

6. Aubel, J., 1985. Verbal Communication. Dar Al Yemen Hydro Consultants. Sana'a, Yemen Arab Republic.

7. Babcock, Melinda, 1979. Bibliography of Water in Yemen. Yemen Minerals and Petroleum Authority. Sana'a, Yemen.

8. Barbarossa, N. L. and D. K. Fuhriman, 1977. Supplemental Report on Water Resources Sector Study in the Yemen Arab Republic. USAID/Sana'a Contract No. AID/NE-C-1389 and 1391, Yemen. August 15, 1977.

9. Bernhardt, C., et al., 1980. Executive Summary and Report - Water Policy Initiatives for Yemen, Recommendations by CID Water Team. CID/Yemen Report 052-1980-1.

10. Boersma, L., et al., 1982. Use of Sewage Effluent for Irrigation of Crops, Sana'a System, Stage One. Cid/Yemen Report 1982-83. Tucson, Arizona. September 1982.

11. Central Planning Organization, Yemen Arab Republic, 1983. Evaluation and Analysis of 1975 Population and Housing Census Concerning Population Distribution and Internal Migration in the Yemen Arab Republic. Sana'a. May, 1983.

12. Central Planning Organization, Department of Statistics, 1984. Population Studies - Population Projections by Sex and Age for the Yemen Arab Republic for the Period 1975-2010. Sana'a. December 1984.

13. Charalmbous, A. N., 1982. Problems of Ground Water Development in the Sana'a Basin, Yemen Arab Republic in Improvements of Methods of Long Term Prediction of Variations in Ground Water Resources and Regimes Due to Human Activity. IAHS Proceedings of the Exeter Symposium,July, 1982. Publ. No. 136.

14. Confederation of Yemen Development Associations, 1981. Preliminary Results for the Co-operative Population Census, YAR. February, 1981.

15. Dubay, L., S. Garabedian, and J. Thiele, 1984. Sana'a Water Resources, Reappraisal. Yemen Arab Republic National Water and Sewerage Authority. November 1984.

16. Grolier, M. J., and W. C. Overstreet, 1978. Geologic Map of the Yemen Arab Republic. USAID/USGS in cooperation with Central Planning Organization, Ministry of Economy, Ministry of Agriculture, and Mineral and Petroleum Authority, YAR.

17. Grolier, M. J., G. C. Tibbits, Jr., and Mohammed Mukred Ibrahim, 1981. USGS Open File Report 80-565. Reston, Virginia.

18. Higgins, David T., 1985. Final Report of David T. Higgins, Study Team Member 30 May - 29 July, 1985, for Irrigation Engineering and Hydrology. Agricultur: Development Support Program, Irrigated Farm Practices Subproject. USAID.

19. Hogan, Edward B., et al, 1982. Yemen Arab Republic Agricultural Sector Assessment, in cooperation with YAR Ministry of Agricultur Repr. 1984. Ref. No. SANAA 2163. 308 pp.

20. Howard Humphreys and Sons, 1983. Hydrogeology and Development of the Tawilah-Mejd Zir Sandstone and Other Sources, Sana'a Water Supply--Phase 2. National Water and Sewerage Authority. Yemen Arab Republic.

21. Howard Humphreys and Sons, 1979. Contract 1A Borehole Drilling--Report on Observation Borehole O2. Yemen Arab Republic National Water and Sewerage Authority. Sana'a Water Supply, Phase 2.

22. Howard Humphreys and Sons, 1979. Contract 1A Borehole Drilling--Report on Exploratory Borehole EX1. YAR, NWSA. Sana'a Water Supply, Phase 2.

23. Howard Humphreys and Sons, 1984. Sana'a Water Supply, Development of Additional Ground Water Resources--A Discussion Document. Surrey, England. 25 January 1985.

24. IBRD, 1983. Yemen Arab Republic Water Supply and Sanitation Sector Memorandum, March 25, 1983. Report No. 3939-YAR.

25. IBRD, 1985. YAR Water Resources Management Sana'a Basin Action Plan.

26. IBRD, Yemen Arab Republic, 1976. Staff Project Report on the Sana'a Second Water Supply and Sewerage Project, December 6, 1976. Report No. 1270-YAR.

27. International Development Association, 1985. Status Report of Economic and Sector Work and of Ongoing and Future Projects, YAR, September 12, 1985. EMENA Country Programs Division 1B.

28. International Development Association, 1979. Yemen Arab Republic: Staff Appraisal Report on the Water Supply and Sewerage Project for Ibb and Dhamar. The World Bank Water Supply and Sewerage Division; Europe, Middle East, and North Africa Regional Office. Report No. 2392a - YAR.

29. Italconsult, 1973a. Water Supply for Sana'a and Hodeida, Sana'a Basin Ground Water Studies, Report, Vol. I. World Health Program No. YEM 507. United Nations Development Program No. Yemen 3203. Doc. No. S10/372/2 YEMEN (3).

30. Italconsult, 1973b. Water Supply for Sana'a and Hodeidah, Sana'a Basin Ground Water Studies, Figures, Vol. II. World Health Program No. YEM 507. United Nations Development Program No. Yemen 3202. Doc. No. S10/372/2 YEMEN (3).

31. Johnson, R. J., 1980. Water Resources Planning and Development Policy Recommendations, YAR. May 14, 1980, Project No. 298-035.

32. Jungfer, Eckhardt, 1984. Water Problems in the Sana'a Basin. Institute for Geography, Erlangen-Norenberg University.

33. Kruck, W., 1983. Geological Map of the Yemen Arab Republic, Sana'a Sheet. FGR Institute for Geosciences and Natural Resources.

34. Lang, Martin, and C. E. Calbert, 1981. Evaluation of Yemen Water Supply Systems Mangement Project. WASH Field Report No. 22. September 1981.

35. Laredo, David, and J. A. McCaffery, 1984. Review of Institutions in the Water and Sanitation Sector in the Near East. WASH Field Report No. 119. July 1984.

36. Layton, Dr. R. F., 1982. Operation and Maintenance Evaluation for NWSA Activities, YAR. January, 1982. AID/Sana'a Contract No. NEB-0028-S-00-2015-00.

37. Leonard, Emily, et al., 1983. Small Rural Water Systems Project Evaluation - The Yemen Arab Republic. October 1983.

38. Maktari, Abdulla M. A. Islamic Water Law, Part I.

39. Ministry of Electricity and Water, 1985. Preliminary Reports for the 1st and 2nd Quarters of 1985. National Water and Sewerage Authority, YAR.

40. Mullick, M. A., 1981. Draft IBRD Report. Environmental Health Promotion and Community Water Supply - Situation Report. March 1981.

41. New Transcentury Foundation, 1984. An Unsolicited Proposal for the Extension of the Yemen Rural Water Project No. 279-0044. Submitted to USAID May 15, 1984. 142 pp, with appendices.

42. Serdahely, S. G., 1981. Office Memo/IBRD. Water Supply Project for Intermediate Cities. September 2, 1981.

43. Swiss Technical Cooperation Service, 1978. Yemen Arab Republic, Final Report on the Airphoto Interpretation Project of the Swiss Technical Cooperation Service, Berne, for Central Planning Organization, Sana'a. Zurich, April 1978.

44. Takhir, Al Kulali, Al Djebali, S. Mukashev, and A. Prokopovich, 1984. Sana'a Basin Water Resources Scheme, Brief Review. YAR Ministry of Agriculture and Fisheries. October 1984.

45. Technical Management Services, Inc., 1981. Comprehensive Long Range Financial Plan - National Water and Sewerage Authority, YAR. USAID Grant No. 279-0028.

46. Technical Management Services, Inc., 1981. Long Range Organizational and Capital Development Plan - National Water Supply and Sewerage Authority, YAR. USAID Grant No. 279-0028.

47. Technical Management Services, Inc., 1981. Comprehensive Long Range Financial Plan - National Water and Sewerage Authority, YAR. USAID Grant No. 279D0028.

48. Technical Management Services, Inc., (undated). Training and Development Plan (1984-1988). USAID Grant No. 279-0028.

49. Tibbits, G. C. Jr., and James Aubel, 1980. Ground-Water Resources in the Amran Valley, Yemen Arab Republic. US Geological Survey Open File Report 80-774. Reston, Virginia.

50. Tutwiler, Richard, 1978. A Report on Small Water Projects in Yemen: Aspects of Social Impact and Recommendations for Future Actions. USAID Contract No. AID 279-78-414.

51. Tutwiler, Richard and Christine Ansell, 1980. Social Aspects of Water Distribution and Consumption in a Sub-District of Mahweit Province. American Save the Children/Yemen. February 1980.

52. UNDP, 1985. Development Cooperation Report for the Year 1984- Yemen Arab Republic. Sana'a, YAR. July, 1985.

53. USAID, 1985. FY 1987 Country Development Strategy Statement. USAID/Yemen Sana'a, Yemen Arab Republic.

54. USAID, 1985. Economic Report on YAR, August, 1985. Prepared for A/NEB by J. A. Manarolla.

55. USAID, 1985. Draft Subproject Authorization Report, Agriculture Development Support Program, Irrigated Farm Practices Subproject. USAID Project 279D0052.

56. USAID, 1984. Irrigated Farm Practices Paper, Title XII Agriculture Development Support Program, AID Project 279-0052, Yemen Arab Republic. USAID Project Identification Document (PID), Sana'a, YAR, 266 pp.

57. USAID, 1979. Baseline Field Study Report. Prepared by CID Design Team.

58. Varisco, Daniel M., 1982. The Adaptive Dynamics of Water Allocation in Al-Ahjur, Yemen Arab Republic. Ann Arbor, Michigan, 1982.

59. Varisco, D. M., 1982. Sayl and Ghayl: The Ecology of Water Allocation in Yemen. Accepted for Publication in: Human Ecology.

60. Varisco, D. M. (undated). Land and Water Resources (YAR).

61. Varisco, D. M. et al., 1984. A Social and Institutional Profine of the Yemen Arab Republic. American Institute for Yemeni Studies. N. Illinois University. AID/Sana'a Contract No. NEB-0035-C-00-2085-00.

62. World Health Organization, 1981. Yemen Arab Republic, Water Supply an Sector Study. World Health Organization/World Bank Cooperative Programme. Geneva, Switzerland.

63. World Health Organization (undated). Rapid Assessment Report - Yemen Arab Republic.

64. WRAY 1 Report, Hydrology and Hydrogeology of the Yeman Arab Republic compiled under Dutch Aid, as directed by D.C. Van Enk, and J.A.M. VanDerGun. August 1984.

65. Zohra, Merabet, 1980. A Survey on Development and Management of Water Resources in the Yemen Arab Republic. By German Volunteer Service in the YAR, Occasional Papers No. 1. Sana'a, Yemen.

66. Zohra, Merabet, 1980. A Survey of Water Activities Under Foreign Assistance in the Yemen Arab Republic. USAID/Yemen Contract No. 279-80-589.