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# **WATER POLICY INITIATIVES FOR YEMEN**

## **RECOMMENDATIONS BY CID WATER TEAM**

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CONSORTIUM FOR INTERNATIONAL DEVELOPMENT  
Tucson, Arizona  
Project 052 - Yemen  
Field Office in Sana'a, Yemen  
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# EXECUTIVE SUMMARY

## WATER POLICY INITIATIVES FOR YEMEN

### RECOMMENDATIONS BY CID WATER TEAM

C. BERNHARDT    R. GRIFFIN    R. HAWKINS,    D. HENDRICKS    M. NORVELLE

#### 1. BACKGROUND

The project, upon which this report is based, was outlined by the USAID Mission Sana'a at the request of the government of the Yemen Arab Republic. Subsequently, the Mission, in cooperation with the Government, prepared the terms of reference, and arranged for a water resources management design team through contact with the Consortium for International Development. The Team arrived in Yemen on August 13 and departed beginning September 11, 1980.

#### 2. TERMS OF REFERENCE

The terms of reference are summarized as the following tasks:

- (1) Review existing water resources studies.
- (2) Outline additional studies required for a comprehensive picture of the Yemen water situation.
- (3) Delineate a procedural framework for development of a Yemen Water Plan.
- (4) Recommend a national water policy.
- (5) Recommend emergency statutes for control of groundwater.
- (6) Review agricultural water management practices.
- (7) Review watershed management practices.
- (8) Provide programmatic recommendations for a long-range water resources development and management program for YAR.

#### 3. ORGANIZATION OF EXECUTIVE SUMMARY

The salient findings, conclusions, and opinions resulting from the study are enumerated under the section headings which follow.

#### 4. WATER RESOURCES OVERVIEW

- (1) The native water supply of Yemen, occurring as surface runoff in wadis and recharge to aquifers, is scanty. An appropriate index is annual rainfall, which is less than 200 to 400 mm over much of the country. An exception is the mountain highlands near Ibb, which may have rainfall in excess of 1,000 mm.
- (2) The arid character of the country limits the prospects for development of new water supplies.
- (3) Surface water flows in the wadis of Yemen have been fully appropriated for centuries by the practice of spate irrigation. Only a few flood events escape total diversion to irrigated lands.
- (4) Surface water storage sites exist in many of the mountain canyons. While it appears doubtful that a significant amount of new water would be developed, the feasibility should be investigated. This should be examined also in terms of using storage to permit more efficient irrigation scheduling.
- (5) Conjunctive use of groundwater with surface flood flows could permit improved scheduling of irrigation. Probably higher crop yields would result.
- (6) Overpumping of groundwater is causing rapid decline of water tables in some regions of Yemen. Since groundwater is the major source of domestic water supplies, its protection is imperative.
- (7) Groundwater basins must be developed and managed on a sustained yield basis.
- (8) Because water is a rate limiting factor, i.e., there is not enough to meet all demands, water has a strategic role in the social and economic metamorphosis now occurring in Yemen.
- (9) Resolution of water problems and conflicts must come through adoption and implementation of a national water policy. The policy must provide for allocation of amounts, setting priorities in use, effective administration, and development of institutions for meeting management objectives.



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## 5. STATUS OF EXISTING KNOWLEDGE

- (1) About 46 water oriented project studies have been completed throughout the country and were reviewed.
- (2) The first reports began to appear about 1970.
- (3) Comprehensive water resources planning studies have not been undertaken as yet.

Water resources data are generally sparse and of short duration. Data collection networks have only recently been established.

## 6. WATER PLANNING

- (1) Water management regions for Yemen should be defined. They should conform to hydrologic boundaries where possible.
- (2) The basic procedural framework for planning should address the questions: How much water exists? What are the projected demands? What plans are feasible?
- (3) As a basis for planning, regional framework studies should be developed. Reports should result as follows:
  - Volume 1 - Regional Background Information
  - Volume 2 - Water Resources
  - Volume 3 - Municipal-Industrial Water Demands
  - Volume 4 - Agricultural Water Demands
  - Volume 5 - Projects Existing and Proposed
  - Volume 6 - System-Wide Planning Matrix
- (4) A regional water plan should be prepared for each region, based upon the results of the respective framework studies.

## 7. NATIONAL WATER RESOURCES POLICY

- (1) Premises
  - Strong local governments exist
  - Demands for water are increasing
  - Water is a limiting factor
  - There is a sparse cadre of water professionals
- (2) Policy:
  - Water is a public resource
  - There should be continuity with Islamic legal doctrine and tradition
  - Water resources should be managed toward objectives of economic efficiency, and assurance of domestic supplies
  - Management of groundwater should be on a sustained yield basis
- (3) Recommendations:
  - A water resources council should be formed
  - Regional water commissions should be formed
  - Leadership and coordination is a national government responsibility
  - Responsibility for execution should be at regional and local levels
  - Institutional adjustments may be necessary
  - Education and training to develop a strong cadre of water professionals is needed
  - Extension services and demonstration activities at the local level is advocated
  - Enactment of statutes should be paced in time

## 8. GROUNDWATER POLICY

- (1) Premises:
  - Excessive overdraft will damage an aquifer
  - Pollution of an aquifer is essentially irreversible
  - Seawater intrusion is essentially irreversible
- (2) Policy:
  - Groundwater should be managed as a renewable source
- (3) Recommendations:
  - Groundwater basins should be identified
  - Groundwater basins should be managed at the regional level
  - Metering of all groundwater withdrawals should be mandatory
  - Permits should be required to drill a well
  - An operating permit should be required to pump water from a well
  - Emergency controls should be enacted for the Sana'a basin, Taiz, and Hodeida and for any other areas in which domestic water supplies are in jeopardy from over-pumping of aquifers
  - Implementation of the comprehensive policy should be paced over time
  - Public education programs should be coincident with implementation

## 9. URBAN WATER

- (1) Premises:
  - Several urban areas in Yemen are growing at a rapid rate due to migration from rural areas. If continued this may cause severe stress on urban services. Water is likely to be one of the services so stressed and it could be a limiting factor for some cities.
- (2) Policy:
  - Whenever water supply is provided to individual houses, drainage is necessary at the same time. The drainage system need not be sewerage if the wastewater is only "gray water", i.e. from bathing, laundry, etc.
  - Water carriage of human excreta is very capital intensive. Traditional or other non-water carriage methods should be considered as alternatives for towns and villages, and perhaps even for portions of some cities.
- (3) Recommendations:
  - Planning criteria for water services should be studied for cities, towns and villages. Per capita water use, rate structures, financing plans, types of institutions, water service levels, sewerage service policy, etc., should be ascertained.

## 10. ON-FARM WATER USE MANAGEMENT

- (1) Premises:
  - Traditional Yemen spate irrigation practice is inefficient compared to other methods of water distribution.
  - Traditional irrigation practice relies upon an irregular and uncertain water system
  - Unit area agricultural production is comparatively low due to use of traditional spate irrigation systems and other farm practices
  - The recent introduction of modern pumping equipment has led to an expansion of cultivated area instead of regularizing irrigation water supply and has contributed to a continuing low level of production
- (2) Policy:
  - Traditional upland terrace systems are about as efficient as possible
  - Surface and groundwater should be managed conjunctively for a regularized irrigation supply
  - Irrigation water application rates should be determined and applied according to crop requirements
  - Associated agricultural practices and production techniques should be employed to maximize unit area production and water use efficiency
- (3) Recommendations:
  - Demonstration farms should be developed to promote proper utilization of irrigation water and associated cultural practices
  - Extension and education programs should accompany the demonstration farm program

## 11. WATERSHED MANAGEMENT

- (1) Premises:
  - Yemen's land and vegetative coordination has evolved under natural and man caused conditions. Much land has been eroded already, but presently the landscape is stable.
  - The well developed terrace system comprises a major agricultural and capital resource, a hydrologic buffer, and a basis for the agricultural society. Terrace maintenance is needed for national agricultural production, social well-being and for hydrologic stability.
  - Runoff from mountain land is essential as the irrigation water supply for downstream low lands.
- (2) Policy:
  - Terrace maintenance is potentially the most important watershed management concern at the national level.
  - Traditional watershed management activity should be on a multiple use basis, with accent on production.
- (3) Recommendations:
  - Development of the necessary information, data, and experience base should be undertaken.
  - Demonstration, extension, and education activities are needed
  - A national watershed action program should be formulated



## 12. YEMEN WATER PROGRAMS

Some key elements of a Yemen Water Program include:

- (1) Development of regional water plans,
- (2) A legislative program enacted over a period of years,
- (3) Development of altered institutional forms,
- (4) Demonstration of improved farm water management practices, focused on conjunctive use of groundwater with surface flow flows,
- (5) Development of a national watershed management plan,
- (6) Development of a professional cadre to B.S. and M.S. degree levels including two-year internships in water engineering practice, and
- (7) Development of public education programs to reach local leaders and the population concerning the realities of their local water situation, and the steps the government is taking to promote a balance between supply and demand.

Program elements and associated projects are enumerated in Figure 1 following. The role of each program element in terms of societal goals, and the objectives of the element are seen also. Suggested donor country projects are listed as they may fit into the government projects.

SOCIETAL GOAL	PROGRAM ELEMENT	OBJECTIVES	PROJECTS OF YEMEN GOVERNMENT	POSSIBLE DONOR COUNTRY PROJECTS
Provide for domestic needs and increase agricultural productivity	1 Local Projects Short Term	Alleviate most acute local problem	Wadi Jawf storage diversion dam feasibility study Wadi Jawf village water supply improvement through well construction Wadi Jawf bank protection study	1 Reconnaissance study of Wadi Jawf relative to short-term projects
	2 Water Planning	Determine best combination of projects and measures to achieve supply-demand fit	1 Regional supply-demand studies 2 Regional planning studies 3 Implementation of measures and projects	1 System water planning methodology demonstration for Sana'a Basin six-volume report 2 Input-output methodology demonstration for Sana'a Basin 3 Planning for supply-demand balance for Sana'a Basin
Protect public health	3 Pollution Control	Eradicate waterborne diseases	1 Identification of water related health problems 2 Water supply quality control	1 Epidemiological survey of Yemen for waterborne diseases 2 Design of country-wide strategy for wastewater management
Provide for domestic needs and increase agricultural productivity	4 Water Policy	Provide basic guidelines for management of water resources for Yemen	1 Water Resources Council 2 Regional Water Commissions 3 National Water Policy Act	1 Advice on drafting statutes 2 Coordination of donor activities with WRC
Maintain usefulness of aquifers in perpetuity	5 Groundwater Management	Manage groundwater withdrawals for sustained yield	1 Groundwater management policy act 2 Emergency groundwater statute	1 Advice on drafting statutes
Increase agricultural productivity	6 Surface Water Development	Find opportunities to both increase available water supply and provide for more effective utilization in time	1 Survey feasibility of surface water storage projects	1 Hydrologic analysis of wadi flows, diversions, role of storage
	7 On-Farm Water Management	Conjunctive use of surface and groundwater for meeting crop water requirements and achieve more equitable allocation of water	1 Demonstration farm - Wadi Surdud 2 Demonstration farm - Wadi Jawf	1 Hydrologic analysis of water application efficiencies 2 Demonstration farm - Wadi Surdud. Qumeisha Project is a possible site 3 Demonstration farm - Wadi Jawf
Maintain role of terraces in agricultural productivity	8 Watershed Management	Preserve terraces and provide for revegetation of uplands	1 Range and field revegetation of uplands 2 Condition-trend census to ascertain time trends in terraces condition 3 Background information study of terraces as basis for an action program 4 Action plan development for terrace preservation 5 Adoption of national watershed plan	1 Foundation information for development of action plan 2 Historical survey of terraces
	9 Institutional Development	Develop water management capabilities to implement national water policy	1 Codification of water rights principles 2 Codification of regional water rights structure; institutions recommendations for municipal-industrial water management 3 Institutions modifications for irrigation water management 4 Regional water commissions role and functions	1 Study of water rights and recommended modifications 2 Study of organization needs and recommended structures, financing
Provide for domestic and industrial needs and increase agricultural productivity	10 Professional Cadre	Develop cadre of water professionals to plan and manage utilization of water resources	1 Develop cadre of water professionals as a 20-year project 2 Develop professional leadership capacity of University in Sana'a 3 Develop professional organizations	1 Manpower needs study 2 Lectureships and short courses on water in collaboration with University
	11 Public Education	Influence support of local leaders and public in implementing water policy	1 Extension service development 2 Government program to raise public consciousness about water	1 Expatriate staffing of extension positions in collaboration with Yemeni professionals 2 Expatriate advice on public communication programs
	12 Research	Explore all possible ways to handle water problems	1 Weather modification appraisal	1 Reconnaissance survey of weather modification potential

Figure 1 Elements and projects of Yemen water program.

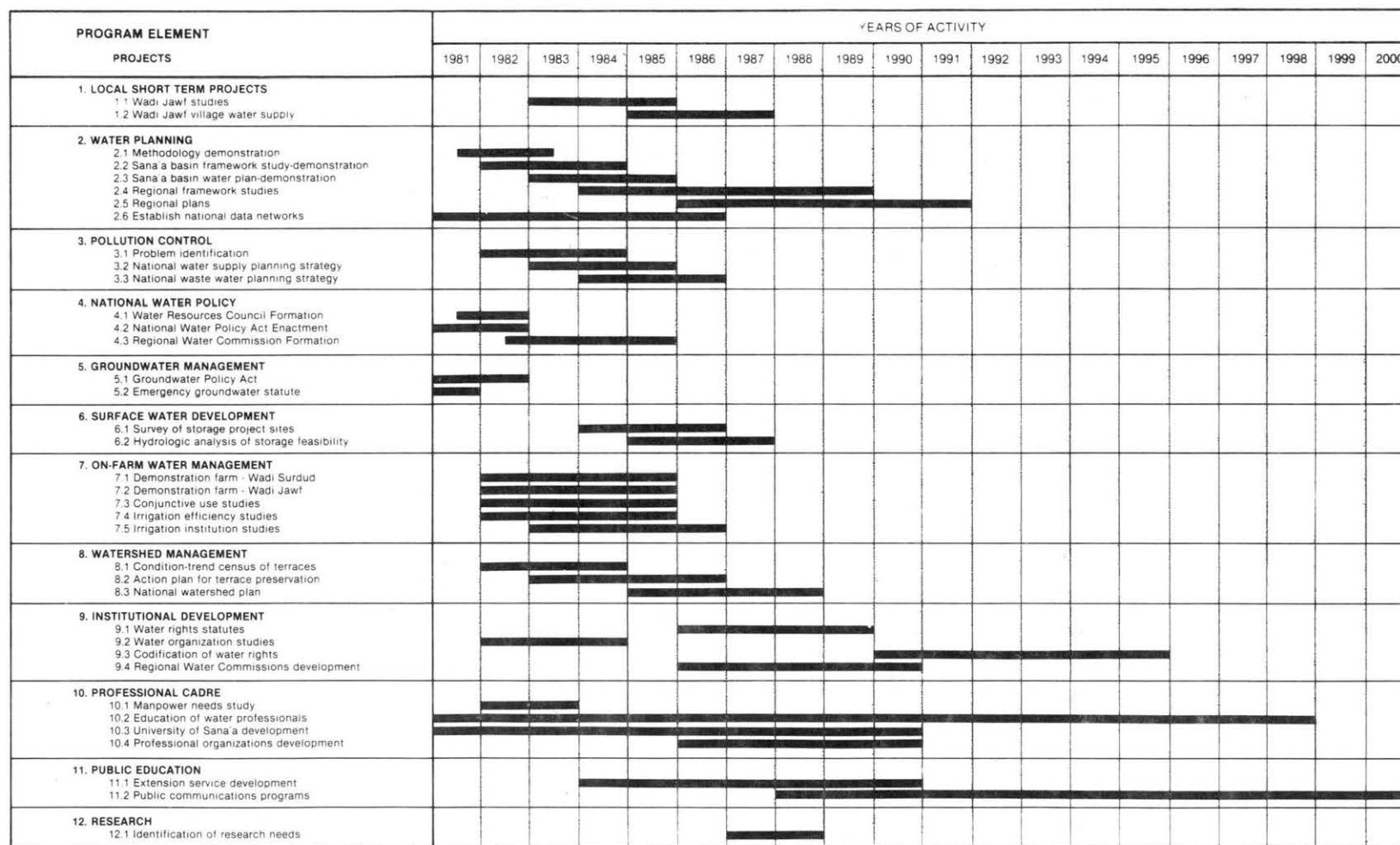


Figure 2 Tentative implementation schedule for elements of Yemen water program.



# **WATER POLICY INITIATIVES FOR YEMEN**

## **RECOMMENDATIONS BY CID WATER TEAM**

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Dr. Ed Weber and Dr. Barry Bainton of CID organized the team for the study. The Director of CID is Bernard G. Henrie.

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Dr. Dirhem Amin Noaman	Major General, Governor and Commander-in-Chief Al-Jawf Marib Area

## ORGANIZATIONS

AWRP	Agricultural Water Resources Project
YARG	Yemen Arab Republic Government
YOMINCO	Yemen Oil and Mineral Corporation
DOH	Department of Hydrology
TDA	Tihama Development Authority
SURDP	Southern Uplands Rural Development Project
ACAM	Authority of Civil Aviation and Meteorological Organization
MPW	Ministry of Public Works
WMO	World Meteorological Organization
NWAS	National Water and Sewerage Authority
CARTO	Central Agricultural Research and Training Organization
COP	Central Planning Organization
LDA	Local Development Authority
YGEC	Yemen General Electric Corporation
RWSD	Rural Water Supply Department
CID	Consortium for International Development

## PREFACE

The idea for this study was germinated during discussions between His Excellency, Abdul Aziz Ghani, Prime Minister of the YAR, and His Excellency George Lane, U.S. Ambassador to the YAR concerning the critical role of water in the economic development of the country. The context of the dialogue related to the present rapid rate of groundwater exploitation by private parties, the growing economic expectations of the people, and the realization by the government that long-term planning and management of water resources is necessary. From these discussions, water management in the YAR was given high priority in the U.S. technical assistance program.

Subsequently, a request for technical assistance was issued by the Ministry of Agriculture of the YAR to the USAID Mission Sana'a. The mission responded through the auspices of its contractual arrangement with the Consortium for International Development (CID), i.e., the Title XII Project 279-0052. The Mission, in cooperation with the Ministry of Agriculture of the Yemen Arab Republic, then drew up the terms of reference for the ensuing project for the CID. The CID selected a five-person team comprised of the authors, to execute the project.

The tasks assigned to the CID water team are summarized as follows:

- (1) Review the status of information pertaining to Yemen's water resources.
- (2) Recommend the additional studies required to form a complete and comprehensive picture of the water resources situation in the Yemen Arab Republic.
- (3) Recommend a water planning procedure to provide a comprehensive picture of the water resources situation.
- (4) Assist the Ministry of Agriculture in drafting a comprehensive national water resources policy.
- (5) Assist in the preparation of emergency regulations to bring currently rapid groundwater depletions under control.
- (6) Recommend avenues for interagency coordination.
- (7) Recommend watershed and on-farm water management practices for adoption in the Yemen Arab Republic.
- (8) Suggest programmatic recommendations for long-range water resources development and management.

The importance of these tasks was reinforced during discussions between the team and officials of the government. In addition, the government asked the team to consider making recommendations for projects having promise of near-term implementation. The government was concerned in particular with the development of Wadi Jawf.

The time for the study was 30 days. During this period, the Team discussed the Yemen water situation with various government agencies and organizations, reviewed reports, and toured portions of the country to glean a first-hand perspective. The report was written in draft form prior to departure on September 11. Copies of this draft were circulated to various parties in Sana'a for review. The team met in Las Vegas on September 26, 27 and 28 to consider and incorporate these comments in the report, and make their revisions as necessary. The report was then edited through the month of October and a portion of November for organization, consistency, and style.

The agencies visited included the Ministry of Agriculture and its Irrigation Division, the National Water and Sewerage Authority (NWSA), and the Yemen Oil and Mineral Corporation (YOMINCO), and its Department of Hydrology (DOH). Contracts were also established with various donor programs and private interests engaged in Yemen water resources development such as the U.S. Peace Corps, TransCentury Corporation, UNDP, American Institute of Yemeni Studies and private well drilling companies. The field trips included visits to the Tihama coastal plain, the southern highlands, and Wadi al-Jawf.

Through these activities, we addressed the tasks outlined in our charge. The overall theme of the report is to provide government with policy direction in the areas outlined.

CID Water Team,  
Sana'a, Yemen Arab Republic  
September 11, 1980

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## **1. PREMISES OF STUDY**

## 1. PREMISES OF STUDY

### 1.1 BACKGROUND

The people of the Yemen Arab Republic are in the throes of economic and social change. Since 1962, and particularly since early 1970's, the society has been in transition from traditional to modern. The latter implies greater emphasis upon education, technology, and economic development with all of the concomitant expectations and aspirations toward improved social well being.

Water is central to this social and economic development. But there is not enough, in absolute country-wide terms, to satisfy existing and future demands. With this situation, it is imperative that the country have a comprehensive water policy.

### 1.2 PURPOSE

The purpose of this report is to provide a policy development reference document for officials of the Yemen Arab Government who are responsible for developing water policy in all of its facets. The basic themes are to assess present water resources information and practices in water use, and then to outline what ought to be done in water planning and management.

### 1.3 OBJECTIVES

The overall objective of this report is to provide suggestions for the development of a comprehensive national water policy. The following are specific areas to be addressed:

- (1) Water resources information in Yemen.
- (2) Gaps in water resource information.
- (3) Water planning methodology.
- (4) National water policy provisions.
- (5) Emergency groundwater regulations.
- (6) Watershed management practices.
- (7) On-farm water use practices.
- (8) National water program.

### 1.4 SIGNIFICANCE

The exploitation of groundwater in Yemen has been occurring over the past decade at a rapid rate due to the utilization of modern pump technology. At

the same time, surface water supplies have been committed fully through centuries of spate irrigation. The other major form of water utilization, rain-fed agriculture, is practiced on an extensive system of ancient terraces.

The exploitation of groundwater is the most serious and immediate problem. Unless this is brought under control quickly, it is quite likely that permanent damage to the affected aquifers will occur. In addition, the limited water resources must not be so over-committed that options are foregone for development of future national interests. Also, there needs to be an appraisal of irrigation practices with respect to the potential for increased economic output. With the rain-fed terrace agriculture, there are two concerns. First, is there potential for increased revenues to the farmers and to the country? Second, if the terraces are neglected due to more attractive employment of labor in nonagricultural pursuits, what might be the consequences in terms of stability of the watersheds?

Thus, Yemen is in the midst of change in which water is a limiting factor. A comprehensive national water policy is needed to guide the planning and management of the water resources of the country such that the needs of the country are met in accordance with its social goals.

### 1.5 METHOD

The main thrust of our activities was focused upon achieving a certain level of understanding of the Yemen water situation and its social-political context. The activities included: (1) discussions with government officials and various persons knowledgeable about the Yemen water situation, (2) review of consultant reports and other literature, and (3) field trips and tours to gain first-hand impressions about water management practices.

The above activities provided the basis for understanding the context in which to address the tasks enumerated above. Thus, the policy suggestions were designed to fit the social-political-physical context of the country. To do this, the team members drew upon their knowledge of water policy and water management practices in the United States and elsewhere.

## **2. GEOGRAPHY**



## 2. GEOGRAPHY

Water planning is inextricably associated with geography in all of its various facets--physical, political, hydrologic, economic, etc. To aid and develop the water-oriented geographic picture of the Yemen Arab Republic, a series of maps are shown in Figures 2-1 through 2-6. These maps show, respectively: topography, physiographic regions, rainfall, wadis, agricultural land, and provinces.

To complement the maps, a set of photographs are included as Figures 2-7 through 2-14. The captions explain the themes. Collectively they provide a pictorial perspective of the country relative to its' water situation. The sections that follow summarize very briefly some of the major facets of geography as related to water resources availability and use. A great deal of the narrative is constructed verbatim from the Final Report on the Air Photo Interpretation Project of the Swiss Technical Cooperation Service and the Central Planning Organization of Yemen (1978), called hereafter the "CPO Swiss Report."

### 2.1 LOCATION

The Yemen Arab Republic is located in the southwestern corner of the Arabian Peninsula. To the west, the country is bounded by the Red Sea, in the north, Yemen adjoins the Kingdom of Saudi Arabia, while in the south, is the People's Democratic Republic of Yemen, commonly called South Yemen. The Yemen Arab Republic is often called North Yemen, and in this report both the terms Yemen and YAR will be used synonymous with Yemen Arab Republic. Some of the boundaries of the country toward the east, with both Saudi Arabia and South Yemen, have not been officially demarcated.

### 2.2 PHYSICAL GEOGRAPHY

An overall topographic relief of the country is seen in Figure 2-1, a satellite photograph. The CPO Swiss Report (1978) has established several physiographic divisions for the country, which are shown in Figure 2-2. This map shows the country divided into three major hydrographic regions: the Western Escarpment, the Eastern Escarpment, and the Southern Escarpment. The designated zones within each of these escarpments are categorized by elevation and are named in Table 2-1, and are identified in the map, Figure 2-2. The area of each of the zones is indicated along with the area for each escarpment, giving a total area for the country of 135,200 sq km. It should be noted that the western lowlands of the Western Escarpment is more commonly called the Tihama Plain.

### 2.3 CLIMATE AND VEGETATION

The climate in Yemen is determined by the country's geographic location and by its' topography, which rises from sea level along the Red Sea to an elevation of 2,700 meters within a distance of only 100 km. From May to September, the climate is mainly influenced by moist air masses of the monsoon circulation systems, which flow from the southwest

against the Yemen highlands and cause heavy precipitation on the mountain slopes exposed to the west, mainly above 1,500 m. From October to February, dry masses, originating in the Central Asian anti-cyclone, are the main reason for the clear and rainless winter season. Figure 2-3 shows the rainfall distribution over the country by month. As noted, the main precipitation occurs in the area of Ibb and on the exposed slopes of the Western Highlands, which dropped abruptly to the Yemen Plain. Most of the rainfall occurs as very heavy localized showers in the afternoon, which are usually confined to limited areas. The frequency and intensity of the rainfall decreases on the lee side of the Western Highlands, the Central Highlands, and the Eastern Escarpment.

In general two rainfall seasons can be distinguished in the country. The first peak occurs in March or April. In May and June the rainfall decreases. The second and usually the strongest rains, start in July and last until September. Usually the weather is extremely dry from November to February, with the exception of Ibb.

Table 2-2 designates the major climatic zones of the country and also shows the average annual rainfall for each zone. Since long-term climatic data are not available, the numerical data shown should be considered as order of magnitude only.

### 2.4 WATERSHEDS

The major wadi drainages of Yemen are shown in Figure 2-4. The drainage areas of each is seen in Table 2-3.

The Western Escarpment has seven major wadis. They all drain westward to the Tihama. For most of the year only small streamlets run into the wadi beds, or they may dry up entirely. In March through April and again from July to September, several heavy floods normally occur along the whole length of the wadi sources. The farmers build earthen barages in the middle of the wadi beds to divert the flood waters onto cultivated lands, irrigated by the ancient practice of spate irrigation. If the rainfall is unusually heavy within the whole catchment area, the floods may be large enough to reach the coast of the Red Sea; but this occurrence is exceptional.

The gradients of the wadis of the Eastern Escarpment are smaller and the precipitation in the inter-regions of the country is less intensive and does not occur with the same seasonal regularity as on the rain exposed Western Escarpment. But the catchment areas are larger and thus the floods may cause inundation of large areas for long periods. In ancient times, earthen dams at Marib and Jawf made possible cultivation of large areas in these regions. Since the Sixth Century A.D. the dams have been broken and the population of this area has diminished considerably.

In the Central Highlands, drainage is not always connected with the large wadi systems. The rainfall

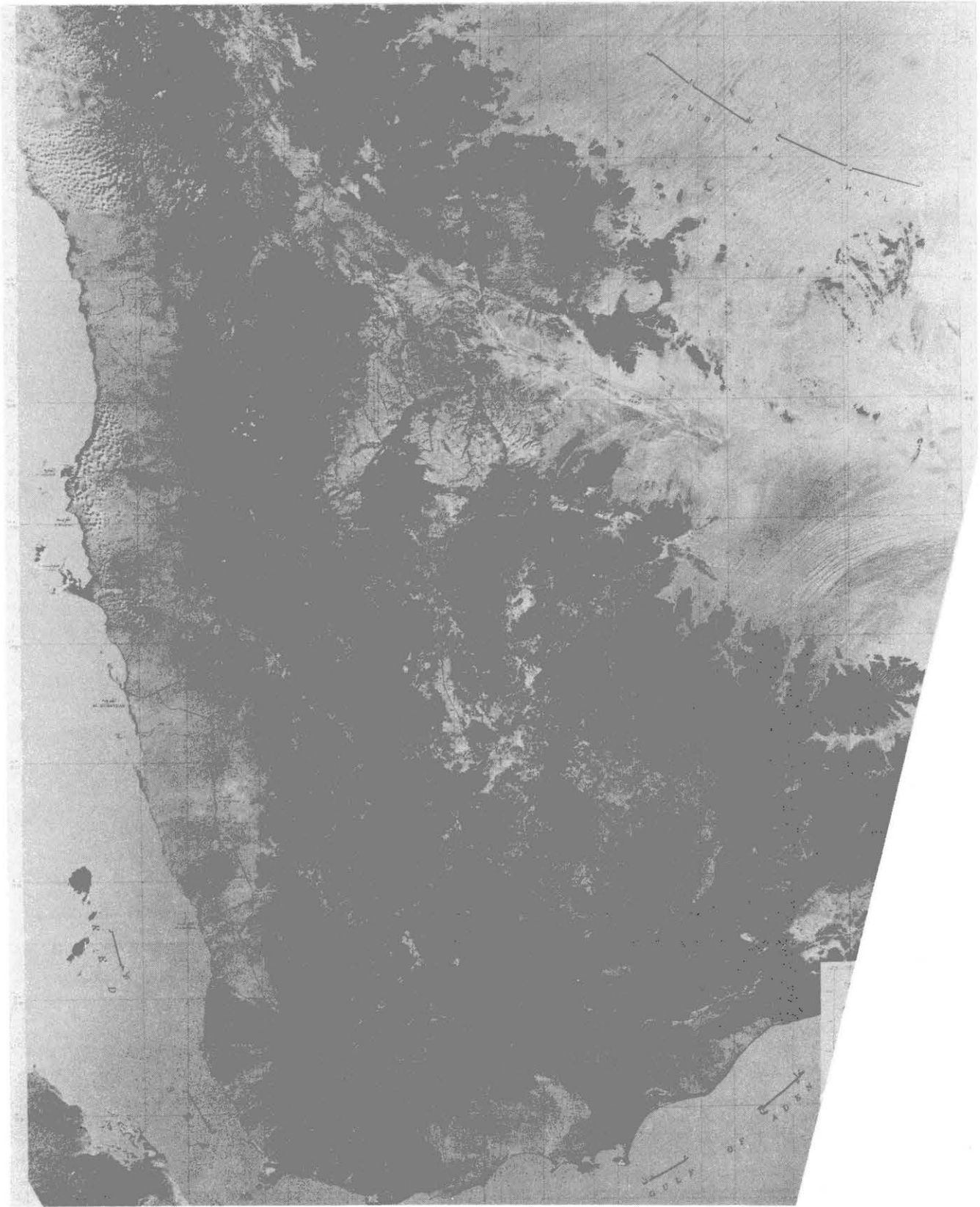


Figure 2.1 Satellite photograph of Yemen. (Taken from satellite imagery prepared by U.S. Geological Survey in cooperation with the Central Planning Organization, 1978)

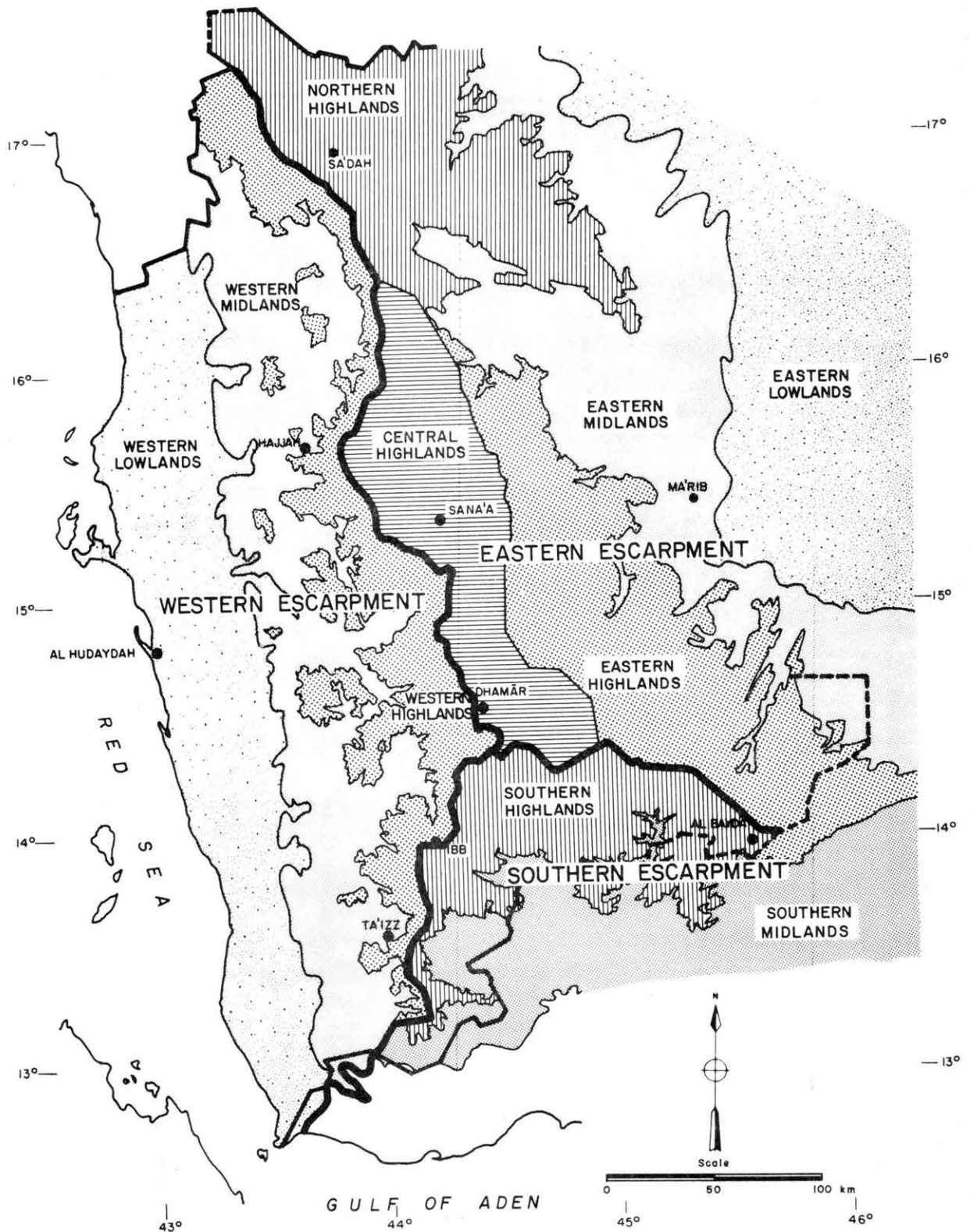


Figure 2.2 Physiographic regions of Yemen Arab Republic (adapted from CPO Swiss Report, 1978).

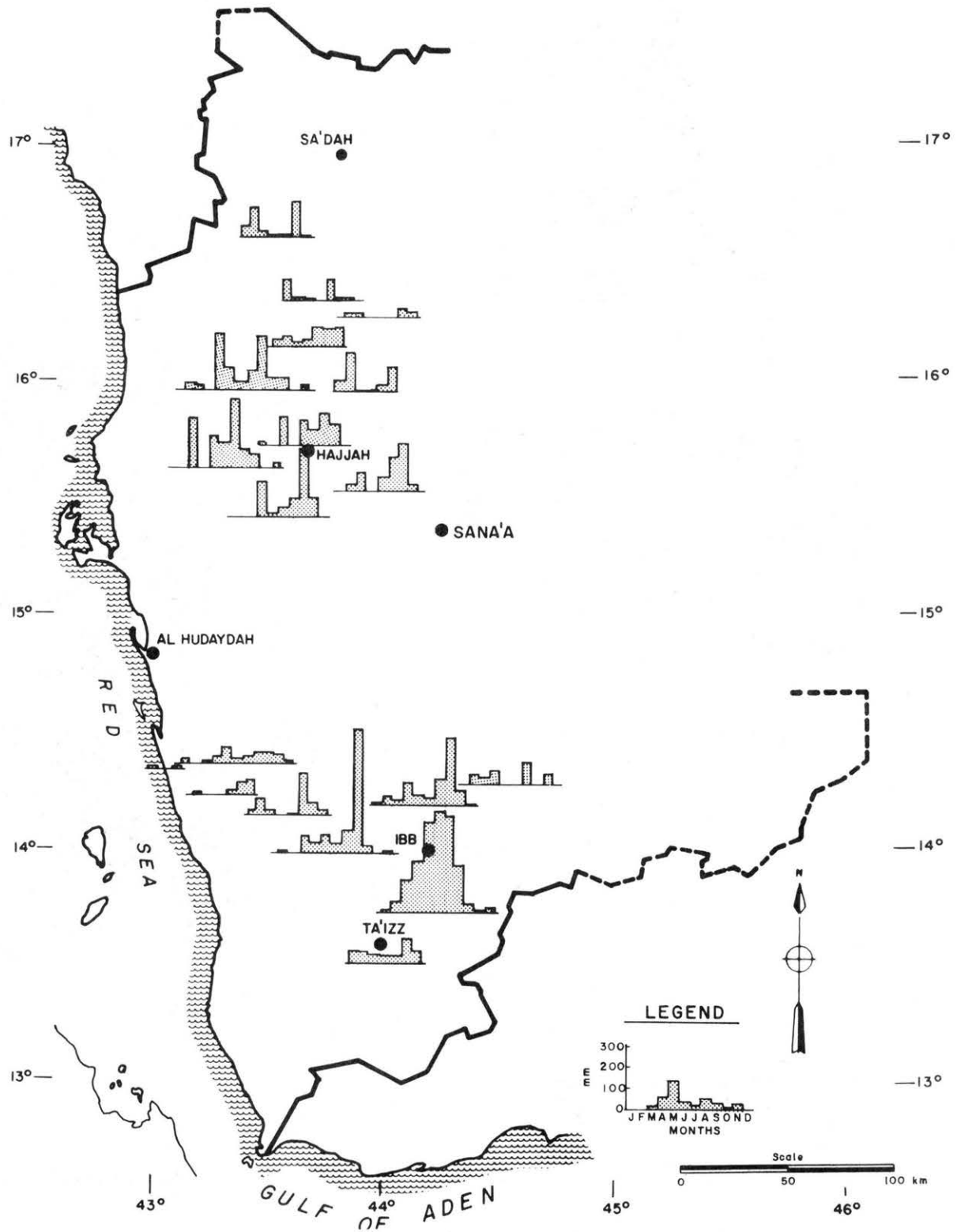


Figure 2.3 Rainfall by months in the Yemen Arab Republic (adapted from CPO Swiss Report, 1978).

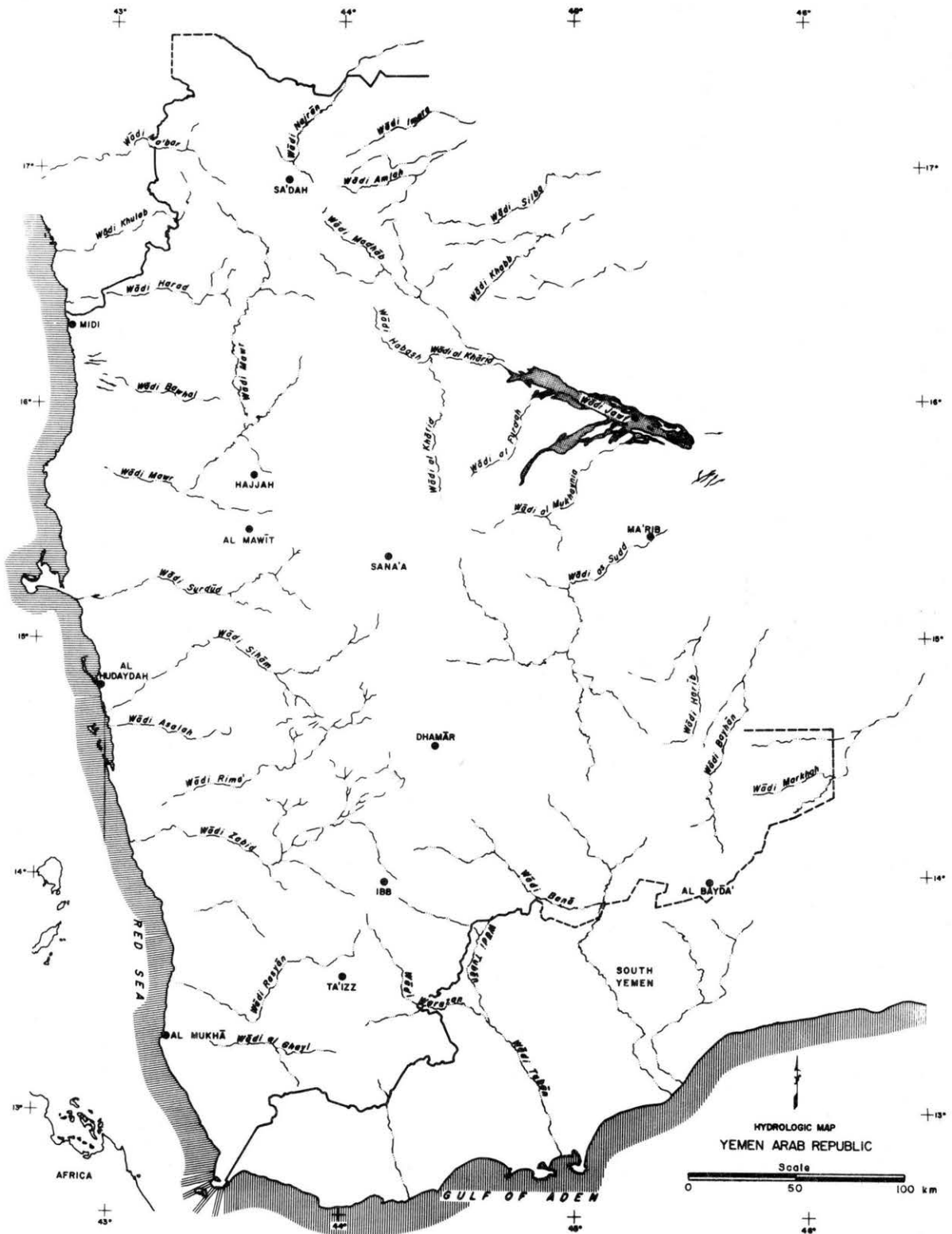


Figure 2.4 Major wadies in the Yemen Arab Republic (adapted from "Land Use in the Yemen Arab Republic," 1:500,000 maps by Swiss Technical Cooperative Service and CPO, Sana'a, 1977).

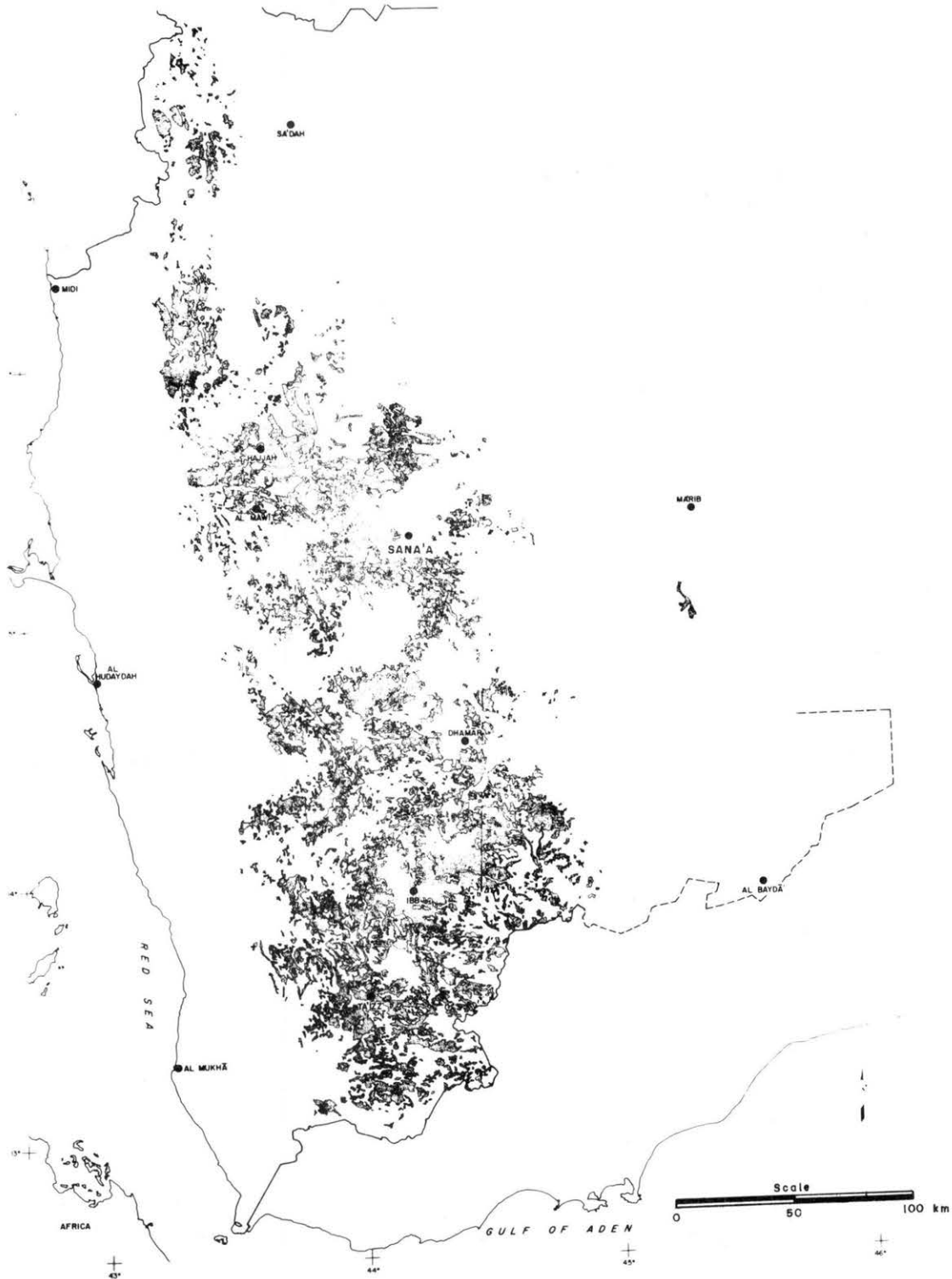


Figure 2.5 Terraced rainfed agricultural lands, Yemen Arab Republic (adapted from "Land Use in the Yemen Arab Republic," 1:500,000 map by Swiss Technical Cooperative Service and CPO, Sana'a, 1977).



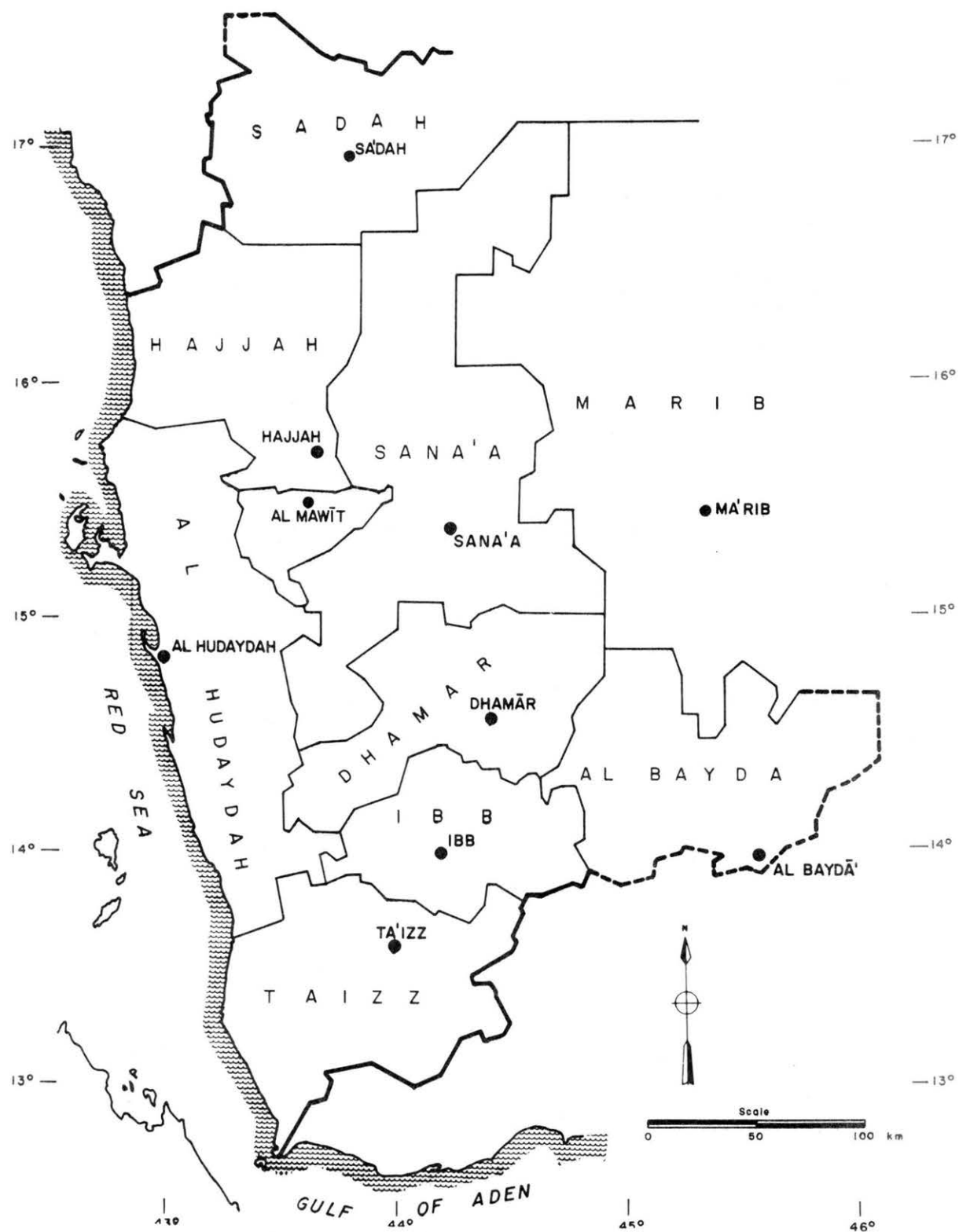


Figure 2.6 Provinces of Yemen Arab Republic (adapted from CPO Swiss Report, 1978).



Figure 2.7 Wadi Surdud, Tihama Plain.



Figure 2.8 Typical Carryon in mountains east of Tihama Plains near Hodeida.



Figure 2.9 Canal diversion to spate irrigated fields, near Wadi Surdud.



Figure 2.10 Modern diversion structure at Wadi Zabid.



Figure 2.11 Village near Sana'a.

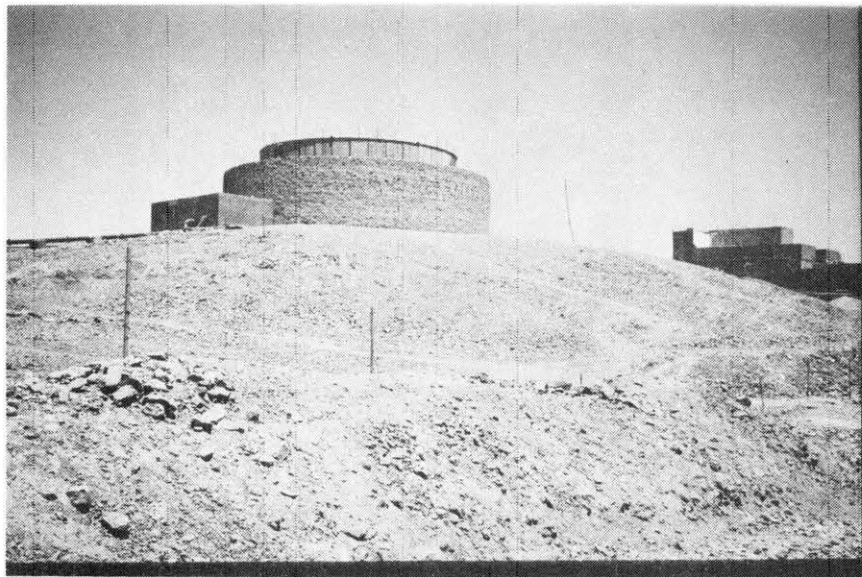


Figure 2.12 Water service storage for villages. A well in the Wadi alluvium below supplies the tank; the plumbing lift may be 500 to 1000 meters. The tank is the distribution point for several villages 1 to 5 km in distance. Village water supply, Ministry of Agriculture.

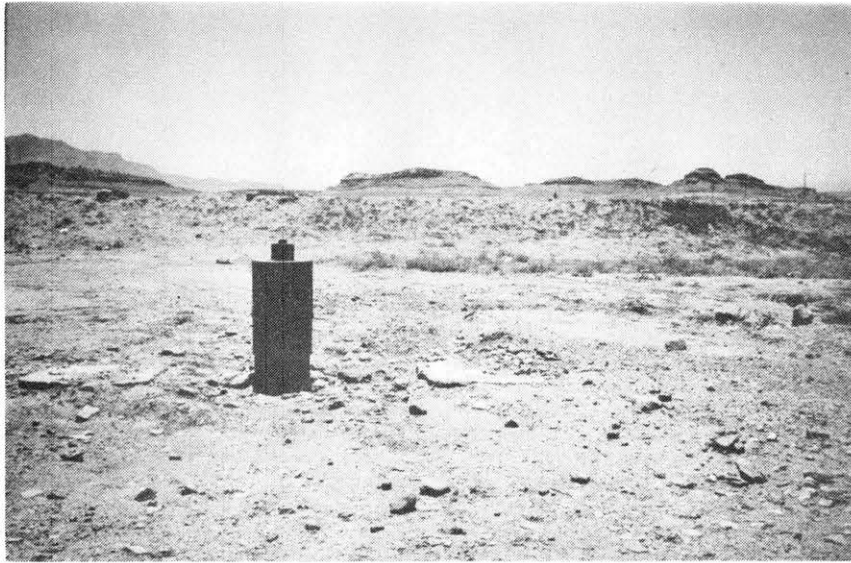


Figure 2-13 Abandoned well, Sana'a Basin.



Figure 2.14 Pump house above well for Sana'a water supply, Sana'a Basin.



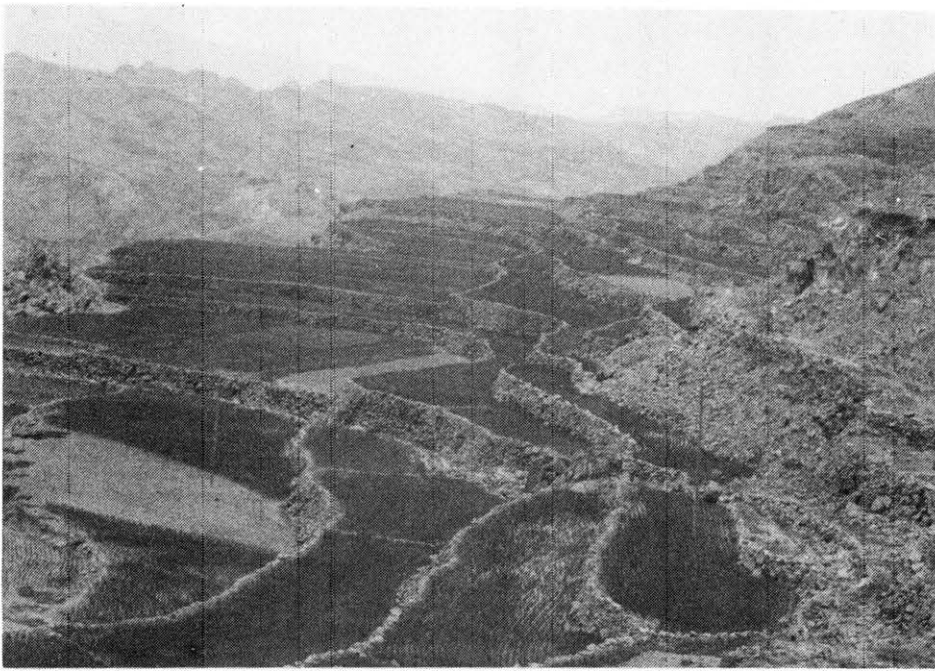


Figure 2.15 Terraces in Central Yemen.

TABLE 2-1

PHYSIOGRAPHIC ZONES OF THE YEMEN ARAB REPUBLIC  
(From CPO Swiss Report, 1978)

<u>Western Escarpment</u>			
Western Highlands	over 1,500 m	11,500 sq km	50,900 sq km
Western Midlands	500 - 1,500 m	19,100 sq km	
Western Lowlands	under 500 m	20,300 sq km	
<u>Eastern Escarpment</u>			
Northern Highlands	over 1,500 m	10,500 sq km	74,400 sq km
Central Highlands	over 1,500 m	10,500 sq km	
Eastern Highlands	over 1,500 m	15,100 sq km	
Eastern Midlands	1,000 - 1,500 m	20,100 sq km	
Eastern Lowlands	under 1,000 m	18,200 sq km	
<u>Southern Escarpment</u>			
Southern Highlands	over 1,500 m	7,800 sq km	9,900 sq km
Southern Midlands	1,000 - 1,500 m	2,100 sq km	
TOTAL			135,200 sq km

TABLE 2-2

THE MAJOR CLIMATIC ZONES OF NORTH YEMEN SHOWING MEAN  
MONTHLY TEMPERATURE AND THE AVERAGE ANNUAL RAINFALL

	ALTITUDE	CLIMATE CHARACTER.	MEAN MONTHLY TEMP. °C	AVERAGE ANNUAL RAINFALL
<b>A TROPICAL TIHĀMAH ZONE</b>				
Coastal Tihāmah plain with high atmospheric humidity and irregular low precipitation	0-50 m	tropical	25-25	0-80 mm
Central Tihāmah plain with low atmospheric humidity and irregular low precipitation	50-300 m	tropical	24-32	0-150 mm
Eastern mountain near Tihāmah plain with low to medium precipitation	300-500 m	tropical	22-32	
<b>B TROPICAL TO SUBTROPICAL ZONE OF THE LOWER WESTERN ESCARPMENT ZONE</b>				
Lower mountain slopes, frost-free zone with low precipitation	500-1,400 m	tropical	22-26	200-400 mm
Upper mountain slopes with medium rainfall	1,400-2,100 m	subtropical	16-24	300-600 mm
<b>C TEMPERATE HIGHLAND ZONE</b>				
Western, mountainous Highlands, with medium to abundant rainfall	2,100-3,700 m	temperate	10-18	600-1,800
Central Highlands, with medium rainfall	1,800-2,400 m	temperate	12-18	200-1,000
<b>D SUBTROPICAL ZONE OF THE EASTERN ESCARPMENT</b>				
Eastern mountain slopes with low, periodical rainfall	1,800-1,200 m	subtropical	16-24	100-400 mm
Eastern desert zones	1,200-800 m	subtropical	22-28	0-200 mm



TABLE 2-3

DRAINAGE AREAS OF MAJOR WADI COURSES IN THE YEMEN ARAB REPUBLIC  
(From Swiss Report, 1978)

<u>WESTERN ESCARPMENT</u>		<u>EASTERN ESCARPMENT</u>	
Wādī Mawr	7,500 sq km	Wādī Amlah	1,000 sq km
Wādī Surdud	2,450 sq km	Wādī Khabb	1,400 sq km
Wādī Sihām	3,200 sq km	Wādī Awban	800 sq km
Wādī Rima'	2,450 sq km	Wādī Madhāb	2,700 sq km
Wādī Zabīd	4,500 sq km	Wādī Hirrān	3,000 sq km
Wādī Rasyān	1,700 sq km	Wādī Kharīd	3,100 - 7,000 sq km
Wādī Mawza'	1,300 sq km	Wādī Saba'	8,900 - 11,300 sq km
Total	23,150 sq km	Wādī Harīb	1,000 sq km
		Wādī Bayhan	2,450 sq km
		Total	30,650 sq km
<u>SOUTHERN ESCARPMENT</u>			
Wādī Tubān	3,550 sq km		
Wādī Banā	5,900 sq km		
Total	9,450 sq km		

is often retained on cultivated fields and any surplus waters may remain trapped in interior basins. But if the rainfalls are heavy, the floods from the highland plains will discharge in larger wadi systems.

The water supply is a major constraint on agricultural production. Thus the knowledge of the proportion of rainfall which can be made available for crop growth is of great importance. While no accurate measurements exist, a Swiss report for the Dhamar Plain indicates approximately 70 percent of the rain which falls on uncultivated land becomes runoff, of which one-third enters into the streamflow and two-thirds are diverted onto cultivated lands. To illustrate, if rainfall is 400 mm for an average year, evapotranspiration is about 200 mm, runoff is 185 mm, and groundwater recharge is 15 mm. Springs are another important water supply in the country. Approximately 320,000 households (about one-third of the households of the country) depend upon springs for domestic water supply.

## 2.5 AGRICULTURE

Every visitor to Yemen is impressed by the labor intensive and sophisticated agricultural techniques which have been practiced for centuries on the slopes of steep and rugged mountains. The Yemeni farmer spares no effort to gain maximum profit from the scanty rainfall for the cultivation of his crops even on difficult terrain. Tremendous efforts are put into the production of grains the whole year-round. Plowing, leveling, manuring, breaking clods of soil with a wooden hammer, removing crop residues, sowing, conducting additional irrigation water to the fields, harvesting, repairing the containing walls of the terraces, etc., are some of the major operations carried out by the farmers by hand, using only simple tools and domestic animals. The special effort made in agricultural pursuits in areas with such marginal conditions is remarkable. This can be explained only by the fact that up to very recently, the overwhelming majority of the country's population had no other means of securing their daily living other than by intensifying agriculture production. The recent opportunities for work in the adjacent oil-rich countries present serious competition for existing agriculture, which is labor intensive. Large areas of the terrace farming systems could be irreparably damaged by the rural exodus.

The total area of cultivated land in North Yemen is estimated to cover 1,515,000 ha. The rain-fed lands comprise about 1,277,000 ha. The spate and perennially spring irrigated areas are estimated to cover 120,000 ha and 73,000 ha, respectively. The pump irrigated land averages 45,000 ha. These are 1976-1977 data. (Another estimate of cultivated land in Yemen was 1,983,100 ha.) The actual amount of cultivated land varies from year to year depending upon the rainfall. The crops grown are mainly grains such as sorghum, millet, and maize. Potatoes, vegetables, and fruits are grown also. Grains occupied about 90 percent total cultivated land of the country in 1974-1977. Commercial market-oriented agricultural production is limited to a few crops such as cotton, hide and skins, coffee, qat, vegetables, fruits, and live animals. Cotton was introduced as a commercial crop in the Tihama and today is the most important product for export. In 1975-1976 the export value of this crop was 24.6 Yemeni YR, which was 50 percent of the total export revenue of the country. Hides and skin are the next most important export product and bring in an income of 8 million YR annually. Coffee has an export value of 7.6 YR and

contributed 15 percent of the total export revenue in 1975. Qat is another important crop grown at altitudes 1,500 to 2,500 m and is sold on the domestic market. Table 2-4 shows the area planted with each of the major crops of the country for several years and the production amount for each crop.

Agricultural development has been promoted by government agencies and institutions providing technical assistance. Table 2-5 indicates some of the trends in terms of tractors, agricultural pumps, fertilizers, pesticides.

In general the farmers are eager to adopt new methods such as tractors, new seeds, fertilizer, insecticides, drilling wells, etc. But most agricultural projects are limited to small areas with easy access. There are still, however, large remote regions where farmers rely exclusively on traditional farming practice in all aspects of agricultural production. The rugged topography of the land constitutes a serious barrier to the introduction of farm machinery. As the steep and ingeniously terraced slopes offer difficult access to mechanization, the cultivation will continue to require much higher manpower expenditures than any cultivation on the plains. It should be noted parenthetically, however, that the traditional farming practice employs more people.

Even if agricultural yields could be increased by the introduction of better seeds, fertilizer, manure, etc., it is not likely that prices would decrease sharply. Most agricultural goods produced in Yemen are already considerably more expensive than imported products. This fact may represent one of the major problems for the development of agriculture in Yemen because the products cannot be exported as long as prices are far above the level of the world market. The lack of taxes on imported foods jeopardizes the farmer's already weak competitive position.

## 2.6 SOCIAL DIVISIONS

The pattern of society in Yemen varies considerably from one area to another. There is a great deal of local independence, which must be recognized in understanding the political context of the country. Figure 2-6 shows the provinces of the country. Most of these provinces comprise a geographical region with a common historical past. The province of Sana'a, by contrast, has highly diversified geographical zones. The political heads at the province level are the governors, who are appointed by the Prime Minister's office in Sana'a. As the main representatives of the central government outside of Sana'a, the governors are responsible for executing policy and for enforcing the administrative regulations of the government. They are the highest authority of appeal, passing judgement on personal, communal, and regional conflicts which cannot be resolved satisfactorily at a lower administrative level. The provincial centers also include various officials who are under the direct control of the representative ministries of Sana'a, such as the Director of Finance, Director of Education, Director of Municipalities, Director of Health, Director of Agriculture, Administrator of Waqf, etc. A area of each province is indicated in Table 2-6.

The provinces are divided further into districts. The main officials at district level are: the District Director Judge, Tax Collector, Military Commander, and Chairman of the Local Development Association

TABLE 2-4

## AREA AND PRODUCTION OF THE MAJOR AGRICULTURAL CROPS IN YEMEN

	1973/74 ha	1974/75 areas in ha	1975/76 ha	1976/77 ha	1976/77 yield	1976/77 production
sorghum & millet	952,000	1,215,000	1,145,000	786,000	0.8	660,000 t
maize	52,000	50,000	50,000	67,000	1.7	110,000 t
wheat	70,000	50,000	50,000	55,000	0.9	51,000 t
barley	77,000	73,000	68,000	60,000	0.9	54,000 t
cotton	20,000	28,000	15,000	5,000	1.0	5,000 t
tobacco	4,000	4,000	5,000	5,000	1.2	6,000 t
sesame	8,000	9,000	10,000	10,000	0.6	6,000 t
coffee	9,000	8,000	7,000	8,000	0.4	3,000 t
grapes	8,000	8,000	9,000	10,000	4.7	47,000 t
other fruits	10,000	12,000	12,000	15,000	5.6	84,000 t
potatoes	6,000	6,000	7,000	11,000	11.5	124,000 t
pulses	65,000	71,000	76,000	72,000	1.1	82,000 t
other vegetables	16,000	18,000	20,000	25,000	9.6	240,000 t
Total YEMEN	1,297,000	1,552,000	1,474,000	1,129,000	---	-----

TABLE 2-5 AGRICULTURAL TECHNOLOGY TO YEMEN 1970-1976

(From Swiss Report, 1978)

Year	Number of tractors		Number of agricult. water-pumps		Fertilizer (tons)		Pesticides (tons)	
1970	20	1%	1,382	6%	3,153	13%	135	3%
1971	80	4%	1,205	5%	4,046	16%	218	5%
1972	31	2%	3,928	17%	1,699	7%	345	7%
1973	63	3%	3,479	15%	4,256	17%	457	10%
1974	63	3%	3,285	14%	3,869	16%	717	15%
1975	238	13%	4,333	18%	3,363	13%	1,834	39%
1976	1,420	74%	5,916	25%	4,471	18%	1,004	21%
1970-76	1,915	100%	23,528	100%	24,857	100%	4,710	100%

TABLE 2-6 AREA OF PROVINCES IN THE YEMEN ARAB REPUBLIC

(From Swiss Report, 1978)

Province of Sa`a'	20,310 sq km
Province of Ta'izz	10,420 sq km
Province of Al Hudaydah	13,580 sq km
Province of Sa`dah	12,810 sq km
Province of Hajjah	9,590 sq km
Province of Al Mahwit	2,160 sq km
Province of Ma'rib	39,890 sq km
Province of Dhamar	8,870 sq km
Province of Ibb	6,430 sq km
Province of Al Bayda'	11,170 sq km
Yemen Arab Republic	135,230 sq km

Board. Below the district level are the villages. The administrative authority at this level is the shaykh.

One of the most important administrative entities is the Local Development Association Board, which has the function of planning, coordinating, and executing local development projects at the village, district, and sub-province levels. These organizations are, in general, entitled to receive up to 50 percent of the tax revenue of an area and to spend their funds on communal or regional development projects such as the improvement of water supply systems, the construction of feeder roads, the establishment of school and medical centers, etc. The spheres of action of the Local Development Association Boards are the same as congruence of the districts.

The lack of an effective communication network, i.e., the lack of modern roads, telephone connections, and a postal service in large parts of the country, make the integration of numerous, densely populated areas into a uniform system extremely difficult. Remarkable progress has been made, however, since the 1962 Revolution, and even more obviously since the advent of military leadership in 1974.

## 2.7 DEMOGRAPHY

There are about 50,000 settlements in Yemen scattered throughout the country. The total population, in round numbers based on the 1975 census, is about 5 million persons. (The recommended adjusted census population provided in the CPO Swiss Report is an adjusted population figure of 4,705,336.) The population density is 35 inhabitants per square km. This compares with 37 for Egypt, 40 for Syria, 3 for Saudi Arabia, 5 for South Yemen, 155 for Switzerland, and 96 for France. The growth rate is estimated at 1.9 to 2.9 percent. This compares with 2.2 percent for Egypt, 0.7 percent for Switzerland, 0.8 percent for France, and 0.2 percent for the United Kingdom. Table 2-7 shows the population distribution by the major physiographic regions.

The distribution of population by rural and urban populations by province can be seen in Table 2-8. As seen in the rural population column, 88.9 percent of the population live in settlements of less than 2,000 inhabitants. But, at the same time, the major cities are growing rapidly in population. This is seen in Table 2-9, which shows the growth of three cities, Sana'a, Hudaydah, and Taizz during the period 1970 through 1980.

## 2.8 ISLAMIC WATER LAW DOCTRINE

The system of water rights in Yemen is based upon a mixture of Islamic legal principles and local customary practice. Once distribution has taken place, customary practice tends to determine the allocation of water.

The primary rule of surface water diversion is "highest first," or closest to the source, as the case may be. The equally valid Islamic rule of "first in time, first in right" receives little mention.

Local practice intervenes once the water has been distributed. The first user can take as much as he wants without regard to the amount available to downstream users. Some communities of irrigators have avoided this problem, however, by allocating water to main diversion canals within the system at

sequential times during the irrigation season, e.g., one canal for one month, another during the second month, and so on. This is essentially the system employed in Wadi Zabid. Such practice conforms to the doctrines of Islamic law. However, it does not guarantee equity within the secondary distribution system. The upstream users may still take more than their share once the water is diverted into the main canal. A valid Islamic legal doctrine is available, however, to help resolve this issue. According to Hadith, The Prophet, salah alayhi wa salama, directed that the prior irrigator only apply a specified amount of water and is then obliged to pass the water to the next user (Maktari, 1971; Caponera, 1973). This rule applies when water is scarce (Caponera, 1973). But depending on the area of the country, the authorized interpretation of Islamic law in the YAR conforms to the Shafi'i Sunni or Zaydi Shi'i schools of law.

A major defect in present irrigation practice is that an upstream user may take more than he needs. This is because there is no security for any user to have adequate water supply at the times needed by the crops.

The rules of groundwater law in Yemen approximate "common law" doctrine of the United States, i.e., the land owner owns the water underlying his land when he puts in a well. Thus, legally, extraction of groundwater is at the owner's discretion. Within Islamic legal doctrine and notably with Shafi'i doctrine, there is an "equally valid" interpretation which would aid in resolving this issue as well. This view adheres to the rule that groundwater is "common" in ownership. In other words, as it exists in the groundwater system, it is without specific ownership and is held in common by the entire community. The owner of the land or the well has primary right to use and can own the water that he withdraws but the groundwater system remains "res communis." This is similar to the Hanbali doctrine as expressed by Ibn Qudama.

A basic Islamic legal principle is that one may not conduct the use of one's property to the detriment of a neighboring well that was in place at a prior time.

TABLE 2-7

## POPULATION OF THE MAJOR PHYSIOGRAPHIC REGIONS IN YEMEN

	DE FACTO POPULATION 1975	Area	Population density (inhabitants/sq km)
<u>Western Escarpment</u>	<u>2,970,000</u>	<u>50,900</u>	<u>58</u>
Western Highlands	1,110,000	11,500	96
Western Midlands (1a)	1,130,000	19,100	59
Western Lowlands (1b)	730,000	20,300	36
<u>Eastern Escarpment</u>	<u>1,055,000</u>	<u>74,400</u>	<u>14</u>
Northern Highlands	112,000	10,000	11
Central Highlands (1c)	750,000	10,500	71
Eastern Highlands	133,000	15,100	9
Eastern Midlands	60,000	20,100	3
Eastern Lowlands		18,000	0
<u>Southern Escarpment</u>	<u>680,000</u>	<u>9,900</u>	<u>69</u>
Southern Highlands	595,000	7,800	76
Southern Midlands	85,000	2,100	40
Yemen Arab Republic	4,705,000	135,200	35

TABLE 2-8 PROPORTION OF RURAL AND URBAN POPULATION BY PROVINCE

(From Swiss Report, 1978)

PROVINCE	RURAL POPULATION		URBAN POPULATION			
			Province Center		Other urban settlements <sup>1/</sup>	
	Percent	Numbers	Percent	Numbers	Percent	Numbers
Al Hudaydah	76.2	523,379	11.9	82,724	12.9	89,528
San`ā'	80.2	665,383	16.7	138,625	3.3	27,941
Ta`izz	90.3	796,429	9.2	81,001	0.5	4,633
Al Baydā'	92.6	160,149	3.6	6,154	3.8	6,570
Ibb	94.5	769,412	2.3	19,638	3.2	24,153
Dhamār	95.7	448,735	4.3	20,051	-	-
Hajjah	96.6	399,148	1.4	5,988	2.0	8,238
Ma'rib	96.7	67,250	-	301	3.3	2,289
Sa`dah	97.5	172,226	2.5	4,380	-	-
Al Mahwīt	98.6	178,517	1.4	2,494	-	-
Yemen Arab Republic	88.9	4,180,628	7.7	361,356	3.4	163,352

<sup>1/</sup> Includes persons living in settlements of over 2,000.

TABLE 2-9 GROWTH IN THE CITIES OF SANA'A, AL HUDAYDAH, AND TA'IZZ  
1970 AND 1980

(From Swiss Report, 1978)

Year	San`ā`	Al Hudaydah	Ta'izz
1970	96,000	58,000	58,500
1971	103,000	52,000	52,500
1972	110,500	67,000	66,500
1973	119,000	72,000	71,000
1974	128,000	77,500	75,500
1975	138,000 census fig.	83,000 census fig.	81,000 census fig.
1976	148,500	89,500	86,500
1977	161,000	97,000	94,000
1978	175,500	106,000	103,000
1979	192,000	115,500	112,500
1980	210,000	127,000	123,000

### **3. INFORMATION ABOUT WATER IN YEMEN**



### 3. INFORMATION ABOUT WATER IN YEMEN

#### 3.1 PURPOSE

Water oriented projects and studies have been going on in Yemen over the past decade. The government feels it is now time to assess these past activities in terms of overall national needs for water planning information. Once this is done, information gaps can be identified more easily and future studies can be coordinated with those completed. To aid in this process our first task was to "summarize for the MOA and the Yemen government, in general, the state of knowledge of Yemen's water resources." This was done at a reconnaissance level based upon review of existing reports.

#### 3.2 SUMMARY OF WATER INFORMATION BY REGION

About 50 reports were reviewed for this task. They are listed in Appendix A where they are categorized by region and as general information. Probably these reports represent most of the body of knowledge of Yemen water resources since they were obtained from the agencies having reason to accumulate complete libraries on the subject. But the search was not exhaustive and some omissions are likely.

A summary of subject area coverage of water information in Yemen has been prepared in matrix format, seen in Figures 3-1 through 3-4, for west, central, south, and east regions, respectively. In these figures, pertinent water oriented subjects are identified in the columns. The rows show the major wadis and cities and identifies by author the specific studies conducted. The extent of coverage of each subject by the respective report authors and for each wadi or city is seen by how the corresponding elements are filled in; whether the coverage is thorough, moderate, or nonexistent is demarked by the symbols used.

The graphic format of Figures 3-1 through 3-4 provides an overall "birds eye" view of the current status of water information. The figures show that studies have not been conducted for a number of geographical areas. But for most of the major wadis, their potentials for development have been investigated, along with the needed supporting information on groundwater and surface water resources. What seems to be lacking most is attention to water rights, and perhaps the kind of comprehensive study of all subjects as would be appropriate in a water resources planning study vis-a-vis a project study. But the project reports do provide data useful for comprehensive studies. A weakness not seen in the graphical summary is the rather thin data base which exists. This is recognized and is being addressed in the current development of data networks by the Department of Hydrology.

It must be recognized, however, that the project reports serve a different purpose than what is needed for comprehensive planning. Thus, the needs for developing water resources information can be ascertained best by stating the requirements for comprehensive water planning--the subject of the next

chapter. The past reports and studies can be used as reference documents in this activity.

#### 3.3 COMMENTARY

To complement the graphical summary of water information, impressions are given below concerning the adequacy of existing knowledge.

(1) Tihama. The Tihama has received considerable attention with respect to agricultural development. Also the groundwater resource supplying a major urban area, Hodeida, has been investigated by Italconsult (1973, 1976) and Kocks (1978). Of the "seven major wadis" only one, Wadi al Ghayh on Wadi al-Kabir, has not been the subject of an agricultural development study. Wadi Mawr has been reported on by Tipton-Kalmbach (1979) and Tesco-Viziterra-Vituki (1971). Sir William Halcrow examined Wadi Surdud (1978), and Wadi Siham was investigated by Sogreah (1979). Wadi Rima has been reported on by DHV (1978), Wadi Zabid by Tesco-Viziterra-Vituki (1971) and Wadi Raysan by Sir Alexander Gibb (1978). Some further comments are given below concerning Wadi Surdud, Wadi Rima, and Wadi Raydan.

Wadi Surdud. The characterization of surface and groundwater resource availability and dynamics has been based upon very scanty information. Also, data derived from other wadies in the Tihama has been used. Long-term and detailed examination of both surface and groundwater should be undertaken for this drainage.

Wadi Rima<sup>1/</sup>. Although a relatively complete description of surface water hydrology is provided by the study completed, it appears that the groundwater system has received little attention to data. Since, in most cases in the Tihama, surface water is relatively completely utilized, groundwater systems may provide the only surplus. This being the case, it is recommended that a groundwater investigation be conducted for Wadi Rima'.

Wadi Raysan. The information available for Wadi Raysan was found to be similar to that for Wadi Surdud, i.e., there is very scanty direct information characterizing both surface and groundwater resources. Data from other areas or one-point datum are used as a basis extrapolation to characterize conditions applying through the wadi. Groundwater assessment is limited to monitoring dug wells and springs. Detailed investigations of surface and groundwater conditions in Wadi Raysan are needed.

(2) South. Although longer periods of records and more data points are desirable, the record is relatively complete within those studies accomplished in this region. But, as seen in Figure 3-3, two

<sup>1/</sup> An ODA study was overlooked in this review.

## Yemen Water Resources Information Summary

STUDY IDENTIFICATION		SUBJECTS DISCUSSED									EXPLANATION
AREA	REGION	Agricultural Development	Domestic Use	Sewerage	Groundwater	Surface Water	Present Water Use	Water Rights	Watershed	None	
Study											<div><div></div>Thorough coverage</div> <div><div></div>Some attention</div> <div><div></div>No coverage</div> <div><div></div>No study</div>
WEST / TIHAMA											NOTES
WADI MA'BAR										⊙	
WADI KHULAB										⊙	
WADI HARAD										⊙	
WADI HAYRAN										⊙	
WADI BAWHAL										⊙	
WADI MAWR		■			■	■	■	■	■		
(1) Tipton-Kalmbach (1979)											
(2) Tesco-Viziter (1971)					■	■			■		Recon study
WADI SURDUD					■	■	■	■	■		Needs more detailed study
(1) Wm. Halcrow (1978)					■	■	■	■	■		Limited data
WADI SIHAM					■	■	■	■	■		
(1) Sogreah (1979)					■	■	■	■	■		
HUDAYDAH						■					
(1) Italconsult (1973)			■		■	■	■	■	■		
(2) Italconsult (1976)			■			■					
(3) Kocks (1978)			■		■						
WADI 'ASALAH										⊙	
WADI RIMA'		■			■	■	■	■	■		Needs detailed groundwater study
(1) DHV (1978)					■	■	■	■	■		Groundwater data sparse
WADI ZABID					■	■	■	■	■		
(1) Tesco-Viziter (1971)					■	■	■	■	■		
WADI NAKHLAH										⊙	
WADI RAYSAN		■			■	■	■	■	■		Needs more detailed study
(1) Sir Alex. Gibb (1978)					■	■	■	■	■		Limited data provided
WADI AL-GHAYL (WADI AL-KABIR)										⊙	

Figure 3.1 Yemen Water Resources Information Summary, West (Tihama) Region.

Figure 3.2 Yemen Water Resources Information Summary, Central Region.

Figure 3.3 Yemen Water Resources Information Summary, South Region.

Figure 3.3 Yemen Water Resources Information Summary, South Region.

Figure 3.4 Yemen Water Resources Information Summary, East Region.

Figure 3.4 Yemen Water Resources Information Summary, East Region.

wadis have no studies, and some types of information are missing for the others.

(3) Central. From al-Harf south to Sana'a along the central highlands, information is available for Amran (USGS, 1980), Al Mahwit (Sir William Halcrow, 1978), Bani Hushaysh (Awad and Dewar, 1977), and Sana'a, which has been covered extremely well (Italconsult, 1973 and 1975, H. Humphreys, 1977, 1979, and 1980, and Mullick, 1977). From Sana'a south along the central highlands, information is available for Dhamar (Italconsult, 1978), Taiz, and the al-Haima Basin (Montgomery, 1975, and Hazen and Sawyer, 1977), and Wadi Bana (Sir Alexander Gibb, 1977-78). Additional comments which follow are focused upon al Mahwit and Bani Hushaysh.

al-Mahwit. The existing data base is very limited. The information available provided is not sufficient for decision making. Prior to considering the water resources picture for this area, an investigation of surface and groundwater is needed.

Bani Hushaysh. The study completed focuses on soil and water quality regarding their appropriateness for agricultural use. Little quantitative information is provided, however, on surface and groundwater resources, except that historical records have been made of static water levels in dug wells. Such information should be developed through establishment of gaging stations in the area with observations on a continuing basis.

(4) East. In the east, from Sa'dah and Wadi Nijran in the north along the eastern drainage south to Wadi Marakah information is very sparse with the exception of Wadi Jawf and its tributaries. Wadi Jawf

and Wadi Kharid were given reconnaissance coverage by Sir Alexander Gibb (1978). Somewhat more extensive study was made by Agrar-Und Hydrotechnik in 1980, a study which is ongoing at this time. As the eastern desert area receives the drainage from a rather extensive watershed with rather high runoff characteristics, there may be the potential for this area to contain exploitable amounts of groundwater as it travels east and north into the Rub'al-Khali. Additional comments follow concerning Wadi Jawf.

Wadi Jawf Basin. A comprehensive survey of surface water hydrologic characteristics has been done, including the lower reaches of Wadi Madhab, Wadi Kharid, and Wadi Furday. A groundwater assessment is being conducted but the data are not available yet. Reports indicate that the survey is comprehensive in nature. This work should be assessed in terms of long-term needs for developing a comprehensive picture of the water resources of the area.

### 3.3 INSTITUTIONS

The institutional situation at the national level has been outlined by Johnson (1980) and Merabet (1980). Also, they have given recommendations concerning the coordination of the activities of the various agencies involved.

Information regarding water rights and practices related to allocating and distributing water in the agricultural sector is meager. Some enlightenment is given, however, but the studies of Maktari (1971) and Caponera (1973), while useful in providing general background, they are not sufficient in specific content or in geographic extent to serve as a basis for water resource management in Yemen.

## **4. WATER PLANNING METHODOLOGY**



#### 4. WATER PLANNING METHODOLOGY

To support the rapid economic development now occurring in Yemen, comprehensive planning and management of its water resources is recognized by the government as a means to implement its water policy. Such planning has two preliminary steps: (1) acquire the needed data in a systematic manner, and (2) accomplish an in-depth description and analysis of the water resources situation in each region of the country. These two steps should provide the contextual basis for a third step, which is to generate alternative plans. Evaluation, selection and implementation are succeeding steps. This chapter focuses upon the first two steps enumerated above.

##### 4.1 PROCEDURAL FRAMEWORK FOR SUPPLY-DEMAND STUDIES

A basic conceptual framework for water planning can be formulated in terms of three simple questions: (1) How much water is available?, (2) What are the demands?, and (3) How can the supply be used to satisfy demands? The best known example of its application is the California Water Plan.

The first two questions address the categories of background information required for addressing the third, i.e., the plan formulation. This section outlines, in terms of six report volumes, the kind of information that ought to be developed for handling these questions. Plan formulation, however, is unique to the circumstances at hand, and is not considered. Neither are several ancillary concerns such as protection of water quality, evaluation of health hazards, flood protection, watershed management, etc.

##### 4.2 REPORT VOLUMES

The respective titles of the suggested report volumes are given in Table 4-1 along with outlines of content. These reports enumerate the kinds of tasks that ought to be undertaken for each region or subregion. They address the first two questions of a comprehensive procedural framework for water planning. The third question, i.e., how to satisfy demands, is not considered.

##### 4.3 INPUT-OUTPUT TABLES

The set of block diagrams and the input-output tables comprising Volume VI warrant special mention since they are recent innovations not yet established in practice. These techniques complement the conventional studies outlined in the first five volumes.

A hypothetical block diagram for the City of Sana'a, which would be a component of a Sana'a Basin regional study, is depicted in Figure 4-1. The diagram shows all water inputs and outputs to and from Sana'a on an annual basis (since the data indicated are not yet known, only arrows are shown). But most important, the documentation for each item of data are indicated in the figure; this permits easy questioning of the data and facilities improvement and provides a format for updating. Also included is a

small photograph to provide a visual idea of the given component and a small location map to show location. The block diagram then contains complete input-output information for each system component. Equally important, the footnotes in the diagram provide indexing to more detailed information and documentation. A complete set of such diagrams in a separate volume provides a quick reference and easy access to a large amount of information.

While the block diagrams depict each system component individually, the input-output table shows the water flows for the whole system at once. Figure 4-2 is a hypothetical input-output water balance table. The table is comprised of rows (outputs of water) and columns (receiving inputs of water) which represent the significant components of any given water system. The system depicted could be for a city, a basin, a region, or a country. The degree of resolution and aggregation would be different for each. The number of components used should be limited to 80 to 100. The time period can be whatever is consistent with the purpose; a year is suggested for overall regional planning.

Concerning the mechanics of using the matrix, the rows show the distribution of water outputs, from each component to the others, and the columns show the distribution of inputs to each component. The total output from any component is seen in the far right column marked "total," and the total inputs to any component is seen in the bottom row. The row totals must equal the column totals.

To use the model to assess the supply-demand situation, for a future year say 2000 or 2020, the projected demands of each component should be imposed on the bottom line in the appropriate column. To meet that demand, the column must contain entries such that their sum equals the bottom row amount. If this is not true, then a row component must either take the needed water from excess system outflow, or by reallocation of the water distributed internally. To accomplish this distribution, new projects may be required, which would appear as new rows and columns.

The input-output table is really a system model of a water system. It can be used for quick reference, for planning, or to explain how the system functions. It can depict a complex water system in quite simple terms. Proposed projects can be added to the table to depict their relationship to the system as a whole and to particular components.

Input-output tables should be constructed for each region of the country and for each major wadi and each major city. They can show at a glance the water situation for both planners and decision makers.

##### 4.4 PLANNING

Once basis information is developed within a systems framework, comprehensive planning can begin. There are three approaches to the supply-

demand aspect. These are: (1) increase degree of exploitation of the water resource by means of new projects, (2) reallocate existing supplies, and (3) regulate per capita demand for water. Each approach requires studies to determine what is feasible and how the change can be achieved.

Evaluation and selection are the next two steps. They are normative in nature and require integration with the political process. The final steps, implementation and operation, require scheduling, financing arrangements and institutional development. Also, if the plan selected is quite large in concept, to the point that years or decades may be required in its implementation, modifications and revisions can be expected to account for changing circumstances. Also, the plan should be flexible to permit such changes and yet achieve the societal goals.

TABLE 4-1

SUGGESTED REPORT VOLUMES FOR DEVELOPING WATER  
RESOURCES PLANNING INFORMATION

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VOLUME I - REGION INFORMATION

## 1.1 Maps

topographic map of Yemen  
topographic map of region  
water management regions and subregions in Yemen  
water management regions  
rainfall isohyets for region  
political boundaries for Yemen  
hydrologic basins in Yemen  
hydrologic basins in region  
groundwater basins in region

## 1.2 Overview of the Region

population  
geography  
economics  
water resources

## 1.3 Institutions

water law  
traditions  
government  
finance

## VOLUME II - WATER RESOURCES

## 2.1 Precipitation

gaging networks  
annual precipitation history  
monthly rainfall distribution  
rainfall isohyets  
evaporation

## 2.2 Streamflow

gaging stations  
annual history of discharges  
monthly distribution of discharge  
flood discharges  
water quality description  
withdrawal amounts  
instream uses

## 2.3 Groundwater

description of groundwater basins  
pumping test data  
well location and annual withdrawals  
water table contours  
estimates of safe yield, outflow to seas, sustained yield  
recharge information

## VOLUME III - WATER USE: MUNICIPAL/INDUSTRIAL

## 3.1 Water Supply

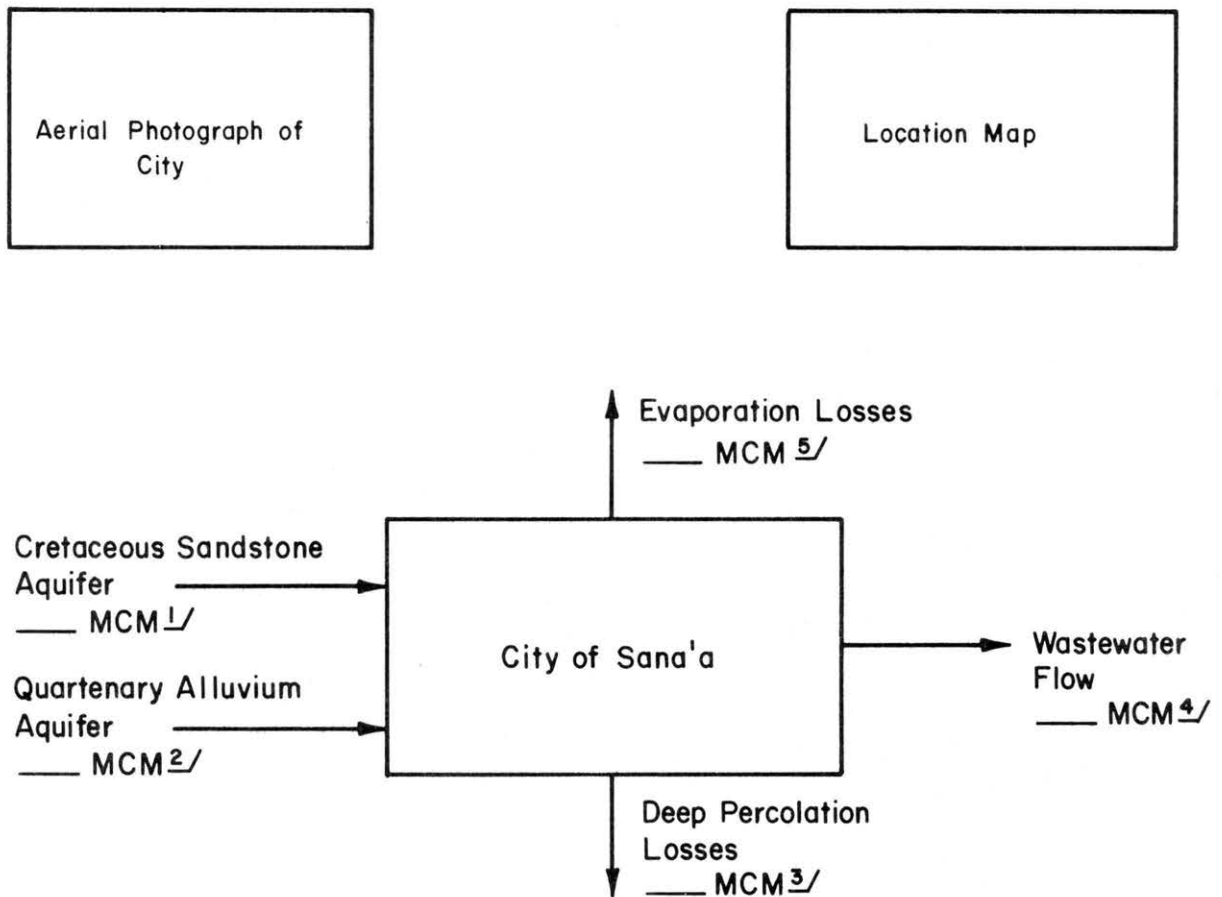
municipal water use, past, present, projected  
industrial water use, past, present, projected  
per capita water use, past, present, projected  
population, past, present, projected  
description of municipal systems  
health hazards

TABLE 4-1. (Continued).

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3.2	Wastewater Production
	sewerage systems description
	effluent quantities, past, present, projected
	wastewater treatment
	prospects for wastewater reuse and water conservation
VOLUME IV - WATER USE: AGRICULTURAL	
4.1	Rainfall Agriculture
	precipitation, acreage, crops produced, etc.
4.2	Irrigated Land
	land classification
	irrigated acreage: 100 percent and 50 percent probabilities
	based upon annual flows
	irrigation institutions
	method of irrigation
	description of systems and condition
	water applied amount
	consumptive use amount
	deep percolation amount
VOLUME V - PROJECTS	
5.1	Existing Projects
	storage, diversion, transport
5.2	Proposed Projects
	location - maps, description
	statistical information
VOLUME VI - INPUT-OUTPUT MODELS OF SUPPLY-DEMAND	
6.1	Block Diagrams
	inputs and outputs of annual water flows to and from each
	system component
	photograph of system component
	location map of system component
	references on water flow data
6.2	Input-Output Tables
	tables for region as whole, 1980 and 2020 for "stress" and
	"average" conditions
	tables for important subsystems, e.g., selected cities, subregions,
	1980 and 2020 for "stress" and "average" conditions

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<sup>1/</sup> Withdrawals are Estimates Based Upon Number of Wells, Inventory of Pumping Lifts, and Sizes. See Volume 2, pp. \_\_\_\_

<sup>2/</sup> Similar Documentation of Data Shown.

<sup>3/</sup> Similar Documentation of Data Shown.

<sup>4/</sup> Similar Documentation of Data Shown.

<sup>5/</sup> Similar Documentation of Data Shown.

Figure 4.1 Hypothetical water balance diagram for a system component.

<div> <div>OUTPUT COMPONENTS (Origins)</div> <div>INPUT COMPONENTS (Destinations)</div> </div>		INTERNAL COMPONENTS										SYSTEM OUTPUTS					TOTAL
		Watershed Land	Wadi B	Pipeline A	City A	City B	Village A	Water District A	Private Service	Ag. Area A	Ag. Area B	Atmosphere	G.W. Storage	Surface Water Stor.	Ground Water	Wadi C	
SYSTEM INPUTS	Atmosphere	60								30	10						100
	Cret. Aquifer			80		15				25	15						135
	Quart Aquifer				25		5	5	5								40
	G.W. Storage				10				5	10	5						30
	Wadi A										10						10
INTERNAL COMPONENTS	Watershed Land		20									40					60
	Wadi B									20							20
	Pipeline A				80												80
	City A											10			20	85	115
	City B										10				5		15
	Village A														5		5
	Water District A														5		5
	Private Service														10		10
	Ag. Area A											45			40		85
	Ag. Area B											30			20		50
TOTAL		60	20	80	115	15	5	5	10	85	50	125	0	0	105	85	315

Figure 4.2 Input-output table for a hypothetical water system. Numerical data shown are annual water transfers in million cubic meters (MCM) per year.



## **5. NATIONAL WATER POLICY**

## 5. NATIONAL WATER POLICY

In a water short country, a national water policy is needed. Such a policy should set forth the basic goals and objectives in water allocation, development, and use, which reflect both the physical realities of water availability and the social-cultural context of the country.

A comprehensive water policy is needed at the present time in Yemen. The current rapid rate of economic development and rising economic expectations of the people coupled with studies and proposals for water projects give emphasis to this need. What is needed is a policy in which the national government fulfills its leadership role in setting direction and taking initiatives for the common good, but which, at the same time, can promote wisdom in water use at the local level and is flexible enough to deal with a range of local conditions.

### 5.1 KEY PROVISIONS OF PROPOSED NATIONAL WATER SUPPLY

A proposed national water policy is set forth in this chapter in the format of an act. The key provisions of the proposed act are outlined as follows:

#### (1) Policy

- ..Water is a public resource to be managed by the government.
- ..Precepts of Islamic water law and local customs should be adapted.
- ..Domestic water use shall have priorities over all other uses.
- ..Industrial water use shall be permitted to purchase agricultural water rights in some local areas if approved by the Regional Water Commissions and local authorities.

#### (2) Goals

- ..The water resources of Yemen should be managed.
- ..Groundwater is to be managed on a long-term sustained yield basis.
- ..The key goals in water management are: maximization of regional and national social well-being and economic output.

#### (3) Means

- ..A Water Resources Council should be created to provide leadership, coordination and direction in water management at the national level.
- ..The Water Resources Council shall approve budgets for all water related government studies.
- ..Responsibility and accountability for implementation of national policy and goals should be decentralized to the provincial and local levels.
- ..Education, extension, and demonstration programs should be founded to reach and motivate local communities.
- ..A legislative program should be set forth to be enacted, over years or decades, at a rate the provisions can be understood and assimilated.
- ..Institutions should be developed and existing ones modified to reflect needs of modern water management.
- ..An education and training program is needed to develop a cadre of experienced water professionals.

### 5.2 PROPOSED ACT

The government requested the CID water team to provide suggestions on national water policy. The suggestions are set forth in the format of an act in order to provide a more definite basis for consideration. The proposed act builds upon the thinking of others. For example, the suggestions of Mr. Rueben Johnson in his report of May 1980 were incorporated almost verbatim in places, modified in others.

It is not intended that the provisions of the proposed act be taken literally without question. If the act identifies the main issues of a water policy and functions as a focus for debate, it will have served its purpose.

# NATIONAL WATER POLICY ACT<sup>1/</sup>

## 1. PURPOSE

The purpose of this Act is first, to set forth the basic provisions of a national water policy, and second to provide an overall blueprint for its implementation.

## 2. POLICY

This act reaffirms as national policy that water is a scarce resource belonging to all of the people. The responsibility for developing a management policy is vested with the national government. The key management objective is to assure that the resource is utilized in such a manner as to maximize the "general welfare."

## 3. THE GENERAL WELFARE AND THE ROLE OF WATER

The term "general welfare" is defined here in terms of (1) social well-being, (2) national economic well-being, and (3) regional economic development. Since water may be a "limiting factor" in achievement of both social well-being and economic development, it shall be managed in such a manner as to promote both objectives. This shall be construed as entitling all citizens to sufficient water allocation to achieve a quality of life commensurate with community norms, as are feasible. The second priority is to manage the existing regional water supplies to maximize economic output, as feasible.

## 4. ADMINISTRATION

**4.1 WATER RESOURCES COUNCIL.** A Water Resources Council is hereby created to develop a national water policy to oversee the development of national and regional water plans, to assure coordination between agencies in water oriented activities, to oversee the programs of Regional Water Commissions and to appoint the Executive Directors to provide leadership in implementing national goals and objectives at the regional and local level, to review reports prepared by all entities involved in water resources development, to assure that any proposed action is consistent with established national goals and objectives and priorities and with regional water plans, to provide for the acquisition and storage of hydrologic data, to develop principles, standards and procedures for planning, and to provide for implementation of the provisions of this Act.

**4.2 COUNCIL MEMBERSHIP.** The Council membership shall include the Minister of Agriculture, the Minister of Public Works, the Minister of Commerce, the Director General of the Central Planning Organization, the Director General of the National Water and Sewerage Authority, the Director General of the Department of Hydrology, the Council Chairman, and other persons as deemed necessary or advisable. The Council membership should be limited in size, e.g., ten persons.

The Chairman of the Council shall have minister rank, shall serve under the authority of the Prime Minister, and shall be appointed by the President.

**4.3 COUNCIL STAFF.** The Council Chairman shall serve also as its Executive Director. The Council staff serving under the Chairman will develop national principles and standards for water planning, will provide leadership and direction to regional planning efforts in the provinces, will prepare a national assessment of water resources and water demands, and will oversee the development of national and regional water plans. The Council staff should be highly qualified technical persons who will interact with, advise, and assist member agencies and others as requested with respect to planning, economic, legal and technical problems. The staff shall be independent of other agencies. The staff shall function in a coordination and leadership role. It should have a budget to conduct or commission needed studies as directed by the Council, but shall not function as an operating agency.

**4.4 COUNCIL MEETINGS.** It is recommended that the Council should meet at least quarterly. The agenda should be prepared by the Chairman. It should be distributed one week prior to the meeting, and set forth the issues upon which decisions are to be taken. A discussion of each issue, including background information, possible alternative solutions, the effects of such solutions and factors supporting the urgency of an early decision should be provided. The agenda, in cognizance of the time demands upon the members, must focus upon reaching decisions on major water policy issues. Less major issues can be delegated to the Chairman, who may ask the advice of interested agencies.

**4.5 DEPARTMENT OF HYDROLOGY.** The Department of Hydrology shall be placed directly under the Chairman of the Water Resources Council. It shall remain a neutral service agency to serve the agencies in providing basic hydrologic data. The Department shall be a repository of all hydrologic, hydrogeologic, and water quality information collected by all ministries, authorities, donors, and other groups involved in water resources activities in Yemen. Also, it shall maintain a library of all water oriented reports. The Department shall prepare a comprehensive hydrologic atlas on all water resources in the country. All data on groundwater, precipitation, streamflow, water quality, and other pertinent hydrologic data collected by various agencies and groups should be provided to the Department. The Department shall provide the format and forms for data collection by various agencies. The forms should be coded for eventual transfer to computer storage. Gaps in data acquisition shall be recognized by the Department and steps taken to set up the needed monitoring stations.

**4.6 REGIONAL WATER COMMISSIONS.** The major hydrologic basins and water management units of the country will be identified. The allocation, development, and management of the water resources of each basin or management unit shall be presided over by a Regional Water Commission. The Commission shall be vested with authority and responsibility to promulgate and enforce the National Water Policy and Act, as applied to the region under its jurisdiction; it shall develop appropriate regulations to do this. For the region under its jurisdiction, the Commission shall have the same charge as the Council. The Commission should provide leadership in stimulating institutional reforms and such changes in water management practices as deemed prudent in achieving greater regional economic productivity and in meeting community needs for water. The Commission may elect to develop a water use extension service.

Membership on the Commission shall be comprised of representatives of regional coordinating councils, the Governor, local development authorities, regional offices of YARG ministries and authorities, agricultural cooperatives, municipalities, villages, and the Executive Director who shall be Chairman.

The Executive Director of the Commission shall be an experienced water professional, who shall be appointed by the Chairman of the WRC and approved by those Provincial Governors whose provinces cover the water management basin or region. The Executive Director of the Commission shall be responsible to the Water Resources Council. All actions of the Commission shall have the involvement and approval of the Provincial Governor. The Commission shall be the ultimate authority in assuring that a supply-demand water balance is attained for the basin.

The Commission shall have an advisory staff who shall advise the Commission through its Executive Director and who shall execute the directives of the Commission. The staff shall be professionally qualified to the same degree as the staff of the Water Resources Council.

## **5. WATER MANAGEMENT REGIONS**

A water management region is defined as any geographic area whose boundaries delineate an area whose water resources are to be managed by a Regional Commission. Initially, the country will have four water management regions: the Western Region, the Eastern Region, the Southern Region, and the Central Region. Within each region water management districts shall be delineated. To the extent possible, the districts should be hydrologic entities, e.g., Wadi Surdud, Wadi Zabid, etc., or a logical management unit such as the Sana'a Basin.

## **6. WATER PLANNING**

The Water Resources Council shall coordinate water planning between government agencies, municipal governments, regional authorities, and any other public or private enterprise involving water use and management. Project initiatives and planning shall come from these other entities.

**6.1 PLANNING GUIDELINES.** The basin planning guidelines to be promulgated by the Council and the Commission are as follows:

- (1) Groundwater basins are to be operated as reservoirs according to the formula: average annual withdrawal equals Average annual inflow minus average annual outflow. Changes in storage, i.e., water table levels, are permitted year to year, but a long-term decline shall not be permitted.
- (2) Priority in allocation shall be given to municipal requirements.
- (3) As second priority, water shall be used in such a manner as to maximize regional and national economic output.
- (4) Water conservation shall be encouraged for all types of uses.
- (5) Water supplies shall be protected from pollution.
- (6) Municipalities receiving a 50 lpcd or greater water supply shall be sewered.
- (7) Reuse of municipal and industrial wastewaters shall be encouraged.
- (8) Water measurement is mandated for all streamflows, groundwater withdrawals, irrigation diversions, and municipal and industrial uses.
- (9) Improved irrigation efficiency through increased reliability of water availability and measurement of water applied.

**6.2 FRAMEWORK STUDIES.** The Council shall direct the preparation of hydrologic framework studies for each of the water management regions. These studies shall be prepared according to format and specifications developed by the staff. The studies shall be conducted by the Council staff, the staffs of the various ministries and agencies, and staffs of the Regional Water Commissions, as arranged by the Council staff. The initial studies shall utilize existing reports and agency information. For each water management region, the studies shall contain the following information:

- (1) Average annual surface water flow volume and description of surface water characteristics of each wadi.
- (2) Description of the characteristics of each producing water aquifer, including water table elevation contours, transmissivity coefficients, aquifer description, and estimates of recharge, outflow, sustained yield, and required outflow to the sea is applicable, etc.

- (3) Prospects for water conservation.
- (4) Determination of existing water use amounts for each water use sector, i.e., domestic, irrigation, industrial, etc.
- (5) Projections of water use for a fifty year time horizon for each use sector.
- (6) Description of existing water management institutions, including water rights structure and recommended changes.
- (7) Description of new data acquisition programs needed.
- (8) Estimates of economic returns for capital investments needed to increase water availability, reliability, and water measurement.
- (9) Prospects for developing new supplies or for using existing supplies more effectively (e.g., conjunctive use of surface and groundwater).

## **7. WATER BUDGET DATA**

Effective water management is founded upon water measurement data sufficient to determine a water budget for each individual component of the water system. Measurements of precipitation and runoff and groundwater levels are basic hydrologic data. The Department of Hydrology is vested with the responsibility to obtain these data in terms of a national network. In addition, the DOH should work with the Regional Commissions to assure that each water use entity measures accurately and maintains records for water intake amounts and timing, and discharges of used water. This principle applies to all withdrawals from both surface water sources and groundwater sources. In like manner, all discharges should be measured. Measurement of water used is an obligation associated with the right to use a public resource. All surface water diversions should be measured by stage recorders used in conjunction with Parshall flumes or sharp crested weirs. All groundwater withdrawals should be measured with totalling propeller meters. Records provided to the DOH must be certified in each case by a responsible authority. Falsification of records or negligence constitutes violation of the law. In event reliable records are not provided, the Department of Hydrology shall have the authority to measure the water, charging costs to the user. Further all water measurement instruments and recorders shall be protected from tampering. Within municipalities, all users shall be metered individually.

These data shall be compiled and published by the Department of Hydrology. Such data may be used in planning by the Water Resources Council, Regional Commissions, and Ministries, municipalities, irrigation districts, and other parties.

## **8. FINANCIAL ARRANGEMENTS**

Financing is a possible limiting factor in implementing any part of a water program. This applies to government service operations as well as capital improvement projects. Possible approaches to finance capital improvement include: issuance of revenue bonds in which repayment is made by the direct beneficiaries, issuance of general obligation bonds in which repayment is made by the public at large, and contributions of donor countries and organizations. To provide the needed financial services, a Yemen Water Bank, to be chartered by the YARG, should be considered. Financing of government agencies may be through special district taxes, revenues from charges, and general taxes. All financing arrangements for new projects are subject to approval of the Water Resources Council. Also, the Council shall recommend and review water related appropriations to the various ministries.

## **9. WATER QUALITY CONTROL**

The first obligation to water quality control is protection of public health. Thus all wastewaters should be treated. Also groundwater should be protected against contamination. Toward these ends, the following objectives should be implemented:

- (1) All communities receiving a water supply of 50 lpd or greater shall be sewerred.
- (2) Effluent standards should be established for all point source wastewater discharges.
- (3) All point source wastewater discharges should be treated to meet the effluent discharge standards.
- (4) Where reuse is feasible, the effluent should be treated to a commensurate water quality level.
- (5) Water quality monitoring networks should be set up for both surface waters and groundwaters.
- (6) Standards shall be established for providing safe, palatable water for public water supply systems (e.g., involving treatment, monitoring, cross connection control, etc.).

## **10. ENVIRONMENTAL PROTECTION**

Construction of new water projects or changes in practices should be assessed with respect to possible environmental damage, loss of antiquities, and disruption of social structure. The rate at which change can be assimilated by the social and political systems should be assessed as well.

## **11. GROUNDWATER DEVELOPMENT**

The Water Resources Council will provide leadership in the development and use of groundwater. The leadership objective is to assure that the "sustained yield" of the groundwater basin will not be exceeded, and to provide information on efficient use

of water. Licensing of well drillers, well permits, metering, etc. is desired as outlined in the corresponding document on groundwater policy. Because of special importance of groundwater, a Groundwater Management Act shall be promulgated separately from this document. This Act shall prevail in the event of conflict.

## **12. INSTITUTIONAL DEVELOPMENT**

The achievement of efficient and equitable water use and the assurance that overdevelopment of groundwater will be controlled will require new national institutions (e.g., the Water Resources Council, development of a water conscious ethic, etc.), new regional institutions (e.g., Regional Water Commissions), and reforms in local water institutions. The institutional development should include means to settle disputes.

## **13. TECHNICAL SERVICES**

The Water Resources Council shall support and promulgate the development of a Department of Hydrology Library, its data acquisition and storage service, and its information dissemination activities. Also the Council shall provide and promulgate the development of an extension service to advise and educate groups and persons about water use.

## **14. DONOR ACTIVITIES**

The Water Resources Council shall be informed on all water related activities of donor countries and organizations, and shall coordinate these activities. The Council, along with Regional Water Commissions, shall provide leadership in identifying needs in which donor activities can serve, and shall approve and monitor these activities.

## **15. NATIONAL WATER CODE**

A National Water Code should be developed over a period of years. Portions of the Code should be specific to the water regions and water districts to reflect the variations in local customs. The Code should be based upon Islamic law and local tradition, adopted to fit the modernizing development context of the country.

## **16. EXTENSION**

A water extension service shall be initiated at the University of Sana'a. Service personnel shall be attached to each of the Regional Commissions. They shall work with cities, irrigation districts, and farmers on all matters related to efficient water use. Also, the Service shall develop programs for public education about water use, e.g. video cassettes, short courses, site demonstrations, technical assistance, etc.

## **17. PROFESSIONAL CADRE**

A country-wide cadre of water professionals shall be institutionalized as a professional group. The group shall be comprised of persons in various fields such as economics, law, finance, sanitation, irrigation, water planning, etc. Members of the group shall be certified in their specialty area by an Academy of Water Professionals. Membership shall require a degree in a water field, two years of foreign practice, four years of practice in Yemen, an oral interview, and a satisfactory mark on written examination. Salary and rank in government shall be tied to Academy membership. Seals of Academy members shall be required on all documents pertaining to water.

Manpower requirements shall be assessed by the Water Resources Council. The Council shall arrange scholarships abroad for selected candidate for degree programs at the B.S., M.S. and Ph.D. levels. Two year foreign internships shall be required as a part of each scholarship. Upon return to Yemen, a twelve-month Yemen water indoctrination course shall be taken, supervised by the University. Academic studies, field trips, and internships with two or more private and government organizations shall be required.

## **18. IMPLEMENTATION TIME-TABLE**

The provisions of this Act shall be implemented in accordance with a time-table developed by the staff of the Water Resources Council. Years or decades may be required for some provisions. The staff should recommend amendments to the Act to reflect changing conditions and circumstances.

## **19. ANNUAL REPORT**

The Council staff shall prepare an annual report for the Council which will: review the current water situation in Yemen, indicate acute problems, and give direction for future activities. The report shall be disseminated widely. Each of the Regional Commissions shall prepare similar reports for the Provincial governors, to be distributed widely within the region.

## **6. GROUNDWATER POLICY**



## 6. GROUNDWATER POLICY

The government of the Yemen Arab Republic is very much concerned with the recent rapid decline of the groundwater table in many areas of the country. The problem is particularly acute in the Sana'a Basin. It is caused by the widespread adoption of modern drilling and pump technology, which has occurred over the past decade. Prior to this period, shallow hand-dug wells were used.

The groundwater resource in Yemen is invaluable and needs to be protected. Overpumping, seawater intrusion, and contamination are the hazards. Consequently, the government requested the CID Water Team to recommend emergency groundwater regulations to provide the needed protection.

As with out recommendations on national water policy, we have responded using the format of an act. Again, this format facilitates discussion and debate about definite provisions and which can be viewed from the broader perspective of a complete program.

### 6.1 KEY PROVISIONS

The themes of the proposed Groundwater Management Act are: (1) that a water balance must be maintained for each aquifer, i.e., over the long-term, annual withdrawals cannot exceed average annual recharge, and (2) that it is the policy of the government to manage the aquifer on such basis. The key provisions of the Act are:

- (1) Groundwater is a public resource belonging to all the people.
- (2) The right to use the groundwater resource shall be granted by the government.
- (3) The groundwater resource shall be managed as a renewable resource to be maintained in perpetuity.
- (4) Implementation responsibility shall be decentralized to the extent possible.
- (5) All groundwater withdrawals shall be metered.
- (6) All wells shall be registered. Permits will be required to drill a new well and to operate a well.
- (7) Well drillers shall be licensed.
- (8) The proposed Water Resources Council and the Regional Water Commissions shall have emergency authority to cut back on withdrawals.

### 6.2 PROPOSED GROUNDWATER MANAGEMENT ACT

The proposed Act which we have drafted deals with the need for emergency regulations as requested. But because the long-term need is for groundwater management, we have addressed this problem also.

# NATIONAL GROUNDWATER MANAGEMENT ACT INCLUDING PROVISIONS FOR EMERGENCY CONTROL

## 1. PURPOSE

It is the purpose of this Act to establish a national groundwater management policy and to provide for its implementation. The Act is intended to establish a policy which may work to meet short-term emergency needs and to provide for long-term practices to manage groundwater.

## 2. POLICY

It is hereby declared national policy that groundwaters within the Yemen Arab Republic shall be managed as a renewable resource to be maintained in perpetuity. Further, it is affirmed in accordance with the principles of the **Shari'a** that groundwater is a national resource common to and therefore owned by the people of the Yemen Arab Republic. As a consequence of this affirmation, this national resource will be managed and administered by the Government of the Republic for the common well-being and mutual benefit of its citizens. Therefore, the right to make withdrawals from the groundwater resources by the people of this Republic shall be subject to the rules established herein.

Within the guidelines of the Islamic Law **Shari'a**, priorities in the allocation of groundwater resources are by this Act established as being in the order of domestic, agricultural, and industrial uses. They shall also follow the **Shari'a** principle that the landowner has preferential rights to use groundwater underlying his lands because they exist in his lands, and the Islamic principle of right of prior appropriation or first in time, first in right as set forth in the texts of **fiqh** which are accepted by the appropriate authorities of the Republic.

## 3. RATIONALE

Groundwater occurs in underground formations of porous soil or fissured material. It moves through the formation under the influence of hydraulic gradients which exist naturally from recharge areas or which are imposed by artificial means such as injection wells. The basic premise in the management of a groundwater basin is that the sum of annual withdrawals from wells and natural outflows cannot exceed the average annual recharge rate. A continuous trend of static water table decline, for example, indicates the principle is being violated and that the aquifer is being overdrawn. Such condition will be to the detriment of all users. Not only will it become necessary to incur the expense of deepening wells, with higher pumping costs, the aquifer could be literally depleted of water. Because of the slow movement of groundwater, recovery of an aquifer is usually in terms of years or decades; thus, excessive water table decline may be considered as irreversible damage to the aquifer. Therefore, it is incumbent upon government to promulgate rules for the common good so that any aquifer can be maintained as a water source in perpetuity. Such rules shall be enforced in an equitable manner as determined by the agency administering the Act, and subject to appeals by the courts.

By the same token, an aquifer may be irreversibly damaged by pollution from contaminants finding their way to the aquifer. Protection of the groundwater body against damaging contaminants shall be a further responsibility of both citizens and public authorities.

Seawater intrusion is a special case of groundwater contamination which, in Yemen, is unique to the Tihama Plain. Once an aquifer is so contaminated the effect is, again, irreversible. Thus, development of the Tihama Aquifer requires special analysis and controls such that intrusion of seawater can be averted.

## 4. ADMINISTRATION

4.1 WATER RESOURCES COUNCIL. The responsibility for the promulgation of this Act shall be vested with the Water Resources Council. The Council shall designate an agency to administer the Act, or in lieu of a single agency, two or more agencies to administer different portions of it. Unless specified otherwise, the administration shall be delegated as follows:

- (1) Aquifers serving as principal water sources for urban populations shall be managed by the National Water and Sewerage Authority.
- (2) All other aquifers, i.e., those serving villages and as irrigation water supplies principally, shall be managed by the Ministry of Agriculture.
- (3) Monitoring of aquifer water levels and withdrawals and water quality data shall be coordinated by the Department of Hydrology.

4.2 AUTHORITY. The responsibility and authority for implementation of this Act shall be decentralized to the Regional Water Commissions working with the cooperation of the Provincial Governors. The Provincial Governors within a given water region shall be members of the Regional Water Commission.

4.3 REGIONAL WATER COMMISSIONS. Regional Water Commissions are discussed in the National Water Policy Act.

This section expands on the makeup of Commission members and the responsibility and authority of the Commission as related to groundwater management. The membership of the Commission shall be comprised of the Governor or his delegate, one or more representatives of water oriented regional development authorities as may exist (e.g., the Tihama Development Authority), a representative from each Local Development Authority, a representative from each municipal water department, and representatives of other agencies as may be appropriate, including regional representatives of MOA, NWSA, etc. At least two members of the Commission shall be engineers. The Commission shall retain the services of an attorney who shall advise on matters of water law. The Commission shall have an Executive Director who shall be an educationally and professionally experienced water qualified personnel. The Commissions members shall serve terms of four years, individually staggered. The executive director shall serve a term of five years, renewable at the pleasure of the Water Resources Council who shall consider the recommendations of the Governor and of the Commission.

**4.4 DUTIES OF THE COMMISSION.** The commissions shall enforce the Act in a manner and at a rate of implementation that is sensitive to local conditions including political atmosphere, social conditions, the need for economic development, and the imperative that a long-term water balance be achieved or maintained. The Commission shall levy penalties to individuals including corporations, municipalities, or groups who withdraw water in violation of their permits or to well drillers to enforce the provisions of this Act and to develop any necessary regulations to protect the aquifers under its jurisdiction from long-term overdraft, from pollution, and from seawater intrusion (for those aquifers of the Tihama Plain).

The Commission shall authorize studies as necessary, in cooperation with the pertinent agency of the national government, to determine the "sustained yield" or each aquifer under its jurisdiction. Generally, this determination shall be based upon long-term records of water table measurements, e.g., empirically, vis-a-vis by modeling approaches. For the short-term, however, the sustained yield shall be based upon whatever methods are determined appropriate by qualified professionals.

The Commission shall assure that all water withdrawals from each aquifer under its jurisdiction will be measured, and that records will be maintained and analyzed. Such records will serve as the basis for enforcement and for determination of total annual withdrawals of water. If total withdrawals for any given year are determined to be in excess of the long-term sustained yield, the Commission shall determine a formula for cutback of withdrawal amounts on individual permits as they are renewed.

## **5. GROUNDWATER REGIONS**

The country will be subdivided into "hydrologic regions" and into "water management regions." The Tihama Plain is an example of a hydrologic region. Within each hydrologic region, hydrologic units shall be identified. Wadi Zabid is an example within the Tihama. In some cases, the hydrologic region may have only one hydrologic unit identical with the region. Within each hydrological unit, groundwater basins will be identified. In some cases where an aquifer intersects several hydrologic units, as in the Tihama Plain, groundwater basins may be artificially designated in accordance with hydrologic units. These basins will be the basis for management of the groundwater resource. The knowledge will be used in the formulation of the water management districts described in Section 5 of the National Water Policy Act.

## **6. METERING**

**6.1 GENERAL.** All pumped water withdrawals from any groundwater basin shall be measured by a propellor type totaling water meter. All meters within the Yemen shall be of one proprietary brand. The choice shall be based upon reliability, simplicity, accuracy, ease of maintenance, tamper-proof qualities, reading features, and availability of spare parts and cost. Several meters shall be installed for one year trials prior to the final selection. The WRC will make the final selection with the advice to the Regional Commissions. The meters shall be owned by the respective Regional Commissions. They shall be paid for by the well owner's permit fees; the cost may be amortized over a ten-year period.

**6.2 READING AND MAINTENANCE.** Each meter shall be read at regular intervals, which may be quarterly, semiannually, or annually, as appropriate. The meter readings shall be recorded on forms provided by the WRC. The owner shall be informed of the amount of water used during the period relative to the permit allowance, and of the quarterly charges for the water pumped. The meter shall receive routine maintenance in accordance with a regular schedule. Any evidence of tampering with a meter shall be a misdemeanor and subject to penalties.

## **7. PERMIT REQUIREMENTS**

All owners of wells having mechanical pumps must: (1) have registration for the well, and (2) have an operating permit. In addition, any party desiring to drill a new well must have a drilling permit.

**7.1 WELL REGISTRATION.** Every well, either new or old, having a mechanical pump shall be registered. The registration shall contain the following information:

- (1) Purpose of well (e.g., irrigation, municipal water supply, individual water supply).
- (2) Number of persons to be served or number of hectares to be irrigated.

- (3) Date well was drilled.
- (4) Date registration is submitted.
- (5) Pump and motor specifications (e.g., type of pump, impellor diameter, capacity of pump at specified head, power of motor, type of motor, motor rpm).
- (6) Well log data.
- (7) Diameter of well.
- (8) Drilling method used.
- (9) Casing information.
- (10) Depth of static water level at date of filing.
- (11) Protection provided from surface drainage.
- (12) Proposed daily and annual operating schedule.
- (13) Coordinates of well.
- (14) Distances to other wells.
- (15) Descriptive location of well.
- (16) Pumping test results.
- (17) Name of drilling contractor.

An addendum to the registration shall be filed at the time any significant changes are made.

The well registration shall be filed with the Regional Commission, who shall provide a copy to the Department of Hydrology. The DOH shall maintain the records by computer file and shall map the location of each well. A registration certificate shall be a metal plate attached to the motor housing and shall contain information on the date of registration, the name of the owner, and the name of the drilling contractor.

**7.2 OPERATING PERMIT.** Each well owner must have an operating permit. The initial permit application shall be filed with the Regional Commission and shall be accompanied by an application fee sufficient to cover the cost of processing the application. The application shall contain the following information: (1) date, (2) date of filing of registration, (3) annual amount of water to be pumped, and (4) daily maximum amounts of water to be pumped.

The permit application shall be processed within 60 days of filing. The permit shall state the limit on the annual amount of water to be pumped, the daily maximum withdrawal amount, and the charges to be levied annually, and the penalties for non-compliance. At the time the permit is issued, the well owner must pay a one time fee to cover the cost of the meter and the cost of installation. The fee shall include also the first year fee for meter reading costs and maintenance. The latter fee is payable annually in advance. The owner shall be charged for any damage to the meter and shall be levied a penalty charge for not reporting such damage within thirty days. All permit applications shall be renewed every five years, i.e., in 1985, 1990, 1995, 2000, etc.

**7.3 ENFORCEMENT OF REGISTRATION REQUIREMENT AND PERMIT COMPLIANCE.** Each well owner shall register the well or wells owned within six months of passage of the Act. If the owner is unable to process the registration and or the permit application, the Commission should be notified. A staff member will provide the necessary assistance. A licensed well driller may provide the information needed.

The operating permit must be obtained within six months of passage of the Act. Noncompliance with permit procurement shall cause the well owner to be subject to a fine. Penalties for noncompliance with the permit withdrawal amount shall be in terms of either user charges, or reduction in withdrawal, or in the case of chronic violation, well shutdown, as determined by the Commission.

**7.4 EXTENSION PROGRAM.** Education of well owners to operate their pumps in compliance with their respective permits shall take place on a continuous basis as a program of each Regional Commission. Penalties for noncompliance with the operating permit shall be waived until two years after passage of the Act. Flagrant and willfull violators will be subject to penalties.

**7.5 DRILLING PERMIT.** Any party desiring to drill a new well must obtain a drilling permit prior to commencing work. The application should state all information feasible to state on the well registration form and should be accompanied by an operating permit application. These two documents comprise a drilling permit application. The application shall be processed within 90 days of receipt by the Commission.

A drilling permit may be denied or modified for the following reasons: (1) the well may interfere with existing ones in the vicinity, (2) the groundwater basin is already overappropriated, (3) plans have been developed or are developing for full appropriation of the groundwater basin, and (4) uncertainty exists as to whether the basin is overappropriated. If a permit is denied or modified substantially, the applicant may appeal to the Commission, and if not satisfied, through courts. Application for wells to supply domestic water shall be given highest priority, but no permit shall be given if the persons to be served are within the service area of a public water supply capable of supplying the necessary service.

## **8. LICENSING OF WELL DRILLERS**

Well drilling shall be done only by qualified licensed well drilling contractors. The granting of a license and its renewal shall be based upon experience, equipment inventory, past record of accomplishments, financial responsibility, and continued compliance with the provisions of the license. To maintain a current license, the contractor shall submit an annual report indicating the number of wells drilled, the location of each, well logs, and results of drawdown pumping tests for each. Both shall be certified by the well driller and copies shall be furnished to the well owners. The contractor shall inform the Regional Commission of any well drilling activities ongoing or planned. This is to serve as a cross-check on the compliance of owners with well drilling permit application.

The license shall be renewed annually by the Commission subject to payment of a license renewal fee and the filing of the required report. Failure to comply within thirty days will result in a late fee penalty. Failure to comply within 90 days will result in another late fee and the license will be suspended. Failure to comply within six months will result in the license being revoked. Reinstatement will require payment of penalty fees and reapplication. Notifications will not be given by the Commission.

## **9. WATER QUALITY MONITORING**

Water samples shall be obtained from each well at least once each year. The samples are to be collected by representatives of the Commission at the time meters are read or as routine meter maintenance is performed. Sample collection and reporting procedures are to be specified by the DOH. Both chemical and bacteriological analyses shall be performed.

## **10. EMERGENCY CONTROLS**

The WRC shall review, together with the Regional Water Commissions and the Provincial Governors, the status of each groundwater region of the country within 60 days of passage of this Act. The Council will then classify all regions with respect to severity of overpumping, pollution, or seawater intrusion.

Those aquifers in danger of irreversible damage, as perceived by the judgement of the Commissions and the Governors shall be declared subject to emergency controls. If Commissions have not been formed the WRC shall assume that role. In such cases, the Council shall have authority to: (1) define the boundaries of the emergency zone, (2) categorically ban construction of any new wells, and (3) issue pumping cut back schedules for existing wells. The authority of the Commission to implement these provisions shall be absolute. Violations will be subject to fines, to withdrawal of the owner operating permit, or to closure of the well, as necessary. An Appeals Board shall be appointed by the Commission to hear appeals of parties having contentions.

At any time this provision is implemented the Commission shall institute simultaneously a citizen education program. The program shall be aimed toward explaining to the well owners, the affected parties, and the citizens at large the reasons for invoking the emergency control provision.

## **11. REALLOCATION OF WATER RIGHTS**

Because the emergency control section of this Act is likely to be invoked for a long-term, provision shall be made for reallocation of water withdrawal permit allocations through purchase. Such purchases shall be permitted from agricultural users to domestic users. In some cases private agricultural wells may be condemned by Regional Commissions in behalf of municipal water districts. Condemnation shall be granted only after the municipality has made diligent efforts to reduce consumption through household metering and adoption of a rate structure aimed at reducing waste and at controlling of leaks within the system. Also there should be consideration of the feasibility to replace a portion of the condemned water with treated wastewater. Prior to condemnation, the municipality shall make every effort toward purchase of a permit allocation. Such purchase efforts shall be initiated years in advance of actual need. In event purchase is not possible, the condemnation shall start with the most junior permit holder.

## **12. EXCEPTIONS**

The policy of sustained yield for all groundwater basins shall prevail as the general operating policy of the country. Exceptions are: (1) a groundwater basin already may be depleted of significant storage at the time this Act is implemented, and (2) it may be justifiable to utilize groundwater in some basins as a stock resource. In the former case, the basin should be operated on a sustained yield basis for all subsequent years. In the latter case, a groundwater basin may be operated as a stock resource only after development of a long-term plan and upon recommendation of the Regional Commission and approval of the Council.

## **13. SCHEDULE OF IMPLEMENTATION**

The SRC shall draw up a schedule for implementing the provisions of this Act consistent with funds, available staff, and a commensurate citizen education program appropriate to the different regions of the country. In general however, Section 10, Emergency Controls, shall apply immediately and so shall Section 7.4, Drilling permit, and Section 8, Licensing of Well Drillers.

It is recommended that full implementation of the Act be carried out at a fast timetable in two or more selected groundwater basins or regions.

#### **14. STAFFING**

Full implementation of the Act will require both a professional engineer cadre in the responsible agencies and a group of trained technicians and clerks to maintain meters, read meters, measure water table levels, record and store data, process permit applications, direct the data acquisition and processing, interpret data results, enforce the Act, and advise the Council and the Regional Commissions, as the case may be. The professional cadre should be baccalaureate level graduates of recognized engineering schools with two or four year internships with established agencies. An Engineer-in-Training certificate is strongly recommended and a professional engineer's license is encouraged.

Development of sufficient professional cadre may require 10 to 15 years. The professional cadre will train the technicians and clerks. It is recommended that a training program be instituted at one of the two recommended pilot management regions. In addition, the pilot management region should be used to establish operating procedures and to more accurately determine staffing requirements.

#### **15. FINANCING**

The beneficiaries of the groundwater resource shall bear the primary cost of the groundwater management costs. The fees charged shall, after 10 years, be adequate to cover the cost of operating the Regional Commissions and the central staffs at the national government. The fee structure shall begin slowly. Those paying the fees should be educated that such management costs are necessary both to assure a degree of equity in allocation of the resource and to preserve its long-term productivity.

## **7. ON-FARM WATER MANAGEMENT**



## 7. ON-FARM WATER MANAGEMENT

Agriculture has been an economic pursuit in Yemen for thousands of years. But it has been subsistence largely, with only a nominal amount of market orientation. Recent increases in personal income due to employment opportunities abroad have upset this ancient balance. With the country committed to economic development, agricultural productivity is of special concern. This chapter reviews some of the factors related to agricultural productivity, with special focus upon water.

### 7.1 BACKGROUND

Useful background information on agricultural activity in Yemen is provided in the CPO Swiss Report (1978). A few facts are extracted from this report to provide a brief contextual overview of the subject.

The area of Yemen is about 135,200 sq. km. Cultivated land amounts to 1,515,000 ha, or about 11 percent of the land area. Rain-fed agricultural land is about 1,277,000 ha, most of which is terraced land. Figure 2.5 shows its geographic distribution. The other 238,000 ha are irrigated of which 120,000 ha are spate irrigated and 73,000 ha are irrigated by pumped groundwater.

Grains, e.g., sorghum, millet, maize, wheat and barley are grown on 90 percent of the cultivated land. However, these crops are not marketed. The market oriented production is limited to a few crops such as cotton, hides, coffee, qat, vegetables, fruits, and live animals.

Of special interest is the level of exports of food and fiber in relation to imports. In 1975 through 1976, the exports of the above mentioned market crops was 40.6 million Yemen Rials, compared with commodity imports of 839 million Yemen Rials. Total exports and imports were 50.0 and 1797 YR, respectively.

### 7.2 PROBLEM

The question of how to increase the productivity of agriculture has many facets, e.g., technical, economic, social, political, cultural, etc. Agricultural economics is the most prominent and must be the analytical basis for any comprehensive program related to this subject.

Another facet relates to water. How can the water resources be exploited and utilized to maximize agricultural production? The question is addressed in this chapter. Both rain-fed terraced agriculture and irrigated agriculture are considered. The main emphasis on the latter.

### 7.3 PRESENT PRACTICES - OBSERVATIONS

Terraces. Growing crops on the steep mountain terraces of Yemen is a highly labor intensive operation. It lends itself to very little, if any, economical mechanization. Further, due to the terrain

characteristics, mechanization would be difficult and perhaps not economic. But this ought to be studied.

Productivity of these terraces varies from good to poor. The fertility of the soils was not determined but this variation in production is no doubt due to differences in such factors as fertility, frequency and amount of rainfall, and management.

Irrigation of crops on these mountain terraces is dependent entirely upon rainfall. Fertility and crop rotation appear to offer the best possibilities for increasing both the quality and quantity of crops grown. Nontillage is proving very effective throughout the world and should be given consideration also. Planting a new crop with the residue of the recently harvested crop still on the ground is proving beneficial in erosion control, tilth, etc.

Transporting crops off the terraces has and always will remain a tremendously difficult job and adds to the fact that terrace farming will always remain a rigorous way of life. Consideration should be given to what might happen if farming should cease on these terraces.

High Plains. Some of the high plains areas of Yemen offer good possibilities for increased food production. In some areas, the flow of water in the wadis is continuous, in others, it is intermittent. Areas where the streams are intermittent offer possibilities for underground water development. With careful development and use of the underground supply, wells could be utilized to supplement irrigation water during periods when the wadis are dry. "Safe yield" which is the balance between withdrawals and recharging capabilities should be the determinant. It should be kept in mind, however, the improved water application efficiency will result not only in less water lost to the atmosphere by evaporation, but also in less water percolating into the underground supply.

Tihama Plain. Traditionally, crop water requirements on the Tihama Plain have been met by the flood waters from rains in the mountains. Groundwater has been another source of supply which has been developed rapidly over recent years. More effective management of both the surface and groundwaters could increase substantially the productivity of these lands. The basic idea is to provide the means for all farmers to irrigate in accordance with crop water needs rather than only when water is available. This could be done by utilizing groundwater conjunctively with surface water and perhaps developing additional surface storage. Institutional modifications would be necessary to permit this practice.

The flood waters in the wadis are generally of high intensity and short duration, although some have a constant base flow which is somewhat dependable. Use of these flood waters for irrigation is accomplished by constructing diversion dams to direct the water out of the wadis and into canals. Most diversion dams are built by hand or tractor from the sediment deposits in the wadi. High intensity floods wash away these dams and constant replacement is

necessary. Construction of a more durable diversion structure should be a long-term goal. The large one at Wadi Zabid is an example, but it is very expensive.

These designed structures will not only reduce labor requirements, but they will provide for both better control of the water and measurement. Good control and measurement are necessary if improved water distribution is to be practiced. It was not clear that measurement devices were a part of the diversion works at Wadi Zabid. Nor were headgates seen in the distribution system to control the flow of water onto the land.

At Wadi Zabid it was reported that as much as 100 cm is applied at one time. The project could be further developed to permit both measurement and better control. Such upgrading would provide a good model for similar development of other wadis.

Groundwater development in the Tihama Plain provides a strategic opportunity to provide assurance that crop water needs may be satisfied, which could greatly increase the productivity of the irrigated lands. Such groundwater development should not be committed to new irrigated lands. Rather the groundwater should be used in the conjunctive use mode to stabilize the water availability to lands presently irrigated. Also measurement of such groundwater withdrawals is imperative. Measurement of withdrawals combined with observations of the water table over a period of years can permit determination of the "safe yield" of the aquifer. The penalty for violation of the safe yield concept can be severe or disastrous. This is especially true on the Tihama Plain where the penalty is seawater intrusion.

#### 7.4 GENERAL RECOMMENDATIONS RELATED TO AGRICULTURE

While the main emphasis is upon water, a variety of factors are involved, and are addressed below. They include the following:

- (1) Timing of Water Applications. Water needs to be applied to a crop when the root zone moisture is depleted. This requires storage so that the timing of irrigations can be controlled rather than be dependent upon the vagaries of natural floods. Such a storage reservoir exists in groundwater, which should be utilized in this manner, i.e., in conjunction with flood flows in adjacent wadis.
- (2) Efficient Irrigation. Irrigation in excess of the amount needed to bring the moisture in the crop root zone to field capacity is not beneficial to the crop. The current practice of spate irrigation often irrigates fields with 100 cm of water during a single irrigation; the root zone may need only 10 to 30 cm, depending upon type of crop, stage of growth, soil type, etc. While it may be argued that the excess water applied replenishes groundwater, alternative practices ought to be studied relative to costs and benefits of increasing irrigation efficiency, and the role of low irrigation efficiency in maintaining groundwater.
- (3) Land Leveling. The terraces in the mountain areas are well graded and well drained. But on the coastal plains, land

leveling is needed. Fields which are not level cannot be irrigated efficiently by flood methods.

- (4) Cultural Practices. Cultural practices have been developed over the years. Mechanization and utilization of pumps for irrigation have created a need to develop new practices appropriate for modern agriculture.
- (5) Mechanization. In some instances, utilization of agricultural machinery is needed. The use of smaller mechanized equipment should be investigated also. This would include small hand tractors, implements, sprayers, etc., such as found throughout the Far East.
- (6) Fertilizers, Insecticides, Weed Control. There is need to study the role of fertilizers, insecticides, and herbicides. Weed control may be also a matter of improved cultural practice.
- (7) Seed. The farmers tend to sow and plant their own seed from year to year. Even under the best conditions, this is not good practice. Even good seed through natural selective processes tend to "run out." Good seed, both local and imported, appears available but not widely distributed or utilized. There is a need for an expanded and active seed multiplication project.
- (8) New and Improved Varieties. The need for new and improved varieties is often exaggerated and overemphasized in developing countries. More often, much can be accomplished through selection and improvement of local varieties. Varying the date, rate, and method of planting can accomplish much.
- (9) Agricultural Storage and Farmer Cooperatives. Marketing in Yemen appears to be carried out by the private sector. In many instances, marketing is done on a weekly basis and is highly monetized. Thus exchange is based on the market value of the goods exchanged. Farm cooperatives could play a vital part in the marketing of produce. On-farm storage appears totally inadequate and that of the trader or middleman little better. The need for government guidance in storage and marketing appears critical. There is an important relationship between the cost of local production and imported goods from countries more fully mechanized.
- (10) Land Tenure and Tribal Dispute. Land tenure is generally detrimental to agricultural development, particularly large scale development. Tribal disputes apparently most serious in the northeastern portion of the country contributed little to development. Regardless, these are factors that must be lived with and considered when planning development programs.

In traveling throughout YAR, it was evident that the Government, as well as various donor agencies, were placing emphasis on the above points. Much has yet

to be done, however, and the above considerations should be addressed further.

## 7.5 SPECIFIC RECOMMENDATIONS FOR IMPROVED ON-FARM WATER MANAGEMENT

**Local Water Administration.** Farmers should become acquainted with legal and administrative structures used in their local areas and then become active in influencing improvements in existing laws and patterns of operation.

**Irrigation Organizations.** The type of organization formed to deliver irrigation water and to drain land is of the utmost importance in implementing efficient water management practices. Good irrigation projects have failed because an inappropriate form of organization was adopted.

The most successful irrigation enterprises have been those owned and operated by the water users. When the users are involved directly their interest is keen and their services are rendered at a more nominal cost. Most of these enterprises are operated on a nonprofit basis.

**Management.** The most important factor in good water application efficiency to provide optimum crop production is management. This involves measurement and control of water applications and timing of such applications to meet the demands of the crop. The type of irrigation system is important but the most sophisticated irrigation system will not operate efficiently if it is managed poorly. Teaching farmers the basic techniques of good on-farm water management is just as important as the technology used. An agricultural extension service must have an important role here.

**Research.** The development of new crop varieties, disease control, investigation of improved water management practices, etc., are topics for research. A research program should be set up through the University to address the continuing questions related to improvement of farm productivity in Yemen.

**Demonstration.** The demonstrating of known facts and practices at the farm level is a necessary adjunct to research. In Yemen this can be accomplished in two ways. Demonstration projects can be established. Within each project, an area can be set aside for the growing of crops intensively and to demonstrate good cultural practices. This would require personnel trained in all aspects of growing crops. A second method is to develop trained extension agents who can take known and proven cultural practices to the farmer and assist him in adapting them to his own farming conditions.

**Drainage.** In the reports and plans for irrigation projects in Yemen, not enough attention has been given to drainage. No irrigated agricultural project has been successful for any length of time without including drainage. Irrigation and drainage go hand in hand. Adequate drainage improves soil structure and perpetuates the productivity of soils. Drainage is the first requirement in reclamation of waterlogged saline and alkali soils. Drainage also improves sanitary and health conditions and makes rural life more desirable. A drainage program should be an integral part in each irrigation project.

**Demonstration Farms.** Recognizing the need for applied agricultural research and extension, and in accord with a request from the Ministry, the establishment of two demonstration farms is recommended. The principle function of these farms would be to develop and demonstrate improved water management and other cultural practices essential to increase food production. Demonstration plots would also be established on the property of the more progressive farmers, thus encouraging other farmers in the area to adopt improved practices and techniques. It is envisioned that these farms need be no larger than 25 to 30 hectares. Although not specifically included in the program, consideration should be given to storage facilities, transport, marketing, and seed production. Some cooperative effort could be undertaken with the recently established FAO Seed Multiplication Program located in the Tihama.

Training programs for local personnel should be an integral part of the program. This should include on-farm training as well as overseas degree work. It would be possible to develop short courses (six months) with such companies as International Harvester and John Deere.

**Tihama Plain Demonstration Farm.** Several locations have been suggested as possible sites for a demonstration farm. One of the more promising sites seen on the Tihama Plain was the Gumeisha Project in the Wadi Surdud area. This site has graded land and proven sources of water. Also it is easily accessible from Hodeida. Such a location would offer the opportunity to establish a project which would make a significant contribution to the agricultural production in Yemen within a period of one year. To establish a similar project on undeveloped land would require possibly three years. The recommended work to be undertaken could be:

- (1) Demonstration of new and proven methods of on-farm irrigation, utilizing both surface and groundwater.
- (2) Development of new and improved cultural practices and techniques.
- (3) Testing of different crop varieties and development of cultivars more suited for arid and semiarid conditions with limited irrigation.
- (4) Testing and evaluation of different levels of fertilizer application.
- (5) Test and evaluate insecticides and herbicides.

**Wadi Jawf Demonstration Farm.** Development in the Wadi Jawf region is considered especially important by the Yemen government. Social conditions have resulted in different methods and practices of agricultural production and animal husbandary. There is a need for demonstration and extension in the following areas:

- (1) Development of new and improved on-farm water application techniques.
- (2) Development of new and improved cultivars adapted to local conditions. Emphasis should be placed on crops having drought and salinity resistance.

- (3) Development of new or improved cultural practices and techniques are needed, related to date, rate, method of planting cultivation and harvest, and investigation of possibilities for mechanization.
- (4) Determination of appropriate type, rate, and timing of fertilizer application.
- (5) Crop production. Study local pests and diseases to determine control measures.
- (6) Investigate drainage needs and include needed practices.

Much agricultural development work has been undertaken and completed in the coastal plains region. Still there is need for more demonstration and development of improved methods which will increase food production. Wadi Jawf presents a different situation in that the area has been largely ignored insofar as development is concerned. The development of improved water utilization or management is coincident with other aspects of development. The proposed demonstration fits with this overall impetus to develop the region. With proper planning and careful screening of expatriate personnel, the proposed projects could yield significant results. The program would be in harmony with the USAID goal to improve the daily life of individual farmers.

## 7.6 IRRIGATION PRINCIPLES

The importance of modifying irrigation practices to conform to modern notions of scientific irrigation cannot be over-stressed. Not only will the water supply go farther, but crop yields will increase.

There are two basic principles in scientific irrigation. They are: (1) irrigate before the crop is physiologically stressed by moisture depletion in the root zone, and (2) irrigate the root zone to field capacity and no more. Timing of irrigation and irrigation efficiency are the ideas embodied in these principles.

To translate these principles into practice the following steps comprise a workable protocol. They are:

- (1) Determine depth of root zone of the crop, and soil type. From this information determine water depth stored in the root zone at field capacity. For example the root zone of barley is about 77 cm. The available water stored in the root zone for consumptive use would be about 10.7 cm for a medium soil.
- (2) Schedule irrigation based upon depletion of about half of the available moisture from the root zone (for maximizing crop production). For example, if the consumptive use is 7 mm per day, irrigation would begin after  $107 \text{ mm} \times .50/7 \text{ mm/day} = 7.5 \text{ days}$ .
- (3) The use of water by crops varies over the farming season. The consumptive use rate of crops in millimeters per day generally increases from the time of planting until flowering, and then declines to harvest. Soil moisture sampling is the best guide for irrigation timing. It is important that the crop have sufficient water in the root zone during flowering, a most critical period.

- (4) Water should be applied to the depth required to fill the root zone. This requires measurement of the water flow to the field and calculating the time required for the flow. For example, if the root zone requires 5.4 cm of water, the field is 5 ha in size and the flow of the irrigation stream is 30 liters per second, the time,  $t$ , required for irrigation is:

$$t = \frac{28 \times 5 \text{ ha} \times 54 \text{ mm}}{30 \text{ liters/sec}} = 25.2 \text{ hours.}$$

(The factor 28 is a conversion for the heterogenous units.)

- (5) Irrigation efficiency is defined as:

$$\text{Eff.} = \frac{100 \times \text{water used by crop}}{\text{water delivered}}$$

If the depth of water applied in the above example is 13.5 cm, the irrigation efficiency would be:

$$\text{Eff.} = \frac{5.5 \text{ cm}}{13.5 \text{ cm}} \times 100 = 40 \text{ percent.}$$

Different irrigation systems have different efficiencies. For Example, wild flooding may have 30 to 50 percent efficiency with good management and 10 to 30 percent with poor management. By comparison, the corresponding figures for drip irrigation are 60 to 80 percent and 50 to 60 percent.

Although the above principles are ideals, they can be implemented into practice. To do so may require institutional modifications, education of farmers, and capital investment. Whether they are worth pursuing and to what extent is a question which should be addressed. The answer could be the basis for a water policy for irrigation agriculture.

## **8. WATERSHED MANAGEMENT**



## 8. WATERSHED MANAGEMENT

The present landscape of Yemen has been formed over eons of geologic time. Upon this primeval landscape the influences of an agrarian civilization has been superimposed; this has occurred recently, over the last several millennia.

This influence of man's activities on onsite land condition and downstream hydrology is not well understood, nor is it appreciated. These "watershed management" considerations are seen in the steeper mountainous regions of Yemen, typified by the central mountain chain which parallels the Tihama Plain.

Attention here will focus on the effects of land use and condition of such lands on local and downstream hydrology. The existing and potential influences are indeed immense.

### 8.1 MOUNTAIN WATERSHEDS

The mountainous lands which serve as the source of most of Yemen's water supply are characterized by steep slopes on a variety of rock types and soils which reflect a long history of land use. Precipitation occurs as rainfall; it varies with elevation, latitude, and season. A network of steep rocky channels drain into deeply entrenched canyons, which open onto the lowland forming wadis. The wadis are often intermittent, depending upon whether they are fed by groundwater during the periods between floods. Springs are scattered throughout but do not appear to be especially numerous, and some hot springs can be found. The majority of the streamflow arises directly from rainfall, and is thus both episodic and sediment-laden. The chemical quality of the streamflow is generally good; it is largely calcium bicarbonate at concentrations in the 400 to 600 mg/l range.

### 8.2 LAND TYPES

Small plot agriculture and rangeland grazing occupy virtually all of the watershed lands. These lands are categorized as the following types.

- (1) **Terraces.** The terraces are the most conspicuous and noteworthy feature of the Yemen landscape. They were constructed by hand labor over a long period of time. The terraces are used for both irrigated and rain-fed agriculture, and to a lesser extent for grazing. When properly maintained and operated, erosion is minimal.
- (2) **Bare Areas.** A sizeable portion of the watershed lands are free of both soil and cover. This condition has resulted from abusive land use on erosion-prone sites. In extreme cases, such erosion has proceeded to bedrock, which allows only sparse vegetation. These lands generate runoff, feeding both local terraces and downstream riparian areas. It is also possible that some of the original soil cover

is now in nearby terraces, transported by the runoff. Because soil loss has been complete, very little erosion occurs on these lands.

- (3) **Erosion Pavements.** In some cases, especially on shallower slopes, erosion has proceeded to an equilibrium situation consisting of soils protected by a stony cover. The resident soils lack upper horizons and are low in organic material, having evolved under conditions of low cover from heavy land use and constant incipient erosion of fine particles. Occasionally, they may be cropped, but usually they are grazed. Soil loss occurs on these lands, but it may not be excessive. Potential for further erosion does exist given exceptional abuse.
- (4) **Riparian Lands.** In streamside situations and small valleys, alluvium from upland erosion has accumulated. Almost all of these lands are used for agriculture and much of it is irrigated. The soils are mostly textured and azonal, and seem to be productive. Sometimes the channel bottoms are cultivated too. Bank erosion is common, and constitutes a major source of stream sediment, especially from the steeper upland channels.
- (5) **Abused Forest and Range Lands.** Several observers (e.g., Harris, 1979) have mentioned lands recently deforested and/or subject to markedly increased grazing pressures. Such lands are said to be undergoing desertification, a process characterized by a plant community of a more xeric nature, erosion, and reduced productivity. They may be seen as evolving towards Types 2 and 3 above, i.e., bare areas and erosion pavements. It may thus be presumed that many of these lands (especially on steeper slopes) are currently eroding, and contributing a large sediment burden to downstream channels.

### 8.3 HYDROLOGY—THE ROLE OF THE TERRACES

Under primeval conditions a variety of native vegetation probably covered the watersheds ranging from hardwood forests in the highlands to brush, grass-savannah, and finally grasses and denser vegetation in the extreme lowlands. Resident soils have developed accordingly. Corresponding to these watershed conditions, the hydrologic regime was much more subdued than exists presently. It was characterized by less response to rainfall, less erosion and sediment transport, more uniform flow distribution over time, and perhaps less total streamflow.

This virgin situation has been changed markedly but not in the usual classic despoliation sense witnessed in many other parts of the world. The mitigating factor is the extensive terrace system which traps rainfall on its flat surfaces and receives

stormflows from nearby source areas. At the same time, the terraces serve as a major agricultural resource; they are comprised of flat land in the midst of steep mountains. The terraces also counterbalance the hydrologic characteristics of the bare areas.

The storm runoff not used for upland irrigation forms a major portion of the lowland water supply, both in spate irrigation and groundwater recharge. In fact, the downstream areas have become dependent on this irregular water resource. The flood waves from the uplands are diverted into the spate irrigation systems and otherwise infiltrate through channel beds and by deep percolation recharge groundwater.

The present balance, which has existed for several millennia, occurs because there are sufficient terraces to trap rainfall and receive a portion of the flood flows, and to hold the upland soil in place. Without the terraces, the hillsides would erode, sediments would pour downstream, enormous wasteful rainfloods would ensue, and the valuable agricultural base of the country would be lost. Clearly the terraces are important both hydrologically and agriculturally.

#### 8.4 WATERSHED MANAGEMENT PROBLEMS

Given the long history of agricultural development and land use, exacerbated by recent deforestation and increased grazing, problems on Yemen's watersheds are expected, obvious, and widespread. Two general categories are: (1) those related to forestry and range management, and (2) those associated with terrace systems. The latter is by far the more important.

- (1) Forest and Range. The range and forestry problems are those which may be anticipated for the existing watershed conditions. The unmanaged range is depleted and producing at low levels. Also, it is providing meager protection from erosion. Recent extensive cutting and grazing on already limited forested lands has reduced forest products production and increased erosion potential. This has occurred not only over the ages of Yemen history, but also, according to some sources with increasing intensity over the past several decades.
- (2) Terraces. The upland terraces found in Yemen's mountain slopes are both an agricultural resource and a major runoff control system. The downstream flow regime and sediment supply and transport is strongly influenced by their presence. Their effectiveness, however, is dependent upon their being maintained. Without the regular maintenance, their eventual deterioration and failure is certain to occur. Under such a case, breaching of terrace berms, sloughing of rock faces, and mass failures could produce a domino effect on downslope terraces, and the elimination of entire terraced slopes. Downstream effects would include higher flooding and severe sediment problems.

The current hydrologic regime then, is dependent upon the continued maintenance of the upland terraces. Abandonment of the terraces or relaxation of maintenance could lead to commensurate hydrologic disasters and serious decline of agricultural

production in the country. The assurance of continued working terraces constitutes an ongoing need. Considering the potential for both physical catastrophe and social harm, great attention should be devoted to this matter.

It should be stressed that there is no known documented evidence that the terraces are currently undergoing widespread deterioration. Isolated breaks and even individual hillslope failures can be seen, but it is not clear that any overall trend is present, i.e., that these general conditions are not typical of say the past forty years. However, the economic and social factors which would reasonably lead to terrace deterioration are present. This includes a reduction of on-farm force attracted to higher paying work elsewhere.

#### 8.5 PROBLEM RESOLUTION

- (1) Forestry and Range. Given that the present situation constitutes a problem, the general thrust of a solution is obvious. Very simply, range and forest vegetation must be reestablished, lands must be rehabilitated, and continuing management must be instituted at the local level. These will be long-term activities with benefits accruing to the Yemen of the future.

The remedial actions must be consistent with the economic, social, cultural, and political realities present. That the current situation exists is a direct manifestation of such forces and not merely a series of unrelated physical and biological phenomena. Thus, programs of tree planting, range reseeding, etc. probably would not succeed. Progress must begin in the minds of the land user by appealing to his loyalties, motivations, and sense of economic well-being. This demands a patient program of education, extension, demonstration, aid, and auxiliary services. Success, both on-the-land and in the management behavior of the local farmers will be slow in coming, and even with time and resources it is not assured. The watershed stability-hydrology aspects should be present and acknowledged, but not publicly accented. The main thrust should be towards increased forage harvest and forest product production. Even in well instrumented situations, watershed improvements and benefits are difficult to effect with surety, and even more difficult to demonstrate. Also, as many of the benefits accrue to downstream interests, a lack of concern by the upland users is natural.

Demonstration schemes and background strategy in both forestry and range management have been previously outlined by Harris (1979) and by Weber (1980), and form a suitable basis for proceeding. Also a program for development of Yemeni professionals in range, forestry, and soil and water conservation is essential.

- (2) Terraces. The terrace "problem" is elusive because (1) it is not really known that their deterioration is occurring and (2) to



the extent that problems do exist, solution will be difficult and expensive. The threat is, of course, deterioration of the terrace systems followed by the consequent loss of productive lands and erosion and flooding damage downstream. Preliminary field and literature reviews suggests that large scale disasters are possible, but of unknown likelihood. Evaluation of the situation is difficult because of a lack of background information. Development of such information is warranted in view of the rich heritage role of the terraces in Yemen's history and identity.

The very existence of the terrace system is a manifestation of a deeply entrenched social-agricultural custom, dependent upon the existence of a dedicated farm labor force. As terraces are abandoned from crop production, they will no doubt revert to grazing lands, a less intensive use, and probably without the currently felt urgency for maintenance. The reduction of farm labor will eventually be accompanied by an influx to the growing urban centers with attendant social problems. Therefore, continuation of the terrace system is urged from the hydrologic, agricultural, and social-political viewpoints.

To develop the background information needed for a terrace management program, an approach is suggested. First, a reconnaissance phase is needed to appraise the basic physical nature of the potential problem and to determine trends in terrace condition. Second, a concurrent series of longer term studies should be commissioned on the basic background conditions, history, hydrology, engineering, failure potential, and social-economic factors. Third, an action program is needed which is comprised of demonstration-development projects. This strategy is outlined in the following sections.

## 8.6 SHORT-TERM STUDIES OF TERRACES

- (1) Condition-Trend Census. This work would deal mainly with the question of a current time trends in terrace condition. Are they in fact deteriorating and if so, where and to what extent? Some preliminary intelligence on other aspects of the general phenomenon should also emerge as unplanned spinoffs from this effort. Such a study would appear to fit in comfortably with the planned Land Classification and Soil Survey (USAID Project 079-0042), utilizing comparative aerial photography over a series of recent years.
- (2) Physical Reconnaissance and Appraisal. This is seen as a necessary first cut analysis of the on-the-ground physical situation. Through field inspection, interview, literature search, and some field measurements, one could attempt to sculpt the general outline of the problem, highlight possible solutions, and estimate the general dimensions. It is seen as advisory input to the long-term studies in Phase 2 which might begin concurrently. This step includes "problem analysis."

## 8.7 LONG-TERM STUDIES OF TERRACES

This group of activities would proceed while anticipating alarming findings from Phase 1 and assume a need for foundation understanding for an eventual design program. Since so little is known about terraces and the solution alternatives are still amorphous, this phase will function to establish elementary baseline information as well as explore for presently unappreciated possibilities. Several of the following might be amalgamated to more unified packages.

- (1) Engineering Stability and Classification. This would be a descriptive investigation of Yemen's terraces. A classification of terraces would be made creating a taxonomy based on easily observed or measured items of judged importance, such as topographic slope, wall slopes, wall height, aspect, soil type, presence or absence of stone facing, etc. This classification would be used elsewhere in the study. The basic engineering stability and permanence would also be examined with an eye towards crucial factors leading to possible failure. Methods of construction, and site limitations would be established. Many of the conclusions will relate, by reason of economic evolution and survival-of-the-fittest, to findings elsewhere in this phase.
- (2) Failure Prediction Study. This work would correlate empirically the classifications in the study above with field observations of failures of all degrees. From this an index of failure likelihood would result, which would be useful in establishing priorities for rehabilitation attention. By developing a failure index efforts could concentrate on the most failure prone terraces. Similar working tools have been developed and are in operational usage in the United States on similar situations. These include stream channel stability ratings, indexes of stream sedimentation from forest roads, etc.
- (3) Hydrologic Influences. Because hydrologic considerations are central to the stability and effects of terraces, this facet must be well understood. Basic items to be determined should include surface and soil moisture storage potentials, infiltration rates, sediment accumulation rates, and erosion rates. More holistic and applied information would be directly useful: the net basin hydrologic functioning of terraces, definition of extreme event capacity, and the prediction of hydrologic consequences. The trade-offs between upstream terraces and downstream water supply should be investigated and acknowledged. Hydrologic studies might be integrated with demonstration-development projects, as are discussed subsequently.
- (4) Social-Economic Studies. The existence of the Yemen terrace system is related to Yemen history and personality. They represent an enormous capital investment and thus a commensurate possible capital loss. Ostensibly, they originated as agricultural stopgaps because of a shortage of otherwise available suitable land coupled

with a strong will to survive in a mountainous environment. A comprehension of the motivation behind this effort might unlock insights to their continued preservation. Economic, social, or political solutions may be more feasible than blunt straightforward technological solutions.

In a more pragmatic sense, the rationale for terrace preservation should include economic decision making, especially when different projects compete for limited funds. Basic questions relate to the economic value of terraces and the costs of construction.

Social and legal questions bearing on terrace preservation could also be instrumental in any solution scheme. The land tenure problems associated with the creation of new terraces from either clan or "dead" lands or abandonment of previously cultivated terraces raises a variety of questions. Accompanying water rights questions should also be examined. It would be appropriate for this study to derive general insights to the Yemen terrace situation from other similar situations throughout the Middle East.

- (5) **Historical Survey.** It is known that the earliest accounts of Yemen spoke in awe of the terraces, and throughout history travelers have offered commentary. There should exist a rich storehouse of information on terrace construction, location, use failure, etc., in historical literature, both Arab and western. A summarization of this with enlightened technical interpretation should provide valuable perspective for present action. It would also serve to enhance Yemeni pride and awareness of the role of terraces in their cultural heritage, an appreciation that does not appear to be fully developed. Also, while similar terrace systems exist elsewhere in the Middle East, they seem to have attained the greatest expression in Yemen. An understanding of this paradox, which may become apparent from this study, would no doubt contribute to solution strategies.
- (6) **Action Programs.** The above described studies could insure a firm foundation for the design of efforts to salvage or preserve the terrace systems. Two remaining lines of endeavor are envisioned also.
- (7) **Demonstration and Field Measurements.** This might be carried out in consort with the proposed Upland Watershed Renovation Project (Harris, 1979). However, it should be on a substantially larger scale and recast to include terraced areas, agricultural lands, and riparian lands. In addition to demonstration, monitoring, and experimentation, it should have strong direction to technique development in a "pilot" sense. Expansion to a small basin scale would permit inclusion of both small reservoirs and channel stability works with accent on their application and evaluation.

The upland renovation features could comprise one or more smaller scale locations, targeting selected portions of several

Phase 2 studies as well as elements of the agricultural water use studies. Parenthetically, substantial portions of the Harris proposal have direct valid application to the general watershed management problem, and thus, should be encouraged. This combined project should begin as an initial effort simultaneously with Phase 1.

- (8) **Design and Operational Programs.** Field programs should rest on the foundation of the above described studies and experiences. However, some general interim national planning suggestions are made in the following section.

## 8.8 NATIONAL WATERSHED PLAN

Analogous to the National Water Policy, and drawing from the proceeding rhetoric, the following outline is proposed as a discussion draft for a Watershed Management Plan for the Yemen Arab Republic. Policy statements might be drawn from it as desired.

- (1) Recognizing the physical condition of Yemen's land and the intense demands placed upon them, direct programs solely for watershed preservation and flow and sediment control are not generally feasible. These considerations should, however, be included jointly in associated land management activities, including range management and forestry. It should be recognized that "watershed" benefits will accrue only over long time spans, and may perhaps be unappreciated. Terrace preservation in certain special situations may merit special single purpose attention.
  - (2) Public education concerning natural resources is necessary. It should create a national awareness of land-water interactions, appealing to both conscience and economic motives. This is needed to lubricate local cooperation and joint agency programs.
- Likewise, a base of Yemeni professional and technical personnel is essential. Expertise in agriculture, range, forestry, hydrology, agronomy, economics, geology, watershed management, and civil and agricultural engineering is needed for the management of the entire spectrum of Yemen's resources, including its soil, water, and vegetation.
- (3) The establishment of data and experience, and a development and research base is necessary. This could include studies described elsewhere in this report. Furthermore, river basin studies for water resource development should routinely include watershed resource analyses consisting of resource description, identification of status and trends, present and future problems and opportunities, and possible watershed prescriptions.
  - (4) Yemen's terrace system is a distinctive national treasure and should receive special attention, recognizing its agricultural, hydrologic, and national heritage role.

(5) Priorities for concern, by land types should approximate the following order:

- (a) Terraces, especially when tributary to important downstream values.
- (b) Lands tributary to domestic water supplies.
- (c) Lands with potential for salvage or preservation. That is, Class 5 lands and any lands still in near-natural forested cover.
- (d) Riparian lands, acknowledging their superior agricultural value.

## **9. YEMEN WATER PROGRAM**

## 9. YEMEN WATER PROGRAM

Water is a scarce resource in Yemen; there is not enough to satisfy present and potential demand. A comprehensive water management program is necessary if the limited water resource base is to be used to the best advantage of all citizens. Such a program should establish the basic building blocks for continuing long-term water management. The elements of such a program are:

- (1) Development of regional water plans.
- (2) A legislative program, enacted over a period of years.
- (3) Development of altered institutional forms appropriate to the needs of a developing society.
- (4) Demonstration of improved farm management practices focused on conjunctive use of ground and surface waters.
- (5) Development of a watershed management plan.
- (6) Development of a professional cadre to B.S. and M.S. degree levels, including two-year internships in water engineering practice.
- (7) Development of public education programs to reach local leaders and the population concerning the realities of their local water situation, and the steps the government is taking to promote a balance between supply and demand.

The intent of the program outlined is to establish the requisite institutions for implementing a national water policy. The first goal of such a policy is provision of a base level of reliable domestic water supply to inhabitants of all cities and towns, and as many villages as feasible. The second goal is to utilize water efficiently in order to maximize economic output from farms and industries. The implementation of the policy in the various areas noted, and achievement of the above goals, is a matter of years and, indeed, decades.

### 9.1 PROGRAM ELEMENTS

The foregoing program elements are enumerated in Figure 9-1, along with some suggested projects. Donor projects which may contribute toward the program elements are listed also. In each case the projects identified are indicative and suggestive. They are not inclusive, nor are they intended to be final. The major aspects of each program element seen in Figure 9-1 are outlined below.

(1) Short-term local projects. Explicit attention ought to be directed toward identifying worthwhile short-term projects to meet political exigencies at the local level. The problem seems to be caused by rising local expectations and the consequent focus on the national government to provide tangible projects to alleviate some of the acute local problems. From

the long-term planning point of view, it is better to proceed more systematically. But from the short-term point of view, political wisdom may dictate that the most urgent problems be identified immediately. A reconnaissance of the country should be undertaken to identify areas having acute problems and short-term projects which may alleviate such stress. An ongoing program which is a good example of this is the village water supply program of the MOA.

A few other suggested projects are listed in Figure 9-1 for the Wadi Jawf area. One major dam construction project is presently underway.

(2) Water planning. It is essential to know for each area of the country how much water is available and present and projected demands. Rational planning can then proceed. Such planning should consider measures to: (1) increase supply, (2) conserve water, (3) reallocate existing supplies. The planning process is intended to generate alternative plans for what ought to be done and how, based upon appropriate indices of these three basic measures.

Projects are identified in Figure 9-1 for getting the planning process underway. Donor projects listed are intended to demonstrate planning methodology.

(3) Pollution control. Many waterborne diseases are endemic in Yemen. Protection against these diseases should be the first goal in pollution control. Involved is not only sewerage and sewage treatment, but alternative sanitation practices suitable for rural villages. At the same time public education programs will be necessary.

(4) Water policy. The first step in complementing a national water policy is creation of a Water Resources Council. This agency should have budget and approval control over all water activities in the country, i.e., it should have both responsibility and authority. Along with this Council, a Water Resources Policy Act should be enacted to codify the basic guidelines and rules for water development and use. Passage of such an Act will require modifications of many of the provisions and further consideration of others. The process will be facilitated both by persons having intimate knowledge of the country and persons from donor agencies familiar with water organizations.

(5) Groundwater management policy act. It is a simply truism that over the long-term one cannot take out more than what comes in. This is the basic theme of a groundwater management policy. But its implementation is not so simple; it will involve almost insurmountable political impediments. The tool is a statute giving the needed authority to manage. Public education and gradual but steady implementation by the administrative agency is the key.

(6) Surface water development. The promise for surface water storage appears limited. The canyons along the Tihama Plain, however, appear to be possible sites for reservoirs and the ones here and in

SOCIETAL GOAL	PROGRAM ELEMENT	OBJECTIVES	PROJECTS OF YEMEN GOVERNMENT	POSSIBLE DONOR COUNTRY PROJECTS
Provide for domestic needs and increase agricultural productivity	1 Local Projects Short Term	Alleviate most acute local problem	Wadi Jawf storage diversion dam feasibility study Wadi Jawf village water supply improvement through well construction Wadi Jawf bank protection study	1 Reconnaissance study of Wadi Jawf relative to short-term projects
	2 Water Planning	Determine best combination of projects and measures to achieve supply-demand fit	1 Regional supply-demand studies 2 Regional planning studies 3 Implementation of measures and projects	1 System water planning methodology demonstration for Sana'a Basin six-volume report 2 Input-output methodology demonstration for Sana'a Basin 3 Planning for supply-demand balance for Sana'a Basin
Protect public health	3 Pollution Control	Eradicate waterborne diseases	1 Identification of water related health problems 2 Water supply quality control	1 Epidemiological survey of Yemen for waterborne diseases 2 Design of country-wide strategy for wastewater management
Provide for domestic needs and increase agricultural productivity	4 Water Policy	Provide basic guidelines for management of water resources for Yemen	1 Water Resources Council 2 Regional Water Commissions 3 National Water Policy Act	1 Advice on drafting statutes 2 Coordination of donor activities with WRC
Maintain usefulness of aquifers in perpetuity	5 Groundwater Management	Manage groundwater withdrawals for sustained yield	1 Groundwater management policy act 2 Emergency groundwater statute	1 Advice on drafting statutes
Increase agricultural productivity	6 Surface Water Development	Find opportunities to both increase available water supply and provide for more effective utilization in time	1 Survey feasibility of surface water storage projects	1 Hydrologic analysis of wadi flows, diversions, role of storage
	7 On-Farm Water Management	Conjunctive use of surface and groundwater for meeting crop water requirements and achieve more equitable allocation of water	1 Demonstration farm - Wadi Surdud 2 Demonstration farm - Wadi Jawf	1 Hydrologic analysis of water application efficiencies 2 Demonstration farm - Wadi Surdud. Oumeisha Project is a possible site 3 Demonstration farm - Wadi Jawf
Maintain role of terraces in agricultural productivity	8 Watershed Management	Preserve terraces and provide for revegetation of uplands	1 Range and field revegetation of uplands 2 Condition-trend census to ascertain time trends in terraces condition 3 Background information study of terraces as basis for an action program 4 Action plan development for terrace preservation 5 Adoption of national watershed plan	1 Foundation information for development of action plan 2 Historical survey of terraces
Provide for domestic and industrial needs and increase agricultural productivity	9 Institutional Development	Develop water management capabilities to implement national water policy	1 Codification of water rights principles 2 Codification of regional water rights structure; institutions recommendations for municipal-industrial water management 3 Institutions modifications for irrigation water management 4 Regional water commissions role and functions	1 Study of water rights and recommended modifications 2 Study of organization needs and recommended structures, financing
	10 Professional Cadre	Develop cadre of water professionals to plan and manage utilization of water resources	1 Develop cadre of water professionals as a 20-year project 2 Develop professional leadership capacity of University in Sana'a 3 Develop professional organizations	1 Manpower needs study 2 Lectureships and short courses on water in collaboration with University
	11 Public Education	Influence support of local leaders and public in implementing water policy	1 Extension service development 2 Government program to raise public consciousness about water	1 Expatriate staffing of extension positions in collaboration with Yemeni professionals 2 Expatriate advice on public communication programs
	12 Research	Explore all possible ways to handle water problems	1 Weather modification appraisal	1 Reconnaissance survey of weather modification potential

Program Elements and Projects

Figure 9.1 Elements and Projects of Yemen water program.

other regions ought to be examined. Sufficiency of runoff waters, evaporation, and water rights are possible limiting factors. Such storage could have two benefits. They are (1) capture of low frequency floods which could otherwise not be diverted for use and (2) to provide water on demand to the extent of the storage available.

(7) On-farm water management. The key concern here is to use water more efficiently to increase crop production. The present practice of spate irrigation is not equitable in allocation of water, nor is it efficient. Higher lands may be over-irrigated and lower lands may not receive adequate water. Conjunctive use of ground and surface water is a management technology that could improve the welfare of all parties without disbenefits to any, thus increasing net farm output.

In developing groundwater, it is recommended that this resource be used in this conjunctive mode rather than to increase irrigated acreage. To ascertain the feasibility of regional implementation of the concept, two demonstration farms of about a 30 hectare area are suggested. The farms would demonstrate also the merits of improving other practices such as fertilizer use, market timing, storage, seed production, etc.

(8) Watershed management. The major watershed problem in Yemen is the specter of widespread terrace deterioration due to more attractive work abroad and in the cities. The terraces are a part of the heritage of Yemen. They represent a major capital asset and they are important in the hydrology of the country. The terraces ought to be given special attention through the studies outlined in Figure 9-1, which would lead to an action plan for terrace preservation. In addition, a national watershed plan should be formulated which would incorporate both terrace preservation and a program for range and forest revegetation of the uplands.

(9) Institutional development. Some institutional modifications are needed with respect to agricultural water management if the conjunctive use concept is to be implemented. Local water institutions need to be studied to determine what changes are desirable, the feasibility of such changes, and how they can be brought about.

In addition to examination of local institutions, a national water code should be developed. This would be a basic handbook to be widely distributed. It would state the basic promises of water management and the rules for water use. To account for regional and local customs and traditions, the national code would be supplemented by regional water code addendums.

National water management also involves development of administrative organizations such as the Water Resources Council and the suggested Regional Water Commissions. Effective functioning of these organizations will evolve over the years. Patience will be needed since it will not happen rapidly.

(10) Professional cadre. One of the highest priority areas in a national water program is the development of a cadre of water professionals to staff the government agencies, the university, and private firms. This is a 10 to 20 year activity. It should not be a crash program. The deliberate investment of 7 to 10 years in education and experience on

promising young individuals is necessary. About 100 such persons should be identified over a two to three year period to start such professional development identity in the country, helped by the senior professionals now staffing key positions.

Those senior water professionals presently staffing water management positions should be afforded opportunities for further professional development through travel to other countries for site visits, attendance at short courses, periods in residence at various agencies, and participation in professional meetings.

(11) Public education. Water is such a limiting factor in the social and economic development of Yemen that public education programs are necessary to provide an understanding of why some strategic changes are needed. For example, over pumping must be controlled by water measurement and perhaps a system of charges. The idea of the "common pasture" may be adapted to the groundwater case to show why public management is necessary. Also, videotapes could be prepared to explain, in basic terms, the hydrology of underground aquifers. An extension service, coupled with the support of local agencies could be the means of implementing such a program.

(12) Research. While the emphasis of a water program should be on practice, experimental or research approaches may be needed, however, to exploit opportunities. Such an experimental activity is cloud seeding. It is an area that ought to have a reconnaissance level appraisal by a recognized expert in the field. This should be done in terms of its effectiveness in causing increased precipitation, and how much increased precipitation is likely.

## 9.2 TIME PHASING

Figure 9-2 is a schedule for implementation of some of the projects identified in a proposed Yemen Water Program. The projects and the times are indicative only. Such a schedule should be an integral part of a comprehensive water program. It is important to note that years are involved in getting such a program underway. Whether the goals are attained or not is a function of the quality of management.



PROGRAM ELEMENT PROJECTS	YEARS OF ACTIVITY																			
	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
<b>1. LOCAL SHORT TERM PROJECTS</b>																				
1.1 Wadi Jawf studies																				
1.2 Wadi Jawf village water supply																				
<b>2. WATER PLANNING</b>																				
2.1 Methodology demonstration																				
2.2 Sana'a basin framework study-demonstration																				
2.3 Sana'a basin water plan-demonstration																				
2.4 Regional framework studies																				
2.5 Regional plans																				
2.6 Establish national data networks																				
<b>3. POLLUTION CONTROL</b>																				
3.1 Problem identification																				
3.2 National water supply planning strategy																				
3.3 National waste water planning strategy																				
<b>4. NATIONAL WATER POLICY</b>																				
4.1 Water Resources Council Formation																				
4.2 National Water Policy Act Enactment																				
4.3 Regional Water Commission Formation																				
<b>5. GROUNDWATER MANAGEMENT</b>																				
5.1 Groundwater Policy Act																				
5.2 Emergency groundwater statute																				
<b>6. SURFACE WATER DEVELOPMENT</b>																				
6.1 Survey of storage project sites																				
6.2 Hydrologic analysis of storage feasibility																				
<b>7. ON-FARM WATER MANAGEMENT</b>																				
7.1 Demonstration farm - Wadi Surdud																				
7.2 Demonstration farm - Wadi Jawf																				
7.3 Conjunctive use studies																				
7.4 Irrigation efficiency studies																				
7.5 Irrigation institution studies																				
<b>8. WATERSHED MANAGEMENT</b>																				
8.1 Condition-trend census of terraces																				
8.2 Action plan for terrace preservation																				
8.3 National watershed plan																				
<b>9. INSTITUTIONAL DEVELOPMENT</b>																				
9.1 Water rights statutes																				
9.2 Water organization studies																				
9.3 Codification of water rights																				
9.4 Regional Water Commissions development																				
<b>10. PROFESSIONAL CADRE</b>																				
10.1 Manpower needs study																				
10.2 Education of water professionals																				
10.3 University of Sana'a development																				
10.4 Professional organizations development																				
<b>11. PUBLIC EDUCATION</b>																				
11.1 Extension service development																				
11.2 Public communications programs																				
<b>12. RESEARCH</b>																				
12.1 Identification of research needs																				

Figure 9.2 Tentative implementation schedule for elements of Yemen water program.

## APPENDICES

## APPENDIX A

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    - Section M, Ken D. Duft, Yemeni LDA's and Agricultural Cooperatives, Their Composition and Characteristics
    - Section N, Clyde Adams, Editor's Note
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    - Appendix C, CID Design Team, Basline Field Study Report
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--Organizational

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  - Volume 3 - Maps

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## APPENDIX B

### TERMS OF REFERENCE

Telegram Provided by USAID Sana'a, July 1980

(1) We have proposed team's scope of work to NOA as follows, QUOTE:

- A. Compile and analyze existing studies, recommendations, and documentation of water resources development and management. It would be intended that the team not duplicate work carried out by earlier consultants such as Mr. Barbarossa, et al., in 1977 and Reuben Johnson in 1980. The review would concentrate on studies held by the Ministry of Agriculture (MOA). Particular emphasis would be placed on water resources development and management as it relates to agricultural development.
- B. Summarize, for the MOA and the Yemen Government in general, the state-of-knowledge of Yemen's water resources as contained in the documents reviewed by the team. The team would note any significant differences or discrepancies in consultant's reports. The team would identify any additional studies required to provide the MOA and the Yemen Government with a complete picture of Yemen's water resource situation.
- C. Assist the MOA in the drafting of proposals for national resource policy and emergency regulations to bring water consumption under control, including, if required, registration for control of drilling operations. We would hope that the work of the team would be complementary to the activities being carried out by YOMINCO's Department of Hydrology.
- D. Suggest for the MOA the outlines of a long-range program for management of water resources for agriculture. Such a program might include on-farm water management, water use policy, integrated systems of natural resources conservation, water management, dry-land field research, and water inventory. A proposal for an overall inventory of national water resources would need to be coordinated with the Department of Hydrology of YOMINCO. While the team's program would focus on water resources related to agriculture, it would need to take into account other uses of water and therefore would interest other Yemen Government agencies involved in water resources. The team would identify areas where the responsibilities and activities of the MOA might overlap with those of other ministries and other agencies. The team would offer MOA suggestions to enhance coordination among water development agencies and reduce overlapping responsibilities.
- E. The team would suggest ways in which AID Project 279-0052 might assist the MOA and the Yemen Government in implementing a long-range program for development and management of water resources for agriculture. In suggesting such a program, it is important that it be coordinated with and complementary to activities of other Yemen Government agencies and other donors and include other AID assistance in water resources.
- F. If time permits, the team will prepare a "Subproject Identification Document (SPID)" (a document AID uses to decide whether further project investigation should be carried out). The SPID would outline a proposal for AID assistance, under Project 279-0052, Agricultural Development Support. UNQUOTE.

(2) Looking forward to nominations for team. Please advise. We have apprised MOA of August 6 ETA.



SOCIETAL GOAL	PROGRAM ELEMENT	OBJECTIVES	PROJECTS OF YEMEN GOVERNMENT	POSSIBLE DONOR COUNTRY PROJECTS
Provide for domestic needs and increase agricultural productivity	1 Local Projects Short Term	Alleviate most acute local problem	Wadi Jawf storage diversion dam feasibility study Wadi Jawf village water supply improvement through well construction Wadi Jawf bank protection study	1 Reconnaissance study of Wadi Jawf relative to short-term projects
	2 Water Planning	Determine best combination of projects and measures to achieve supply-demand fit	1 Regional supply-demand studies 2 Regional planning studies 3 Implementation of measures and projects	1 System water planning methodology demonstration for Sana'a Basin six-volume report 2 Input-output methodology demonstration for Sana'a Basin 3 Planning for supply-demand balance for Sana'a Basin
Protect public health	3 Pollution Control	Eradicate waterborne diseases	1 Identification of water related health problems 2 Water supply quality control	1 Epidemiological survey of Yemen for waterborne diseases 2 Design of country-wide strategy for wastewater management
Provide for domestic needs and increase agricultural productivity	4 Water Policy	Provide basic guidelines for management of water resources for Yemen	1 Water Resources Council 2 Regional Water Commissions 3 National Water Policy Act	1 Advice on drafting statutes 2 Coordination of donor activities with WRC
Maintain usefulness of aquifers in perpetuity	5 Groundwater Management	Manage groundwater withdrawals for sustained yield	1 Groundwater management policy act 2 Emergency groundwater statute	1 Advice on drafting statutes
Increase agricultural productivity	6 Surface Water Development	Find opportunities to both increase available water supply and provide for more effective utilization in time	1 Survey feasibility of surface water storage projects	1 Hydrologic analysis of wadi flows, diversions, role of storage
	7 On-Farm Water Management	Conjunctive use of surface and groundwater for meeting crop water requirements and achieve more equitable allocation of water	1 Demonstration farm - Wadi Surdud 2 Demonstration farm - Wadi Jawf	1 Hydrologic analysis of water application efficiencies 2 Demonstration farm - Wadi Surdud. Qumeisha Project is a possible site 3 Demonstration farm - Wadi Jawf
Maintain role of terraces in agricultural productivity	8 Watershed Management	Preserve terraces and provide for revegetation of uplands	1 Range and field revegetation of uplands 2 Condition-trend census to ascertain time trends in terraces condition 3 Background information study of terraces as basis for an action program 4 Action plan development for terrace preservation 5 Adoption of national watershed plan	1 Foundation information for development of action plan 2 Historical survey of terraces
Provide for domestic and industrial needs and increase agricultural productivity	9 Institutional Development	Develop water management capabilities to implement national water policy	1 Codification of water rights principles 2 Codification of regional water rights structure; institutions recommendations for municipal-industrial water management 3 Institutions modifications for irrigation water management 4 Regional water commissions role and functions	1 Study of water rights and recommended modifications 2 Study of organization needs and recommended structures, financing
	10 Professional Cadre	Develop cadre of water professionals to plan and manage utilization of water resources	1 Develop cadre of water professionals as a 20-year project 2 Develop professional leadership capacity of University in Sana'a 3 Develop professional organizations	1 Manpower needs study 2 Lectureships and short courses on water in collaboration with University
	11 Public Education	Influence support of local leaders and public in implementing water policy	1 Extension service development 2 Government program to raise public consciousness about water	1 Expatriate staffing of extension positions in collaboration with Yemeni professionals 2 Expatriate advice on public communication programs
	12 Research	Explore all possible ways to handle water problems	1 Weather modification appraisal	1 Reconnaissance survey of weather modification potential

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