FIELD REPORT

TECHNICAL ASSISTANCE PROGRAM FOR THE MINISTRY OF WATER RESOURCES, SULTANATE OF OMAN

TASK 1: DATA MANAGEMENT

Field Report No. 325
May 1991

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TECHNICAL ASSISTANCE PROGRAM FOR THE MINISTRY OF WATER RESOURCES, SULTANATE OF OMAN

Task 1: Data Management

Prepared for the Omani-American
Joint Commission for Economic and Technical Cooperation
under WASH Task No. 176

by

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Related WASH Reports

Technical Assistance Program for the Ministry of Water Resources, Sultanate of Oman, Task 2A: Laboratory Upgrading, by J. David Betsill, Ph.D., Donald G. Muldoon, and Steve S. Luxton, WASH Field Report No. 326, Final Draft.

Technical Assistant Program for the Ministry of Water Resources, Sultanate of Oman, Task 2B: Training, by Thomas Leonhardt, WASH Field Report No. 327, Final Draft.

Evaluation of Alternatives for Interim Treatment and Disposal of Trucked Wastewater in Salalah Town, Sultanate of Oman, by Leo A. St. Michel and Albert B. Pincince, WASH Field Report No. 243, July 1988.

Proposed Hydrological Monitoring and Evaluation Unit for the Ministry of Agriculture and Fisheries Aquifer Recharge Program (Oman), by Charles E. Fuller and John Kent Kane III, WASH Field Report No. 285, February 1990.

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ACRONYMS

ACRINFO	a parented software
CAD	computer-aided design
dBASE	a patented data management software
EC	electrical conductivity
ERDAS	a patented software
ESRI	Environmental Systems Research Institute
ETHERNET	a computer networking system including software and hardware; functions as a link between computers
GIS	geographic information systems
HP	Hewlett Packard
LAN	local area network
MAF	Ministry of Agriculture and Fisheries
MB	megabyte
MbPS	million bits per second
MCI	Ministry of Commerce and Industry
MEW	Ministry of Electricity and Water
MIPS	million instructions per second
MIS	management information systems
MWR	Ministry of Water Resources
OAJC	Omani-American Joint Commission for Economic and Technical Cooperation
ORACLE	a patented software
PARADOX	a patented software for data mangement
PC	personal computer

PCDESR	Planning Committee for Development and Environment in the Southern Region
ppm	parts per million
R.O.	Rial Omani (R.O. 1 = US $2.62)
SCTP	Supreme Committee for Town Planning
SQL	structured query language
UNIX	a patented computer operating system software
USAID	United States Agency for International Development
VGA	video graphics array
WAN	wide area network
WASH	Water and Sanitation for Health Project

EXECUTIVE SUMMARY

At the request of the Sultanate of Oman's Ministry of Water Resources (MWR), the Omani-American Joint Commission for Economic and Technical Cooperation contracted with the Water and Sanitation for Health Project (WASH) to assess and make recommendations for water resources data management. The WASH team worked in Oman and the United States during September and October 1990 with another WASH team evaluating MWR's training and laboratory needs. These two tasks begin a six-part program to foster development of the newly established Ministry. This report reviews the current status of information management at MWR, assesses database needs for the planned national inventory of wells in the Sultanate, discusses the concepts of water resources database management, evaluates training and personnel needs for successful database management, and recommends a plan of action for long-term database management within MWR.

The key findings of the study are:

- Water resources database management stagnated from 1986 until the creation of the Ministry of Water Resources in 1989.

- Until recently, data management practices at MWR provided limited access to historical data.

- Sophisticated computer systems at other ministries facilitate many operations. Many of these systems operate primarily in Arabic and are administered by Omani personnel.

- Water resources information management must be improved if future water resources policy is to be based upon information obtained from data analysis.

- The cost of computer equipment and operations is small relative to their potential benefits in facilitating improved water resources management.

- At present, there is only one staff member who is developing and improving computer systems at the Ministry. There are no Omanis on staff with computer systems development skills.

- The Ministry has recently begun transferring its water resources data from its existing system to a modern database and is acquiring almost 30 additional personal computers (PCs) that should help ease data management problems.

- A national implementation plan for geographic information systems (GIS) has been developed by the Supreme Committee for Town Planning (SCTP), which has staff dedicated to implementing these computer systems. MWR has begun working with SCTP to develop its own GIS capabilities.

- Much valuable water resources data have not been adequately archived.

The principal recommendations of the study are:

- There is an immediate need for the appointment of a permanent MWR computer systems manager.

- Responsibility for computer system management should be assigned to a single department of the Ministry.

- MWR should implement a distributed database network; data would reside in minicomputers and PCs. Responsibility for data management should remain with the departments that generate the data.

- There must be a sustained commitment of personnel and money to maintain the Ministry's computer systems.

- Adequate computer resources must be put in place to accommodate the data that will accumulate from the national well registration, inventory, and metering programs, addition of new regional offices, Ministry management needs, laboratory expansion, and other planned projects.

- More staff should be dedicated to computer systems development. There is an immediate need for computer specialists and entry of trainees into computer training programs.

- Development of GIS would be a timely step as MWR looks to improve its resource management abilities. This program could be implemented in coordination with SCTP.

- Attention must be devoted to computer system development for the Ministry's internal management needs and archiving of original water resources records.

Chapter 1

INTRODUCTION

1.1 Purpose of the Study

At the request of the Ministry of Water Resources (MWR), the Omani-American Joint Commission for Economic and Technical Cooperation (OAJC) contracted with the Water and Sanitation for Health Project (WASH) to assess and make recommendations for water resources data management. The assistance was intended to complement the water resources master plan being prepared by Mott MacDonald International, Ltd. Early implementation of the data management recommendations should also greatly facilitate the collection of data for the planned national inventory of Oman's approximately 167,000 wells.

1.2 Preparation for the Assignment

The scope of work was drawn up by Robert Thomas of WASH, who visited Oman in February 1990 to ascertain the areas in which the Ministry needed assistance. Following approval of the proposed scope of work by OAJC, a four-person team was assembled for this project along with a team for the concurrent laboratory and training needs project. The four other tasks identified in the scope of work will be executed in 1991. A planning meeting held in Washington, D.C. from August 8-10, 1990 was attended by the database management project team, the laboratory and training needs project team, Murl Baker of OAJC, and representatives from WASH and the United States Agency for International Development (USAID).

1.3 Scope of Work

The objectives of the six-task water resources technical assistance program are:

- Collection of supplementary data to support future water resources management
- Preparatory activities that can be undertaken with the MWR master plan being prepared by Mott MacDonald
- Strengthening MWR capabilities for water resources management

Within these objectives, the database management project would:

- Establish the concepts and functions of a database and water resources information management system for MWR

- Establish the software and hardware for such a system

- Establish scopes of work for specific components of the information management system, including a component for a typical basin and a component to accommodate data from the well inventory program

- Establish a program of well-water sampling and analysis to accompany MWR's well inventory and determine the resulting demands on laboratory services

- Develop a visual computer-based information system for well inventory data that could be extended to other water resources uses

1.4 Conduct of the Study

The team worked in Oman and the United States during September and October 1990 with the team evaluating training and laboratory needs. Team members interviewed key data management personnel at the MWR, heard a wide variety of needs and concerns expressed, visited related facilities at other Omani government offices, and attempted to synthesize the most suitable data management plan from the information gathered. Appendix A lists the persons interviewed. The entire team was in Oman for the first three weeks of the project, and two members returned to the United States to research computer hardware and software needs during the middle weeks of the project.

The team met every week with OAJC to present its most recent findings, prepared summary briefings and submitted drafts of its report to OAJC and MWR, and made final presentations to the senior staff of the MWR and OAJC during its final week in Oman.

Chapter 2

BACKGROUND

2.1 Water in Oman

Oman is highly dependent upon groundwater for both irrigation and drinking water. Despite an annual rainfall averaging less than 100 millimeters in most places, the Sultanate has had a strong agricultural base supported by an extensive network of aflaj[1] supplemented by wells tapping the shallow water tables along the fertile lands of the Batinah and Salalah coastal plains.

Rapid modernization and a rising population during the last two decades have placed increasing pressure upon these water resources some of which has been offset by the construction of desalinization plants. However, increased extraction of groundwater, primarily through use of motorized pumps and drilled wells, has led to serious declines in groundwater levels and quailty. The water resources of many communities have been depleted, and many localities have declined as agricultural and population centers.

2.2 National Water Policy

2.2.1 Royal Decree 82/88: Water as a National Resource

In November 1988, His Majesty Sultan Qaboos bin Said issued Royal Decree number 82/88, Considering Water Reservoir as National Wealth, as the first step in conserving the nation's water resources. The decree states that "the Sultanate's water reservoir is considered as public national wealth to be exploited ... according to the Government's instruction." This decree establishes that all groundwater extraction, for any purpose, may be regulated by the government.

2.2.2 Royal Decree 100/89: Establishment of the Ministry of Water Resources

In October 1989, His Majesty issued Royal Decree number 100/89, For the Establishment of the Ministry of Water Resources and Designation of Its Duties and Responsibilities, setting up a central authority for water resources management. The new ministry was formed from the existing Public Authority for Water Resources, which had undergone a number of

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[1]Aflaj (singular: falaj) - traditional conveyance, ownership, and distribution systems that transport water overland from a mountain spring, well, or stream through a lined conduit or by pipe to a village for washing, drinking, and irrigation.

reorganizations since its creation in 1979, and the Ministry of Electricity and Water. The decree directed the MWR to:

- Establish a "...plan for the development [and conservation] of water resources..."
- Establish an "information and data centre" for water resources and related data
- Collect and manage water resources data
- Undertake research to determine the best methods for conservation and use of water resources
- Maintain hydrologic and hydrogeologic monitoring networks
- Issue permits for new wells
- Train its Omani personnel

2.3 MWR Structure and Resources

2.3.1 General Organization

The MWR has four Directorates: Regional Offices, Water Resources Assessment, Water Resources Management, and Finance and Administration. In addition, it has several small units directly responsible to the Minister. Data collection, analysis, and management are shared by several departments. The lines of responsibility are still somewhat fluid, as can be expected in a young and inexperienced organization. An organizational chart is included in Appendix D.

2.3.2 Data Management Staff and Responsibilities

2.3.2.1 Data Acquisition

The Regional Offices Directorate is responsible for well and falaj data collection through its offices in Seeb (Capital District), Sohar (Batinah), Nizwa (Interior), Mudayrib (Sharqiyah), Salalah (Southern), and, most recently, Buraimi. Seven more offices are planned, although it has not yet been decided whether these will be suboffices or define new districts. The offices typically have an expatriate director, one to three expatriate and Omani scientists, and five to seven Omani technicians.

The surface water department of the Water Resources Assessment Directorate is responsible for surface water data collection (precipitation and wadi[2] flow).

The Water Resources Management Directorate has recently begun collecting information on well ownership registration, well construction permit applications, and well construction contractor registration.

An abbreviated information flow diagram has been included in Appendix D. The diagram illustrates some of the major information pathways within the Ministry of Water Resources.

2.3.2.2 Data Management

The Water Resources Assessment Directorate maintains two water resources databases: the surface water department controls wadi and precipitation data, and the groundwater department manages well and falaj data. The staff responsible for well, falaj, and chemistry data consists of two Omani data entry personnel, two data management personnel (one Omani, one expatriate), and an expatriate system manager. The directorate also includes the MWR laboratory, which analyzes water quality samples from the district offices and forwards its analyses to the district offices and the groundwater department database.

2.3.2.3 External Access

The Information Centre is being developed as a clearinghouse for sharing information with other agencies. It is directed by a staff member dedicated to MWR by Mott MacDonald International.

2.3.3 Existing Computer Resources

MWR has 47 personal computers (PCs), of which eight have 80386 processors (high speed) and 14 have 80286 processors (medium speed). Two have 300 megabyte[3] (MB) disk drives (used by the surface water department and for the groundwater database), and several have 100 MB or more. The 47 PCs collectively have over 2000 MB of disk space. The computer hardware also includes 11 laser printers and 26 other printers. Many of the newer machines have VGA (video graphics array) color monitors capable of high resolution graphics. All of the machines have either 1.2 MB or 360 kilobyte diskette drives. Three machines have 40 MB external tape drives. The surface water department operates a small PC network.

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[2]wadi - a river bed that remains dry much of the year.

[3]One megabyte is equal to approximately 300 printed pages of information.

Most of the machines are used for office needs and have typical word processing and spreadsheet software. Some data are stored through KNOWLEDGEMAN software, and some data are stored in text files created by customized BASIC programs. The systems operate primarily in English.

2.4 Existing MWR Databases

2.4.1 Well Registration Data

MWR recently completed a national registry of groundwater wells. More than 167,000 registration forms were submitted. But MWR officials believe that not all wells have been registered, that some registered wells do not exist, and that some wells may have multiple ownership claims. A contract has been issued for data entry from the registry (owner's name, sheikh, town, waliat) in Arabic using the NAFITHA software package, and in English using FOXBASE (similar to dBASE, a popular PC database program). MWR expects to use this database to identify well owners within each town during the planned national well inventory scheduled for completion in 1991.

2.4.2 Water Data

Water levels in selected monitoring wells have been recorded by district office staff for much of the last decade. Data collected since 1985 have been entered in the KNOWLEDGEMAN database and/or on spreadsheets at the district offices and archived on the main groundwater data storage computer. Several offices enter data twice, once in KNOWLEDGEMAN to satisfy reporting requirements, and again on spreadsheets for further analysis. Older data are stored in paper files and on computer spreadsheets. Some of these data are of limited value, as many water levels have been recorded without regard to pumping operations at nearby wells, and measuring points at many wells have not been consistent over time.

2.4.3 Water Quality Analyses

Water quality data are collected in two ways at MWR. Certain parameters, such as electrical conductivity (EC), an indicator of salinity and thus potability and agricultural value, and temperature are measured directly in the field. Other parameters, such as major ion analyses, are determined in the MWR laboratory. The laboratory enters the data into the KNOWLEDGEMAN database and submits copies of the results to the groundwater database. Data collected in the field, which usually accompany water level measurements, are stored at the regional offices and entered on spreadsheets and/or the KNOWLEDGEMAN database. Copies of the data are submitted to MWR headquarters, where the data are transferred to the main groundwater computer. The data are thus stored on both the laboratory's PCs and at MWR headquarters. These data, especially the large numbers of EC measurements, provide much of the information on water quality trends and conditions in Oman.

2.4.4 Well Inventory Data

Well inventories within limited areas have been conducted several times in the past decade. In 1985, four inventory teams located and described almost 10,000 wells in the Capital, Sharqiyah, Interior, and Batinah districts. In 1988, an inventory team described more than 600 in the Sohar area. Data from more than 12,000 wells are stored in KNOWLEDGEMAN files in the main groundwater computer.

2.4.5 Other Well Information

MWR will collect much more information on wells in the future but has already amassed a great amount of valuable data. Essential for any groundwater management study are:

- Pumping records, of which MWR currently has little information
- Drilling logs and well construction data, some of which appear in reports issued in the course of special studies, others only in MWR files
- Geophysical logs, which appear in reports and MWR files
- Pumping tests, which appear in reports and MWR files
- Data on well construction permits, collection of which has recently begun

2.4.6 Surface Water Data

2.4.6.1 Aflaj Data

Aflaj data consist of water quality analyses, flow data, and physical information (location, ownership, etc.). Water quality data are processed as described earlier. Flow data, consisting of flow rates derived from depth, velocity, and cross-section data, are collected by the district offices and stored on computer spreadsheets and in the KNOWLEDGEMAN system. Descriptive information is generally stored in files at the district offices. The flow data are of mixed quality but of great value, as aflaj provide a substantial portion of Oman's water supply. There may be as many as 4,000 operational aflaj and up to 7,000 abandoned systems. No complete inventory of this resource has ever been attempted.

2.4.6.2 Wadi Data

MWR maintains gages at 104 wadi sites and plans to add 150 more in the next few years. These gages electronically record stage (water level) hydrographs of wadi flows and also have non-automated indicators that mark high-water level of flow events. Much qualitative wadi data are recorded on field visits during and following flow events. Stage data are recorded on data chips built into the wadi gages and periodically transferred to the main surface water computer at MWR headquarters. The surface water department also has generally reliable

data on wadi channels and issues regular reports of wadi flow. There are no significant perennial freshwater streams or impoundments in the Sultanate.

2.4.6.3 Precipitation Data

Precipitation data consist of precipitation amounts and measurement intervals and gage description data (location and gage type). There are more than 100 precipitation gages in operation across the Sultanate and approximately 150 more are to be installed in the next few years. Data collected by the surface water department are stored in computer text files and in paper files and used regularly for wadi and groundwater analyses.

2.4.7 Library

The MWR library contains numerous reports that have unique data (e.g., drilling logs, pump test results) on Oman's water resources and plentiful reference materials. Most of the volumes are cataloged on a database that follows the U.S. Library of Congress format. The library needs some upgrading. Few documents have adequate archival storage.

2.4.8 Ministry Administration

The MWR has a lot of information on its personnel, finances, and administration. It is poorly organized and little of it is computerized.

2.5 Current Plans for Information Collection and Management

2.5.1 Well Inventory Program

MWR plans a complete inventory of wells in the Sultanate that is expected to take several years and to yield enormous amounts of invaluable water resources data. It is imperative that this information be computerized for access and analysis. The inventory will provide a baseline for water resources management, making it easier to understand and regulate groundwater use once information is available on who and where the users are. The inventory and water quality sampling methodology are being formulated. Six crews will begin work in 1991 and 20 to 40 teams will operate in subsequent years. (Each crew can inventory an estimated 1,000 wells per year, although the actual number will vary greatly with local conditions.)

2.5.2 PC Network and Database Management System

MWR has recently ordered a PC network and new database management system. Equipment to be procured includes 28 PCs with 80386 and 80386SX processors. One will

be customized as the center of a NOVELL local area network (LAN) to be set up at MWR headquarters to permit communications among users of the connected machines. It will have more than 600 MB of disk storage as well as tape drive backup. Each regional office will receive two new machines. Software to be procured includes PARADOX database management software (Borland Company, Scotts Valley, California), to which the KNOWLEDGEMAN water quality and groundwater databases will be transferred in the next few months.

2.5.3 Geographic Information Systems

Geographic information systems (also called land information systems) facilitate management, display, and analysis of spatially related information (see Section 3.3 for a full discussion of GIS). The Supreme Committee for Town Planning[4] (SCTP) has already invested significant efforts in defining how GIS can work in Oman and in developing national GIS policy, and has several personnel to work on it. SCTP is sponsoring pilot programs for Rustaq, Buraimi, and Khasab, and is working with the Planning Committee for Development and Environment in the Southern Region (PCDESR) on a regional GIS for Salalah. MWR has begun working with PCDESR to develop the water resources aspect of the Salalah GIS, and its surface water department is developing its own GIS facilities using the AUTOCAD software package.

The SCTP GIS implementation plan is described in detail in Sultanate of Oman, Land Information System, Milestone IV, IMPLEMENTATION PLAN by ESKA consultants, September 1989. It was developed after a one-year study entitled Sultanate of Oman, Land Information System by ESKA consultants, September 1989. The SCTP GIS ultimately will be a distributed network system connecting various ministries and other organizations, using a wide area network (WAN) for which SCTP will establish standards and provide logistical support. User organizations such as MWR can develop their own GIS within the SCTP framework but retain responsibility for updating data and generating reports. The SCTP GIS plan is summarized in Appendix B.

2.5.4 Well Metering

MWR plans to install flow meters at more than 20,000 wells in conjunction with the national well inventory and groundwater management plans. Plans for collecting and processing data from the meters have not yet been formulated.

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[4]The Supreme Committee for Town Planning, established by Royal Decree number 27/85, is empowered to "... outline and prepare the General Policy for Town Planning in accordance with the [Five Year] Development Plan..." It develops national planning standards and fosters cooperation between ministries.

2.6 Information Systems at Other Agencies

2.6.1 Overview

The information systems of several other government agencies with similar needs are described below.

2.6.2 Ministry of Commerce and Industry

The Ministry of Commerce and Industry (MCI), using a Hewlett Packard (HP) 3000 computer with 12 terminals in its laboratories and offices, has operated a sample tracking, recording, and invoicing system since July 1990. Samples are logged directly into the computer, which issues all necessary forms, including invoices. The system, which took 18 months to develop, is used by personnel who have completed hands-on training and was programmed in COBOL by the Ministry's computer department, which also manages the computer system and runs the training program. The system hardware cost approximately 20,000 Omani Rials (R.O.). The minicomputer is located in a small room dedicated to it and shares a back-up power supply with the rest of the laboratory complex.

The MCI also uses an HP 3000 Series 58 computer acquired in 1986 to manage most of its daily operations. It has 42 terminals and more than 200 trained users. A computer department of nine Omani and two expatriate civil service employees maintains both computers and also provides support services for the Diwan of the Royal Court, the Ministry of Agriculture and Fisheries, and the Development Council. MCI has programmed its entire computer system, which operates primarily in Arabic but also has English capabilities (approximately 20 percent of overall use, including the English-only laboratory system). The system hardware is valued at approximately R.O. 320,000. The department has its own emergency power supply and off-site storage facility for daily backup tapes. MCI expects to install HP 3000 minicomputers at its planned district laboratories in Sohar and Salalah and UNIX-based minicomputers at its district offices.

2.6.3 Ministry of Agriculture and Fisheries

The Ministry of Agriculture and Fisheries (MAF) has recently acquired an HP 9000 Series 825 UNIX-based computer on which it has installed ORACLE database management software. The system will operate primarily in Arabic. The Ministry has a one-year program development and staff training contract with the system vendor. The computer has 16 terminals and 16 MB of memory and can accommodate up to 42 users. The hardware cost R.O. 80,000, modifications to the building to house the computer cost R.O. 65,000, and the one-year facilities management contract cost R.O. 40,000. Planned improvements to expand the system's capacity are budgeted at R.O. 50,000. The computer is operated by an Omani system manager and a staff of three programmer/analysts, with assistance from three other programmer/analysts provided by the vendor under the facilities management

contract. System backup tapes are compiled weekly and stored in a fire-proof vault. The computer personnel operate as a section within the planning unit, and the system manager reports directly to the Minister. Eventually a separate computer department is planned.

The MAF dams department is in the process of obtaining a PC-based data management and analysis package from Bureau de Recherches Geologiques et Minieres, the geological survey authority of France. The software package utilizes Clipper, a dBASE-like database, and will contain customized data entry and analysis programs. MAF's current data management for its recharge dam well monitoring program is looseleaf binders with observations recorded on printed forms. Limited analysis of well data has been performed manually and with computer spreadsheets. The Ministry expects to link this system with the main computer system in two years.

2.6.4 Ministry of Education

The Ministry of Education has a Wang VS100 mainframe computer for all its administrative operations, including personnel, budget, cashier, projects management, and scholarship program tracking. All applications on the system operate in Arabic. The system, in use since 1986, is managed by an Omani with a staff of five Omanis and two expatriates who operate the computer and do routine program development. Major development work is usually contracted out. The Ministry has had excellent support from the computer dealer, with whom it has a service contract. Although the Ministry building predates the computer, the computer department has been given several rooms and separate ventilation and backup power supplies. System backup tapes are compiled daily and stored in a fire-proof vault.

2.6.5 Planning Committee for Development and Environment in the Southern Region

PCDESR in Salalah operates an eight-machine PC network managed by an Omani who holds a degree in management information systems. The system has network versions of common spreadsheet, database, and word processing software with both Arabic and English capabilities. The system includes a library management component.

2.6.6 Directorate of Town Planning and Surveying

The directorate of town planning and surveying of the Ministry of Housing is reviewing tender offers for a distributed computer network with a UNIX operating system, ORACLE database management software, and ARCINFO GIS software.

2.7 Pertinent Data at Other Agencies

2.7.1 Overview

Several government offices in Oman maintain data for the assessment of water resources. As more of these data are computerized, they will be more readily transferrable among users, permitting timely and more complete water resources analyses. The information includes well data (collected by MAF, Ministry of Electricity and Water, and the Dhofar Waliat), maps (Ministry of Defence), meteorology (Ministry of Communication), contractor registration (Ministry of Commerce), population (Ministry of Housing), and land use (Ministry of Housing and MAF). Information held by other government authorities (e.g., Ministries of Environment and Health) may also be useful but may be difficult to obtain or less critical to water resources management. Data storage at several of these agencies is discussed below.

2.7.2 Recharge Dam Monitoring Well Data

MAF monitors water levels in wells located near its recharge dams, providing a valuable complement to MWR's well monitoring network, and will store this information on the PC-based database system discussed in Section 2.6.3. MAF is also assessing agricultural acreage on the Batinah plain and eventually hopes to survey cropped lands throughout the Sultanate. These data can be very valuable to MWR.

2.7.3 Public Water Supply Wells

The Ministry of Electricity and Water (MEW) collects limited water level and water quality data for its municipal water supply well fields. Little pumpage data have been collected. Since MEW is one of the major groundwater users, these data are needed by MWR as it attempts to quantify water use throughout Oman. These records are not computerized at the present. In the Dhofar Waliat, the directorate of water supply fulfills the function that MEW carries out elsewhere in the Sultanate.

2.7.4 Maps and Geographical Data

The directorate of national survey of the Ministry of Defence is responsible for all maps of Oman. As MWR moves towards implementing a GIS, it will be helpful if it can obtain some of these maps in digital format, or even obtain computerized images of the maps themselves. This process may be facilitated by the efforts of SCTP as it begins its pilot GIS.

2.7.5 Meteorological Data

Meteorological monitoring is performed by the civil aviation and meteorology directorate of the Ministry of Communications. These data are useful for analyzing infiltration of surface

water into the ground and for determining evaporation rates, which are necessary components of water budget analyses.

Chapter 3

COMPUTER SYSTEM CONCEPTS AND NEEDS

3.1 Organizational Framework

A computer and information resources department should provide policy and technical support throughout the organization, establishing policies and procedures for computer hardware and software acquisition, information sharing, configuration, and data integrity, including security and access privileges. Departments that collect data should retain control and responsibility for data maintenance, including determining what data should be made available to other entities. Because it supports the spectrum of functions in the organization, it is important that the computer department be separate from these functions.

3.2 Database System

3.2.1 Database Concepts

Database systems facilitate the collection, retention, and effective use of data. To effectively manage data and eliminate duplication, a distributed database is commonly used in today's computer systems. A distributed database can store information on separate computers (database servers) and in different locations without the user's need to know where the data reside or any special commands to access data from different locations.

With a distributed system, each department in an organization can be responsible for the maintenance and management of its own data, retaining the exclusive right to update or alter these. Other authorized users can only view the data.

There is database software for various applications and for hardware of varying capabilities. The intended uses range from sophisticated scientific applications to standard financial applications. These software systems can be classified into four groups:

- Open databases (such as ORACLE and INGRES) that run on a variety of hardware and provide links to popular computer languages. Most rely on the industry-standard Structured Query Language (SQL) for user interface.

- Bundled databases (such as dBASE and PARADOX) that also run on a variety of computers and often can access programming languages and SQL. A proprietary programming language is included with these databases, which primarily are based on micro-computers with UNIX

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and DOS operating systems although some have been developed for larger computer systems. Their advantage is ease of application development.

- Platform specific databases that can be of the open or bundled type and run on a single operating system or hardware configuration. Examples of this type are Digital Equipment Corporation's RDB (open) and Software House's 1032 (bundled).

- Application specific databases that are designed to perform a unique task or function. These databases typically are used in scientific or specialized fields such as GIS. An example of this type is the INFO database used by ESRI for ARCINFO.

The variety of MWR database functional requirements is noted below. A review will show that MWR requirements are broader than can be met by the platform or application specific databases.

3.2.2 Database Functional Requirements

Typical database functions are:

- Data maintenance

- Data backup and restoration capabilities

- Tracking data access and entry (journaling)

- Permitting recovery from mistaken entries (transaction rollback)

- Data security

MWR specific requirements are:

- User-specified query and reporting functions

- Menu-driven operations and graphical user interface

- GIS capability, including display of tabular data that coincide with geographically selected criteria

- Access from remote sites

- Automatic entry of data from data loggers, telemetry, and automated measuring systems such as laboratory instruments

- Local control of data maintenance activities

- Arabic and English capability

- Ability to keep track of data stored on more than one computer

- General ease of operation

3.2.3 Reporting Requirements

Both novices and advanced users should be able to obtain reports from an MWR database via either menu-driven programs or commands issued directly in a simple query language. A novice should be able to follow a series of menu-driven commands that could, for instance, print a report of all water quality analyses for the Sharqiyah district for a given month and year. This might be done by selecting "Reports" from a main database access menu either by pressing the appropriate key or by using a computer mouse or a touch-sensitive screen (the option could also be indicated graphically with a picture of a report, and both Arabic and English versions of the menu could be offered). A second menu could offer a "Water Quality" option, and further queries could be built in to allow the user to specify the region and dates of interest.

An advanced user might wish to obtain a similar report but prefer to list only those samples where the chloride concentration exceeded 500 parts per million (ppm) and the fluoride concentration exceeded 100 ppm. While such requests could be programmed into the database access menu, it is generally more practical for advanced users to become familiar with the query language of the database system. They might issue a request that specified "list Sharqiyah district water quality for January to June 1990 for chloride greater than 500 ppm and fluoride greater than 100 ppm" (the exact wording would depend on the software and data types).

The built-in capabilities of a water resources database should provide customized reports for all the data stored in the system, including:

- Well location, registration, permit, construction, and inventory information

- Well water levels

- Water quality analyses

- Pumping records
- Catalog of other well information available (e.g., logs, pump tests)
- Wadi flows
- Falaj locations, registration, and inventory information
- Falaj flows
- Precipitation

The system should permit the user to specify the dates and areas of interest and should offer graphical output options for items such as water level time histories. Selective queries, as in the example above, must also be readily available. Appendix C provides a suggested list of water resources database contents.

3.2.4 Compatibility of Existing and Planned Systems

Compatibility of existing and planned systems must be ensured. This should not be difficult, with the trend in recent years towards developing compatibility among the spectrum of widely recognized hardware and software systems available. In particular, the UNIX operating system and SQL, which have come into widespread use in the last few years, permit communication among many different types of computers.

Although MWR's existing database files are not directly compatible with modern database programs, they are being transferred to PARADOX, which can be readily transferred to ORACLE and other relational database programs.

3.2.5 Database Needs Specific to the Well Inventory

The well inventory data, which could easily total more than 600 MB (based on an estimate of one page of information per well), will require significant computer resources. Data will need to be transferred regularly from the inventory crews both by computer and by paper forms to the regional offices and the central databases, and the regional offices will need ready access to laboratory results to help inform the water quality sampling program. In addition, inventory planners will need access to the bilingual well registration database. The earlier these systems are in place, the better organized and effective the inventory can be. Furthermore, data from the inventory will need to be accessible as soon as possible for effective use in management of the nation's water resources.

3.2.6 Database Language Capabilities

Database software that can function in Arabic should be selected wherever possible to facilitate its use by Arabic-speaking personnel. As many MWR operations may continue to be in English, the preferred software packages should function in both languages and be able to exchange information. Certain components such as the laboratory, where English may be preferred, may be designed to operate primarily in one language or the other.

3.3 Geographic Information Systems

3.3.1 GIS Concepts

A geographical information system (GIS) is a computer-based spatial data handling system. Spatial data are different from the alphanumeric data normally handled by computers. Spatial data can have shape, dimensions, and physical form and can be observed without the aid of letters and numbers. Spatial data with specific location are called geographic data because of their fixed reference point. A scaled engineering drawing used to build a car is an example of spatial data. A road map is an example of geographic data. A GIS puts maps into computers and uses the power of the computer to conduct analysis and present the results in a readily understandable form, often as a map.

Maps show what the eye might see, including the relationships between things. Maps have numerous applications including navigation, planning, engineering, construction, and water resources management. The major drawback of using paper maps exclusively for geographical information management is that only limited amounts of data can be represented on a single map, requiring several maps for all the information to be shown.

Spatial data differ from georeferenced data. While a conventional database can contain georeferenced data, it is non-spatial. A phone book is a good example of non-spatial georeferenced data. Georeferenced data are often a list of items and associated coordinates defining the location of each item. A GIS indicates the location visually on a computer display while the coordinates remain unseen in the GIS database as attributes to the "vector" shown on the display. This attachment of data to a display item is the strength of a GIS.

3.3.2 GIS Functions

A GIS connects the physical location of information with the attribute data in a database and produces visual displays, often as maps. For example, maps could be developed to indicate existing and future conditions of saltwater intrusion in the Batinah and Salalah areas.

The primary function of an MWR GIS, at least initially, will be to produce maps showing well locations identified in MWR's well inventory program. A GIS in combination with a database

system will contain all the desired information on each well and make rapid information retrieval possible.

One problem in implementing an MWR GIS will be the lack of digital base maps. Although SCTP is in the process of making base mapping available, the program is expected to take 10 years. MWR needs base mapping soon. A GIS system must enable use of almost any type or combination of maps that contain coordinate information, including satellite imagery to be used as a raster (photograph-like image) base map. Existing maps can be scanned to create a raster file of base maps. Scanning is much quicker than digitizing (the method for creating vector base maps) and makes the best use of existing maps, permitting upgrades to more accurate maps as these become available. An important function of ARCINFO, a popular GIS program produced by Environmental Systems Research Institute (ESRI), is its ability to convert between vector and raster image formats.

Satellite imagery is one option for covering the whole country. Thirty-meter resolution Landsat coverage would require approximately 30 frames, each covering 10,000 square kilometers. The cost on computer tape, including processing for geometric correction and limited image interpretation to identify areas with vegetation, would be approximately R.O. 60,000.

The GIS should also give MWR the capability to store computer-assisted design (CAD) drawings and scanned images such as well logs or photographs as attributes to wells.

3.3.3 Reporting Requirements

A water resources GIS, like a database system, should be usable at all skill levels. With a menu-driven system, an inexperienced user should be able to obtain a contour plot of EC values for the Salalah plain for a specified period, for example. A more sophisticated user should be able to obtain a contour map of the change in EC values for a specified interval (e.g., September 1988 to September 1990). The GIS should permit a user to obtain all the information from the supporting database. Access should be easier than with a standard database, allowing the user to select a particular area from a map of all the regions, or even define a unique area of interest by marking off its boundaries.

3.3.4 Compatibility with Proposed Countrywide GIS

The MWR GIS should be compatible with the countrywide GIS being developed by SCTP, which favors ARCINFO. Similarly, ORACLE has been selected by several ministries as the database to be used in conjunction with GIS. It would be in MWR's best interest to follow SCTP guidelines, especially in software selection and GIS architecture, to reduce the technical problems associated with sharing information.

3.3.5 GIS Application to Well Inventory

It will be of great value ultimately to have every well in the Sultanate located spatially in a computer database, and to have a GIS system capable of identifying and displaying the characteristics of each well on a computer screen. For instance, the GIS could contain rasterized images of photographs taken at each well site, enabling a GIS user at an MWR regional office to identify a well involved in an ownership dispute even though the claimants had no documents or other way of describing it. Such a system might take several years, but it is important to lay the groundwork for it by gathering the necessary data at the time of the inventory.

3.3.6 GIS Language Capabilities

GIS, being primarily graphical, has the advantage of not depending on a user's computer language skills. A GIS that permits instructions to be issued in Arabic as well as English would be particularly useful. An Arabic version of ARCINFO is currently under development.

3.4 Networking

3.4.1 Overview

Networking is the sharing of data and computing resources among computer systems, typically over a local area network (LAN) within one building, and over a wide area network (WAN) embracing several buildings and cities. A network should be tailored to meet future system needs. Concurrent data access, the sizes of the database and computers, the number of connections, and the type of data accessed across the network all affect the optimal design. These factors must be estimated at typical and peak operational requirements.

3.4.2 System Interface Needs

The internal interfaces of a computer system connect its core components, while the external interfaces connect other users to the system. As MWR develops networked computer systems, its needs and the technology available will affect various users. In the next few months many MWR functions will be moving to a new building, dividing the headquarters between two locations. In approximately two years MWR expects to consolidate its operations in a third building. The laboratory and the regional offices are separate anyway. While ideally the entire Ministry should share a common network, it might not be possible to obtain the necessary dedicated phone lines between sites.

As MWR develops a networked computer system, the core components to be linked together might include the groundwater management and assessment databases, the surface water database, and the library database. The laboratory, which manages a large and important

component of the water resources database, will need to be linked to the main database via telephone connections. The regional offices, which collect much of the data for the water resources database, will need to have modem access to the headquarters database and also maintain their own databases. Data transfers between regional offices and headquarters should be frequent to ensure reliability of the data. Large amounts of data should be transferred by reusable media (such as floppy disks). Small data transfers can be made by telephone link.

Data stored at MWR may also be useful to other ministries and could be made available via modem connection. In turn, a considerable amount of data collected by other ministries could be useful to MWR. Data can be shared between ministries by diskette or tape transfers, provided that compatible systems are used. Where frequent exchanges are necessary, telephone connections may be established.

3.4.3 GIS Networking

The GIS at MWR will require specialized hardware, described in Section 3.5.2, and access to the other MWR databases through a LAN. In the near term MWR can use computer tapes and diskettes to share GIS data with other ministries. Later, when SCTP and other ministries have greater needs for information, it would be advantageous to create a WAN. A WAN is included in the SCTP GIS implementation program.

3.5 Hardware Requirements

3.5.1 Database

There are three possible hardware configurations for a multi-user database system:

1. A PC-based client/server operating on a LAN
2. A central computer with terminal access
3. A distributed database client/server on an ethernet WAN

The amount of data and the number of accesses during peak operation of the MWR system could exceed LAN capabilities. However, this option can be used effectively for regional offices and departmental computer systems.

A central computer requires the most support and programming staff and is usually the costliest option to implement.

A distributed database can be effectively implemented and maintained with a combination of in-house staff and vendor support. The Sultanate already has systems of this type that offer advantages not available with the other options:

- Should a failure occur on one node of the network, the rest of the system can still function. Although the data on that node will not be available, the drop of service will affect a small percentage of the user community rather than the entire ministry.

- Nodes can be added to the network and database maintenance can be performed with minimal effect on system access and availability.

The selected hardware should have Arabic and English capabilities, preferably with a selection of keyboard designs to suit individual users (e.g., Arabic key labels with secondary English symbols for tasks with primarily Arabic uses, and the reverse for primarily English uses).

3.5.2 GIS

The spatial data used in a GIS require larger computer storage capacity, and manipulation and display of these data require greater computer processing power than ordinary database or word processing applications. Specialized peripheral equipment including printers, digitizers, plotters, and scanners is also required. The digitizers and scanners should be able to handle E size sheets (91 by 122 centimeters). The plotter should be able to plot vector and raster images on E size media. All peripherals must be compatible with the workstation hardware, and all hardware should be supplied by one local vendor who will be responsible for getting it working as a system.

The GIS application envisaged for MWR will be difficult on PCs and dictates a workstation or larger computer with considerable disk storage capabilities. It also needs to be networked for access to the main MWR database system. The raster images from scanned maps, satellite imagery, drawings, or photographs create very large files that do not tend to change much with time. Storage on a high-capacity optical WORM (write once read many) drive for raster files is advisable.

3.5.3 Field Equipment

Computers used in field work need to be rugged and easily transportable. Field crews could be outfitted with portable PCs with small hard drives, single diskette drives, and dot matrix printers. Today's lightweight laptop machines are fairly rugged and also inexpensive. Power transformers that plug into vehicular electrical systems could also be used.

3.6 Computer System Security Requirements/Access Limitations

Security is defined by the level of access a particular user has to specific data. It can be achieved by requiring passwords and by limiting the actions a user may perform. Sensitive data might be made accessible only to a specific group of users while general information might be available to all. Rights are assigned to groups and users depending on their need to access data. The two types of users are those that can affect the data and those that can only view data.

To accommodate this requirement, there generally are four levels of access: "system," "group," "owner," and "world." "System" files can be accessed only by users with appropriate access privileges, "group" files are available to users defined as members of the specific group, "owner" access limits use to the user who created the file, and "world" files may be accessed by any user of the database.

Actions that can be taken on the files can also be limited. The four action rights generally used are: "read," "write," "delete," and "control." "Read" allows the user to view only, "write" allows the user to update the file, "delete" allows the user to remove files or records, and "control" allows the user to change the action characteristics of a file.

A system security administrator can assign passwords and provide appropriate access rights to departmental security administrators, who in turn can assign passwords to their users. Alternatively, the system administrator can assume this role for the entire organization.

3.7 Personnel Requirements

3.7.1 Database Administration

The functions of a computer and information resources department are presented below. The number of staff needed to perform these functions will depend on the size of the computer system.

Role:	Computer & Information Resources Manager
Duties:	Set policies and procedures
	Manage C&IR staff
Level:	Requires more management than technical expertise

Role:	System Administrator
Duties:	Provide network access and support
	Upgrade operating systems as required
	Provide system backups
	Update application software

	Monitor the operation of the system Maintain operation logs Recognize problems that require external assistance
Level:	Understanding of network and system administration; some systems programming knowledge helpful

Role:	Network Technician
Duties:	Monitor the operation of the network Maintain logs Add, remove, and maintain network nodes and terminals Recognize when help is required.
Level:	Understanding of network administration

Role:	Database Administrator
Duties:	Provide overall support to departmental administrators Upgrade database as required Maintain database backup systems and logs
Level:	Knowledge of the database management software and thorough knowledge of database structure, file manipulation methods, and SQL

Role:	Security Administrator
Duties:	Assign departmental security administrators Define file access levels Maintain security lists and monitor access Maintain 'virus free' environment
Level:	Knowledge of computer administration practices and security procedures

3.7.2 GIS Personnel

GIS personnel require special training in what is one of the most exciting computer technologies available because of its computing power and its ability to produce the finest graphics. The two GIS staff roles to be filled are:

Role:	GIS Administrator
Duties:	Maintain GIS systems and files Perform upgrades as necessary Provide GIS security
Level:	The same expertise as for the database administrator plus an understanding of GIS

Role:	GIS Specialist
Duties:	Work with technical staff to determine GIS uses Use GIS to produce maps
Level:	Understanding of GIS and familiarity with fields addressed by technical staff

3.7.3 Department Administration and Data Entry

The following are departmental positions and may not require additional staff. The level of expertise is not as advanced as for the positions described in Section 3.7.1. Some specialized training may be advisable. Computer department staff could perform some or all of the technical roles.

Role:	Departmental Database Administrator
Duties:	Maintain integrity of departmental data
Level:	Knowledge of the department's data and its processing practices

Role:	Departmental Security Administrator
Duties:	Provide department personnel with privileges and access to data
Level:	Similar to departmental database administrator

Role:	Data Entry Staff/General User
Duties:	Perform data maintenance functions Produce reports from menu selections Extract relevant information for use in producing reports pertaining to specific departmental functions
Level:	Ability to understand and issue simple computer instructions

Chapter 4

TRAINING AND SUPPORT SERVICES STRATEGY

4.1 Overview

No information management system can function effectively without competent personnel to maintain and continually develop the system. Especially where computers are involved, it is imperative that personnel regularly upgrade their skills so as to keep in touch with the technology of this rapidly evolving field. Sections 4.2 and 4.3 respectively discuss the existing MWR computer training program and the needs of a program that will support a strong computer department. The Task 2B—Training report discusses MWR training needs in fuller detail. There must also be institutions and vendors who can provide ongoing hardware and software support. This network is well established in Oman and is discussed in Section 4.4.

4.2 Existing Training Program

At present, MWR employs two Omani data entry trainees, two database managers (one Omani, one expatriate), and an expatriate system manager. The training department is working to place Ministry personnel in appropriate data management training programs for the "typical users" group discussed in Section 4.3. MWR personnel have received little formal computer training.

4.3 Requirements for Training of MWR Data Management Staff

4.3.1 Overview

Data management staff may be classified into four groups for training: system manager, programmers/analysts/operators, advanced users, and typical users. The needs of each group are discussed separately below, but the following requirements apply to all:

- Computer training should be an ongoing process.
- There should be follow-up for all types of instruction.
- Training programs should be appropriately located.

- Training should be relevant to a staff member's role in the organization, both in terms of that person's abilities and interests, and in terms of the actual operations being taught.

4.3.2 System Manager

The system manager is one of the most important users of the computer, ultimately responsible for operation of the entire system. The system manager must supervise a staff of programmers/analysts/operators, fully understand all the systems in use, and coordinate all computer-related activities within the organization. This person must have considerable management skills and training in computer system operation, such as a degree in management information systems. This person is the principal computer skills resource for the other computer department staff, as well as for the entire organization.

Training of the system manager can be divided into three phases: on-the-job training, additional institutional training, and ongoing education.

On-the-job training can be structured effectively if a contractor or staff advisor with advanced computer skills is working on-site to assist the Ministry in developing its computer systems. This phase might last one to two years, during which time the manager is trained to develop the computer system and train computer personnel.

Additional institutional training might take the form of a specialized educational program, such as an advanced degree at an overseas institution, that includes course work in system management, staff supervision, and staff training. The impact of the manager's absence can be minimized by arranging such a program while contract staff are still working.

Ongoing education is necessary to keep the organization in touch with technology and to continue to develop the manager's skills. Such training might include annual attendance at conferences in the manager's areas of interest, reading of literature pertinent to systems management, and regular contact with professional peers.

4.3.3 Computer Specialists

4.3.3.1 Programmers/Analysts/Operators/Administrators

Programmers, analysts, operators, and administrators may work directly for the system manager or within other departments. They take on the daily tasks of operating the system and implementing ongoing system development. They may learn many of their skills on the job but must have the demonstrated skill level necessary for the position. On-the-job training by contract personnel can be very useful. There must also be ongoing training from the system manager, from additional on-site instruction, and through external courses where such services are available.

4.3.3.2 GIS Users

Staff training is essential for implementation of a GIS and should begin as soon as possible. MWR could obtain some support from SCTP, which has a full-time GIS expert dedicated to GIS development in Oman.

Initial hardware setup and pilot studies could be completed by consultants with MWR counterparts. The consultant team would include at least one representative each from the software and the hardware vendors.

4.3.4 Advanced Users

Advanced users include professional staff throughout the organization who use computers to analyze data. They usually are skilled enough to use computers with a minimum of instruction, and training may consist of short in-house or off-site courses to familiarize them with a particular software package. These staff may also work with computer department personnel to develop applications peculiar to their needs. Where they are sufficiently knowledgeable, they may also instruct those working for them. They should be given the opportunity to become acquainted with the spectrum of available computer resources in the organization and should continue to advance their skills in their particular fields.

4.3.5 Typical Users

Typical users make up the bulk of users within the organization. These are the employees responsible for data entry, processing, and office routine, who use menu-driven systems and standard software packages (word processing, spreadsheets, etc.). Training of these personnel is already under consideration by the Ministry's training department and is discussed in depth in the Task 2B: Training report. Generally, these personnel should be given introductory computer usage courses as well as focused training, possibly off-site and also on-site, in the specific applications they will use.

4.4 Support

4.4.1 Training Services

Computer training services are available in Oman through various hardware and software suppliers, and through computer training schools such as the National Institute of Computer Education. These services cover a wide range, from instruction in software operation to provision of in-house trainers who help employees develop and maintain computer systems.

4.4.2 Equipment Vendors

Numerous computer hardware and software vendors have offices in Oman, primarily in the Capital area. These companies typically provide a full range of contract services, from system development to turnkey operations to maintenance. It is important to choose a reputable outfit and equipment that is reliable and backed by strong support.

4.4.3 Contract Labor

Data processing often has short-term demands for personnel. Although there are no agencies in Oman that provide temporary personnel, there are organizations that provide contract data-entry services.

4.4.4 Interagency Cooperation

As many government agencies have similar computer systems and MIS needs, interagency cooperation in training and support would be profitable. This might cover the provision of consulting services or the temporary assignment of personnel. Limited consulting services are currently provided by the computer department of the Ministry of Commerce and Industry (Section 2.6.2).

Chapter 5

RECOMMENDED PROGRAM

5.1 Description

5.1.1 Software

The recommended database software is ORACLE, which has been in existence for several years and recently has been released in an Arabic version. It provides an industry-standard SQL interface and operates on a variety of machine types, offering broad options for computer selection. ORACLE can accommodate databases contained on multiple computers or disk drives, has been selected by a number of other ministries, and is well supported in Oman.

Remote sites and some LANs can use PARADOX database software, at least for the near future. The newest version of this software links up directly with ORACLE. Remote sites will not require the level of service needed for the core database systems and could function with a PC-based product.

The 1990 GIS SOURCEBOOK (GIS World, Inc., 1990) lists the general characteristics and functional capabilities of 80 GIS software packages. A comparison of these packages shows that ARCINFO is an industry leader in functionality and compatibility with other GIS and database products. ESRI claims to be the leading GIS vendor, with more than 10,000 users worldwide. The program is supported on various computer types ranging from personal computers to mainframes. ESRI can provide training materials, including videos and workbooks, and training and consulting services as required. When ARCINFO is run on a workstation (or larger) computer, ORACLE can be accessed directly. The program already has several users in the Middle East, and an Arabic version will be available in the near future. The WASH team recommends that MWR use ARCINFO in combination with ORACLE database software for its GIS.

The use of ARCINFO has several benefits. The long-range advantage is that it will be compatible with SCTP's system design and implementation plan. The immediate advantages are that it will provide the GIS capabilities required by MWR, including an ORACLE interface and the ability to integrate raster and vector cartographic data.

If more versatility with raster images is needed, MWR might consider purchasing ERDAS, Inc. (Atlanta, Georgia) image processing software also. ERDAS software provides the capability to interpret, classify, and vectorize raster images into ARCINFO, among other formats. ARCINFO contains a direct translator between ERDAS and ARCINFO formats.

5.1.2 Hardware

The recommended network design (Figure 1) identifies ethernet as the cabling technology. Ethernet has two characteristics that will ensure relevancy of the network for the entire life of the system: it is an industry standard, and its speed (10 million bits per second [megabits]) will meet or exceed MWR's response requirements. Cheaper alternatives would be inadequate at peak operating conditions.

The size of the database, the number of access points needed, and the types of data that must be made available throughout the system require different types of hardware. Water resources databases should eventually reside in at least four computers:

1. Groundwater Assessment and Management and Aflaj database.
   A UNIX workstation or 32 bit bus microcomputer capable of 10 MIPS and storing at least 4 gigabytes; tape backup system or digital tape or rewritable compact disk.

2. Laboratory
   A UNIX workstation or 32 bit bus microcomputer capable of 4 MIPS and storing at least 4 gigabytes; tape backup system or digital tape or rewritable compact disk.

3. Surface Water
   80486 or 80386 file server residing on a LAN; 500 MB of storage.

4. Library
   80386 based PC with compact disk storage and scanner; 100 MB of disk storage.

5.1.3 Training

A qualified individual, preferably with an MIS or computer degree, must be hired or identified as soon as possible to assume the role of system manager. This person initially can receive on-the-job training from the present system manager or from an advisor and might later be sent to an advanced academic training program. Eventually the system manager will assume responsibilities for directing computer operations throughout the Ministry.

Two or more programmers/analysts/operators must be hired or identified. These personnel preferably would already have had training in computer systems operation and development, but others with potential to fill these roles might be placed in appropriate on-the-job or institutional training programs.

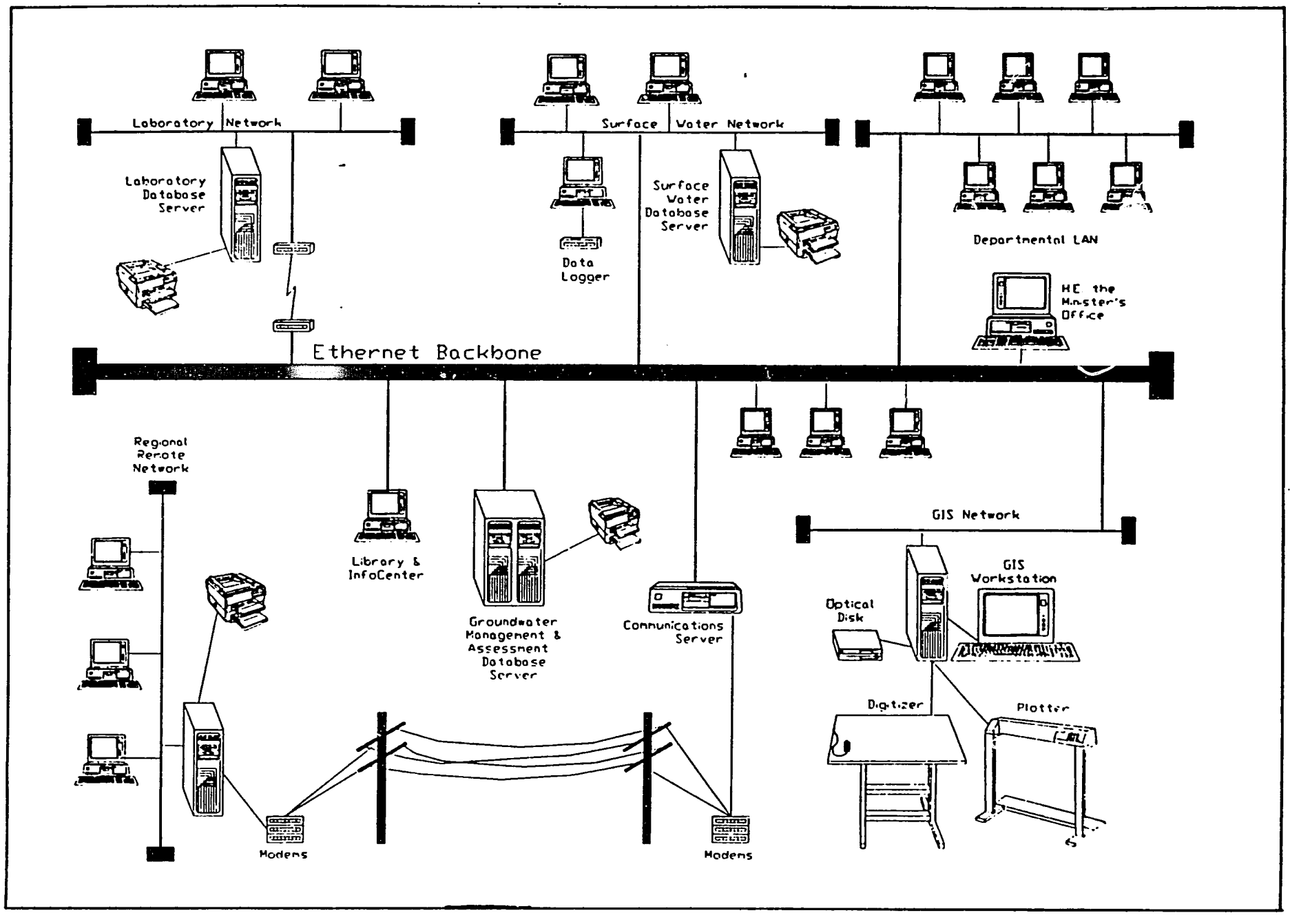


Figure 1
Recommended Network Design

Advanced computer users should be adequately served by training in the operation of the installed systems offered by the computer department, through either contract or in-house staff. Such users will work with the computer department staff to analyze their problems and perhaps develop special computer applications to serve their needs.

Typical computer users—those responsible for routine data entry and analysis, word processing, and accounting tasks—should be offered courses and on-the-job training in computer skills appropriate to their roles. Training in the use of standard software packages may be given through short courses at training institutes. Training in specialized applications, such as a menu-driven system developed exclusively for the Ministry's use, should be provided through in-house courses tailored for that system. Further discussion of the recommended training program for typical users is included in the Task 2B: Training report.

5.1.4 Organizational Needs

A successful water resources data management plan will require the efforts of several personnel and outlays for capital goods and consulting services. A department responsible for overall coordination of computer resources under the direction of a senior MWR official should be designated.

5.2 Implementation

5.2.1 Timetable

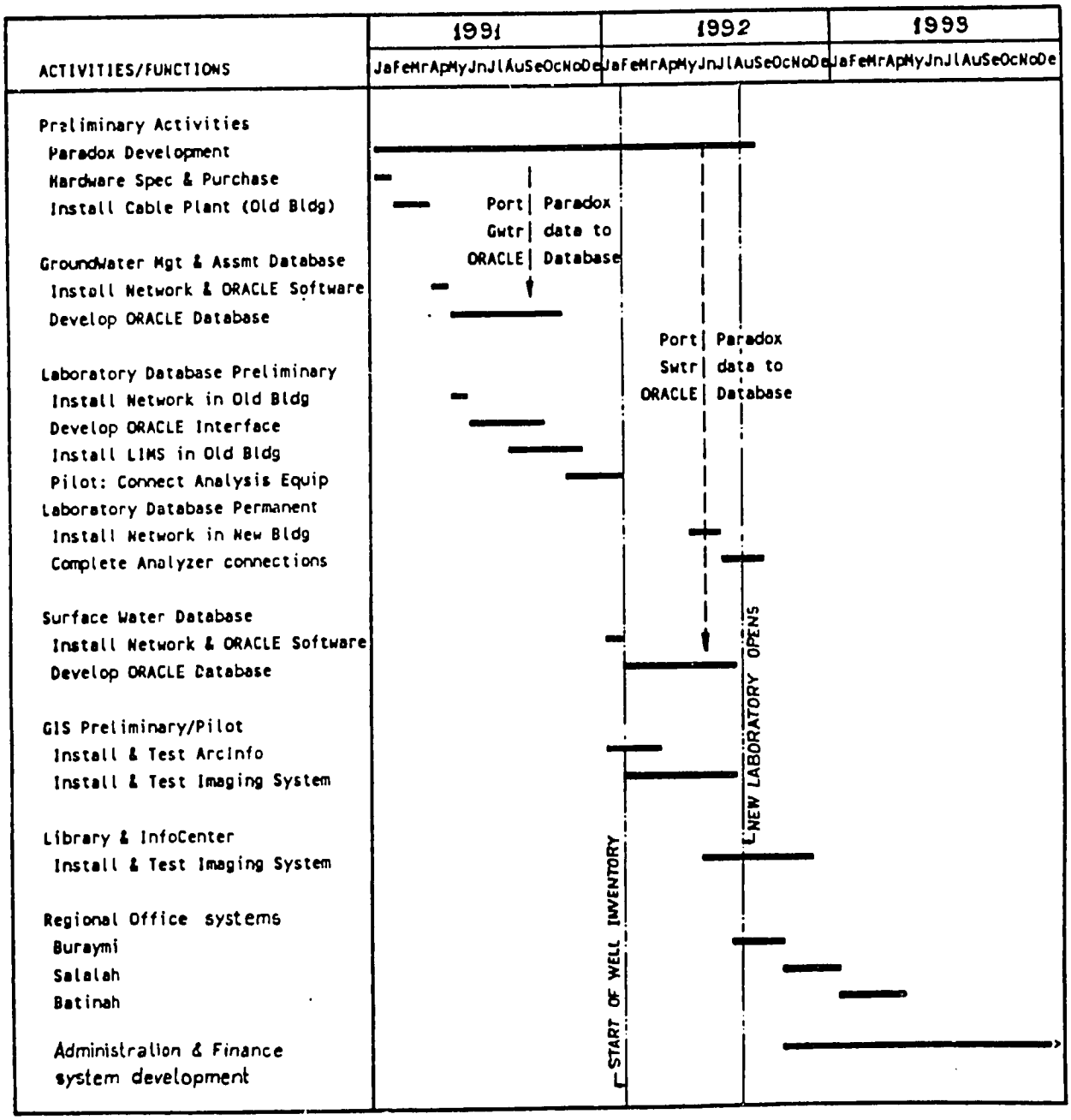
Table 1 presents a suggested timetable for implementation of the recommended database management plan based on the urgency of improvements necessitated by the rapid expansion of the Ministry and by plans for the national well inventory and for upgrading the laboratory. The action plan takes the previously divergent paths of the various departments in database management and gradually brings them together. Thus, this is an evolutionary step rather than a radical departure from previous practice.

Although the timetable phases in some activities to keep the level of effort manageable, it primarily takes a multi-pronged approach since the Ministry is trying to move forward on a number of fronts where it has made little progress. Except for GIS, most of the activities involve one-time acquisitions that need to be put in place to make the program succeed.

5.2.2 Responsibilities

Responsibilities for implementation of the plan must be assigned to ensure its success. A senior Ministry official should be designated to oversee the plan and supervise the staff working on the projects. A system manager must be designated to take responsibility for ongoing implementation. Each department must work with the computer systems

Table 1
Preliminary Computer System Implementation Time Schedule



development personnel to keep the program suited to its changing needs. Finally, any external agency that offers assistance should make sure it serves the Ministry's needs.

5.2.3 Costs

Table 2 presents a summary of annual outlays for capital equipment, staffing, and training amounting to approximately two million Rials for the first five years. Table 3 shows the capital acquisition schedule for a five year term. Table 4 shows the major capital costs for the first two years in the development of the system. Table 5 provides detailed costs of capital equipment and staffing, respectively for a five year period.

5.3 Coordination with Other Agencies

In developing its management information systems, MWR should exploit all opportunities for cooperation with other government agencies. It will especially benefit by coordinating its GIS pilot programs with the SCTP and the PCDESR. These agencies are implementing GIS pilot programs and already have several staff members with GIS expertise. MWR is participating in this program by providing the water resources data for the PCDESR GIS, and in turn will be able to use the maps and other system components that PCDESR develops. Should PCDESR obtain a minicomputer for its GIS pilot program, MWR could operate a terminal or a PC networked to the PCDESR system.

MWR should also take note of the successes and failures of ministries that have similar computer resources and needs, particularly those such as MAF that are implementing ORACLE database systems, and those such as the Ministry of Housing developing ARCINFO GIS capabilities.

5.4 Water Analysis Program

MWR must make many difficult decisions regarding the level of effort for the various components of the national well inventory. But the WASH team believes that water quality samples should be collected and analyzed wherever practical because the incremental costs of water sampling are a small part of overall inventory costs and the value of the information gathered is high. A discussion of water quality analyses in ongoing monitoring programs and as part of the inventory is included in the Task 2A: Laboratory Upgrading report.

As the inventory is due to begin before the completion of the new laboratory (early 1991 versus late 1992 by present estimates), water quality analysis initially will be limited by the capabilities of the existing laboratory (unless contract work is considered). MWR must recognize that samples collected during this period will not receive the quality or range of

Table 2
MWR Computer System Summary

	1991	1992	1993	1994	1995
Capital Equipment	545,000	218,000	234,000	20,000	10,000
Staffing	283,000	301,000	257,000	183,000	180,000
Training	25,000	25,000	20,000	10,000	10,000
Yearly Total:	853,000	544,000	511,000	213,000	200,000
5 Year Total:	**2,321,000**				

Table 3
Capital Acquisition Schedule

Item	1991	1992	1993	1994	1995
Site Preparations	65,000	65,000			
Groundwater System	246,000				
Surface Water System		69,000			
Library/Info Center System		30,000			
Laboratory System	234,000				
GIS Workstation		54,000			
Finance & Administration			234,000		
Other Peripherals				20,000	10,000
Yearly Totals:	**545,000**	**218,000**	**234,000**	**20,000**	**10,000**

Table 4
Capital Equipment Costs
(First Two Years)

System Description	Item Cost	Totals
Groundwater Database system		
UNIX based RISC Server	210,000	
8 Gigabyte Hard Disk		
48 Megabyte RAM		
Rewriteable Optical Disk (Backup)		
ORACLE Database Software	36,000	
		246,000
Surface Water Database System	45,000	
UNIX based RISC Server		
4 Gigabyte Hard Disk		
16 Magebyte RAM		
ORACLE Database Software	24,000	
		69,000
Laboratory Database System	65,000	
UNIX based RISC Server		
4 Gigabyte Hard Disk		
16 Megabyte RAM		
Digital Audio Tape [DAT] (Backup)		
Network Cable plant (old & new)	30,000	
6 PCs (with Graphic Interface)	15,000	
Oracle Database Software	24,000	
Lab Information Management Software	100,000	
		234,000
GIS Workstation	30,000	
UNIX based Workstation		
Compact Digital Disk (Imaging)		

Table 4
Capital Equipment Costs
(First Two Years) (cont.)

Digitizer	5,000	
Plotter	10,000	
ArcInfo Software	9,000	
		54,000
Library/Information Center		
Compact Digital Disk	30,000	
		30,000
Site Preparation (Old Bldg)	50,000	
Ethernet Cable	15,000	
		65,000
Site Preparation (New Bldg)	50,000	
Ethernet Cable	15,000	
		65,000
Total Capital Acquisition Costs:		763,000

Table 5
Staffing and Salary Requirements

STAFF POSITION	RO Salary	1991	1992	1993	1994	1995
MIS Manager	60,000	60,000	61,800	63,654	65,564	67,531
Technical Advisor	60,000	40,000	61,800	22,454	-	-
DB & Program Mgr	48,000	48,000	49,440	50,923	52,451	54,024
System Network Tech	20,000	20,000	20,600	21,218	21,855	22,510
Programmer/Analyst	12,000	12,000	12,360	12,731	13,113	13,506
Programmer	14,000	14,000	14,420	14,853	2,921	-
Programmer	14,000	14,000	14,420	14,853	2,921	-
Programmer	14,000	14,000	14,420	14,853	2,921	-
DB Administrator	12,000	12,000	12,360	12,731	13,113	13,506
DB Administrator	14,000	7,000	7,420	7,865	8,337	8,837
Others	20,000	20,000	20,600	21,218	-	-
Trainers	22,000	22,000	11,660	-	-	-
Total Annual Salaries:		**283,000**	**301,000**	**257,000**	**183,000**	**180,000**

Values expressed in the above table were accumulated from interviews with MWR staff. Yearly increases of 3% are assumed. Totals are rounded to the nearest thousand RO.

analyses that will be available in the new laboratory and that laboratory capacity will strictly govern the number of samples that can be analyzed.

Criteria for sample collection and analysis are being developed by MWR to guide the inventory crews in selecting locations for sample collection and determining analysis parameters, probably using a printed "decision tree" format.

Ideally, sampling criteria should be determined by the needs of the research program. The WASH team recommends the following water quality sampling guidelines:

- Field parameters (e.g., EC and temperature) will be analyzed at each well where a sample can be obtained.

- Analyses that need to be completed on the same day as sample collection (e.g., bacteriological) will be done either in the field or at the operations base for each well where a sample can be obtained.

- The district inventory manager will determine which wells in an area will be sampled, according to the needs and problems of the area. It would be beneficial to submit samples from most wells for a standard set of analyses (e.g., major ions), and from a selected number for comprehensive analyses (e.g., trace metals). Where laboratory capacity is a problem, it might be reasonable to submit a limited number of samples of both kinds. A possible methodology for sample selection is as follows:

  — The inventoried area will be divided into one square kilometer grids and inventoried wells marked on a map.

  — In any gridded square with three or fewer wells, all wells will be analyzed.

  — All multiple family drinking supply wells will be analyzed.

  — In squares with more than 30 wells, at least 10 percent of the wells will be analyzed.

This method will ensure that the water quality of wells throughout the Sultanate is categorized and will spare the expense of additional site visits and limit sampling density in heavily populated areas.

5.5 Recommendations for Follow-Up Assistance

The program outlined above suggests several steps to be taken in the near future. MWR should consider retaining consultants to provide computer systems development expertise, to provide GIS training for selected employees, to develop information management systems for the finance and administration directorate, to assess archival storage options, and to offer follow-up assessment of the database management plan.

Since a single individual in the Directorate of Water Resources Assessment is the only MWR staff member working on Ministry-wide computer systems development, it might be beneficial to obtain the services of a highly skilled consultant to assist with implementing the program recommended in this report. The consultant initially might work full time on detailed systems analysis to get the program moving and later take on an advisory role, providing advice on an as-needed basis. This advisor would work closely with the MWR computer system manager, helping to ensure the development of a useful system and serving as a mentor.

Since GIS is still a relatively new technology and has had limited application in Oman, MWR should consider training a number of its employees in this field. Such training could be obtained in an existing GIS course or might be arranged as a local course or in-house consultancy.

Although this report has addressed the management of MWR's water resources data, the needs of its Finance and Administration Directorate cannot be overlooked since it cannot fulfill its mission if its internal management is not in order. There is a great need for a management information system to improve the work of this directorate.

The need to adequately catalogue and protect water resources data has been only partially addressed in this report. The purchase of optical scanning and storage devices under the proposed computer equipment acquisition program will help a great deal in this regard, but attention must be given to secure storage facilities, microfilming and/or scanning of documents, etc. MWR might consider a study of these options, but what is most important is a permanent archiving program.

Follow-up assessment of the implementation of this management plan should begin in six to eight months to ensure that the program is moving forward successfully and that, if necessary, it can be modified.

5.6 Program Requirements Scope of Work

The final version of this report will contain proposed scopes of work for the following program implementation components:

- Start-up services for the proposed system
- Development of pilot programs
- Staff training

Appendix A

Persons Contacted

Ministry of Agriculture and Fisheries

Zakaria Yahya al Riyami, Director General of Dams
Hilal Malik Mohamed Al Battashi, Technician
Shamsa Lamky, Director of Computer Services
Michel Beurrier, Hydrogeologist
Bernard Blasco, Hydrogeologist

Ministry of Commerce and Industry

Aida al Riyami, Director of Laboratory Services
Haithem al Jamali, Director of Computer Services
Shirin Kharchid, Supervisor of Industrial Laboratory
Shekeela Ibrahim, Receptionist

Ministry of Education

Nasser bin Issa al Ismaili, Director of Computer Services

Ministry of Electricity and Water

Mr. Supramanian, Chief Engineer, Water Department

Office of the Minister of State and Wali of Dhofar

Saeed Salem al Shanfary, Architect, Dhofar Municipality
Azzan bin Ahmed Shanfari, Director General, Water Supply and Transport
Mohammed Abdulla Elmahdi, Engineer
Mohammed al Amin, Sanitary Engineer, Dhofar Municipality

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Ministry of Water Resources

His Excellency Kalfan bin Nassir al Wahaibi, Minister of Water Resources
His Highness Sayyid Bargash bin Ghalib Al Said, Director General of Technical Affairs
Ian G.G. Hogg, Water Information Center Planner
Mike Kaczmarek, Buraimi District Chief
John Kay, Deputy Director Water Resources Assessment
Wayne Curry, Surface Water Department
Dr. Mohamed Iqbal, Laboratory Director
Rebecca Ridley, Public Affairs
James Laver, Batinah District Chief
Simon McNeilage, Groundwater Modeling and Saline Intrusion
Dr. Mohamed Chebaane, Rainfall Network
Donald Davison, Special Projects and Southern District Chief
Dr. Remy L. de Jong, Deputy Director Water Resources Management
Norman Hutchinson, Wadi Gaging Network Manager
Harley Young, Research Director, Groundwater Management
Yasser Salim Al Harthy, Assistant Hydrologist, Sharqiyah District
Gary Corcoran, Database Manager
Brian Eccleston, Groundwater Assessment
Solomio N. Limos, Hydrogeologist, Southern District
Alexander Van der Meer, Sharqiyah District Chief
Hillary Fernandez, Chief Technician, Southern District
Mr. Bhatnagar, Capital District Chief
Geoffrey Wright, Deputy Director Regional Offices
Zuhra al Kindy, Database Manager
Mr. Pillai, Senior Contracts Secretary
Alan D. Rendell, Planning Unit
Mohamad Aslam Zahid, Technician, Southern District
Mr. Sharma, Database Specialist

Omani-American Joint Commission

His Excellency Hamoud bin Hilal al Habsi, Chairman
Duncan Miller, Mission Director
Murl Baker, Deputy Mission Director
Anjab Sajwani, Project Officer
Musa al Mazrui, Project Engineer
Mark Pickett, Training Officer
Roger Russell, Chief Engineer

Planning Committee for Development and Environment in the Southern Region

Dr. Robert Whitcombe, Technical Coordinator and Ecologist
Abdul Qadir, Management Information Systems Specialist
Mohammed Abu al Qasin, Economist

Supreme Committee for Town Planning

Donald Ritson, Advisor
Terek El Ghamrawy, GIS Implementation

Others

Faysal Alami, Resident Manager, Khatib & Alami, Ruwi (GIS Consultant)
Anil Gandhi, Sales Manager, IMTAC (Hewlett Packard, ORACLE, Arc-Info, NOVELL computer systems dealer), Mina al Fahal
S.K. Sridaran, Senior Consultant, IMTAC
Vinesh Malik, Computer Consultant, IMTAC

Appendix B

Supreme Committee for Town Planning GIS Study

The SCTP GIS study included a detailed user needs survey of all agencies identified as potential users. It outlines system design including organization and staffing, software, hardware, and database needs, and recommends a 10-year three-phase implementation program beginning with a pilot program involving seven agencies including MWR.

Phase I Pilot Program

Phase I was scheduled to take place during the first 15 months of the program. It will include the Directorate of National Survey, General Telecommunications Organization, Ministry of Electricity and Water, Ministry of Housing, Ministry of Water Resources, Planning Committee for Development and Environment in the Southern Region, and SCTP. The PCDESR will be responsible for developing a regional level pilot project in the southern region with primary mapping at a scale of 1:100,000. The remaining ministries are to participate together in an urban level pilot project which will include three study areas: Rustaq, Buraimi, and Khasab. The SCTP will act as the lead agency and coordinator of the urban pilot project.

Phase II Program

Phase II, scheduled to take place during years two through five, will focus on development and expansion of the GIS system. Mapping coverages will be expanded beyond the pilot areas and the ministry systems will be linked together in a wide area network.

Phase III Program

Phase III, years six through ten, involves continued database development. Hardware and software will be expanded and upgraded to meet anticipated increase in GIS product demand. The stated goal of this phase is to integrate GIS into the daily work activities of the user organizations.

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Base Mapping

SCTP is planning on three levels of basemap detail. They are: 1:100,000 for countrywide coverage; 1:20,000 for settled areas; and 1:5,000 for dense urban areas. Development of the updated digitized mapping is scheduled to run over a 10-year period.

Training

SCTP is planning to train up to 15 students from the participating ministries. Initial training would focus on data automation procedures and basic processing skills needed for getting a GIS system started and creating a database.

Technical Support

SCTP is planning to provide detailed pilot system design advice to each participating ministry through outside GIS consultants. The consultants will help develop the physical formats for the map layers and attribute files for the pilot system. In addition, SCTP will provide ongoing technical support through a GIS consultant for six to nine months for support of the pilot system program.

The GIS study addressed security issues including staff, hardware, software, and the database levels.

The estimated costs of the GIS program to the MWR as outlined in the above referenced reports are listed below:

Estimated MWR Costs of GIS Program Outlined by SCTP

Item	Hours	Amount R.O
Phase I—Start-up Phase and Pilot Program:		
Computer Hardware: (Assumed that existing PC hardware would work)		0
Software:		5,000
Database Development:		
Well data	300	4,500
Flood zoning	450	7,200
Water quality	300	4,500
	1,050	16,200
Phase I Subtotal:	1,050	21,200
Phase II—System Development		
Training (years 2-5): 24 students		9,100
Hardware (years 2-5) 1 workstation, 12 PCs, 1 printer, 1 plotter 1 digitizer, 1 screen copier		59,600
Database development:		
Aflaj	300	4,980
Well locations	40	660
Watershed boundaries	300	4,960
Climatic zones	100	1,640
Weather Monitoring Stations	250	4,140
Rainfall/Temperature Isopleths	200	3,300
Well field protection zones	200	3,300
	1,390	22,980
Phase II Subtotal:	1,390	91,680

Appendix C

Suggestions for Database Contents

File:	Well locations
Records:	One per well (ca. 150,000)
Contents:	Well identification number, latitude, longitude, x coordinate, y coordinate, elevation

File:	Well registration information
Records:	One per well (ca. 150,000)
Contents:	Well identification number, owner, sheikh, town, wallat
Note:	This database is being developed under a current contract

File:	English—Arabic town and wallat translations
Records:	One per town (approximately 5000)
Contents:	English and Arabic town and wallat names
Note:	MWR is acquiring this database from the Ministry of Posts, Telegraphs, and Telephones as part of the well registration database development project.

File:	Previous well ownership
Records:	Up to 150,000 active
Contents:	Well identification number, previous owner, date of ownership transfer, method of transfer

File:	Well inventory information
Records:	Ca. 150,000
Contents:	Well identification number, sample identification number, inventory date, location, measuring point, well type, water use, well depth, internal diameter, discharge rate, pumpage per day, pump type, power source, physiographic setting, construction date, use, others

File:	Well water levels and EC
Records:	Up to 1 million active
Contents:	Well identification number, sample identification number, date, time, depth to water, electrical conductivity, pH, alkalininty, temperature, others

File:	Water quality analyses
Records:	Up to 1 million active
Contents:	Well identification number, water quality sample number, standard analysis parameter fields (e.g. chloride, nitrate, etc.), comments

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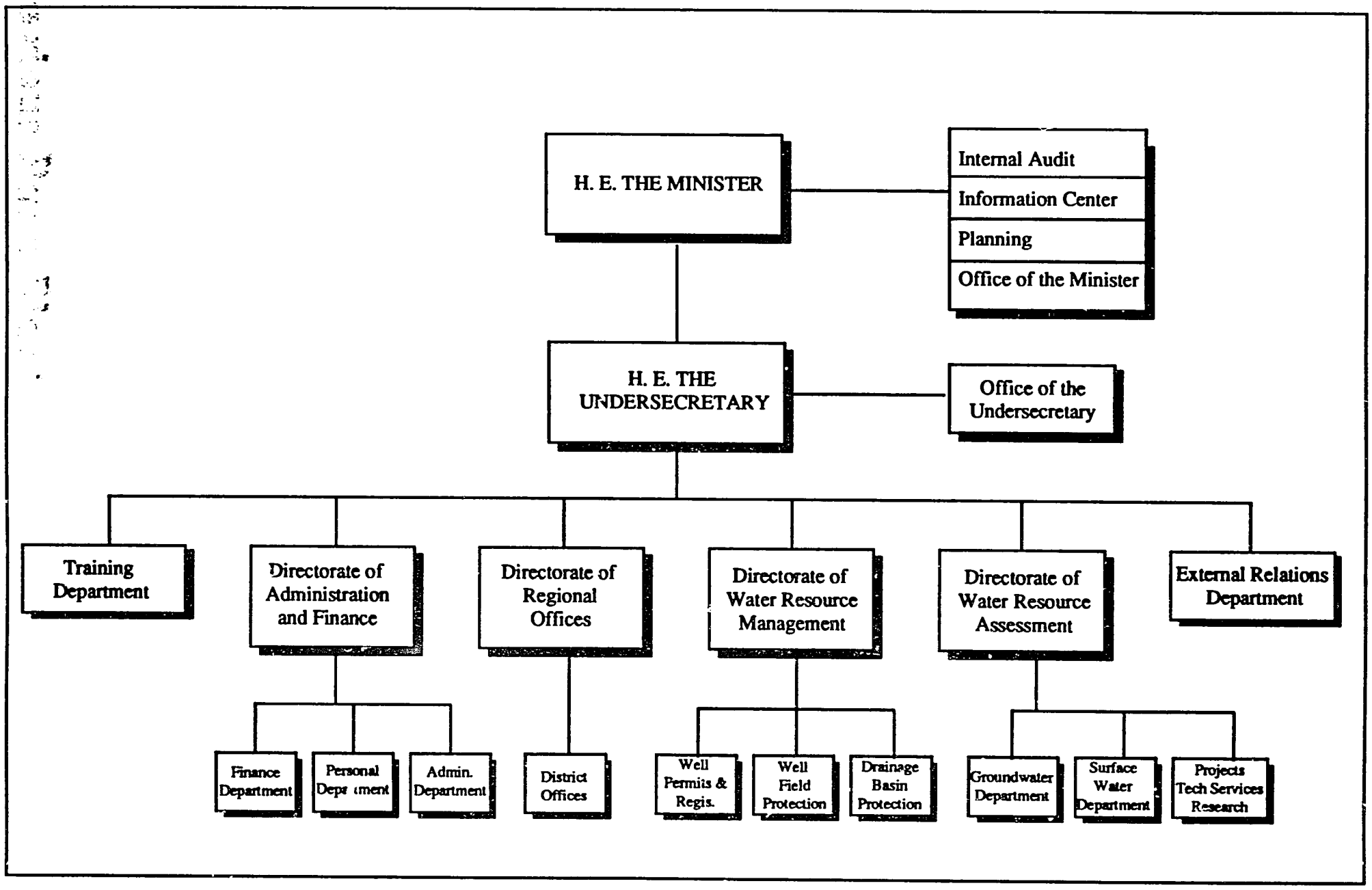
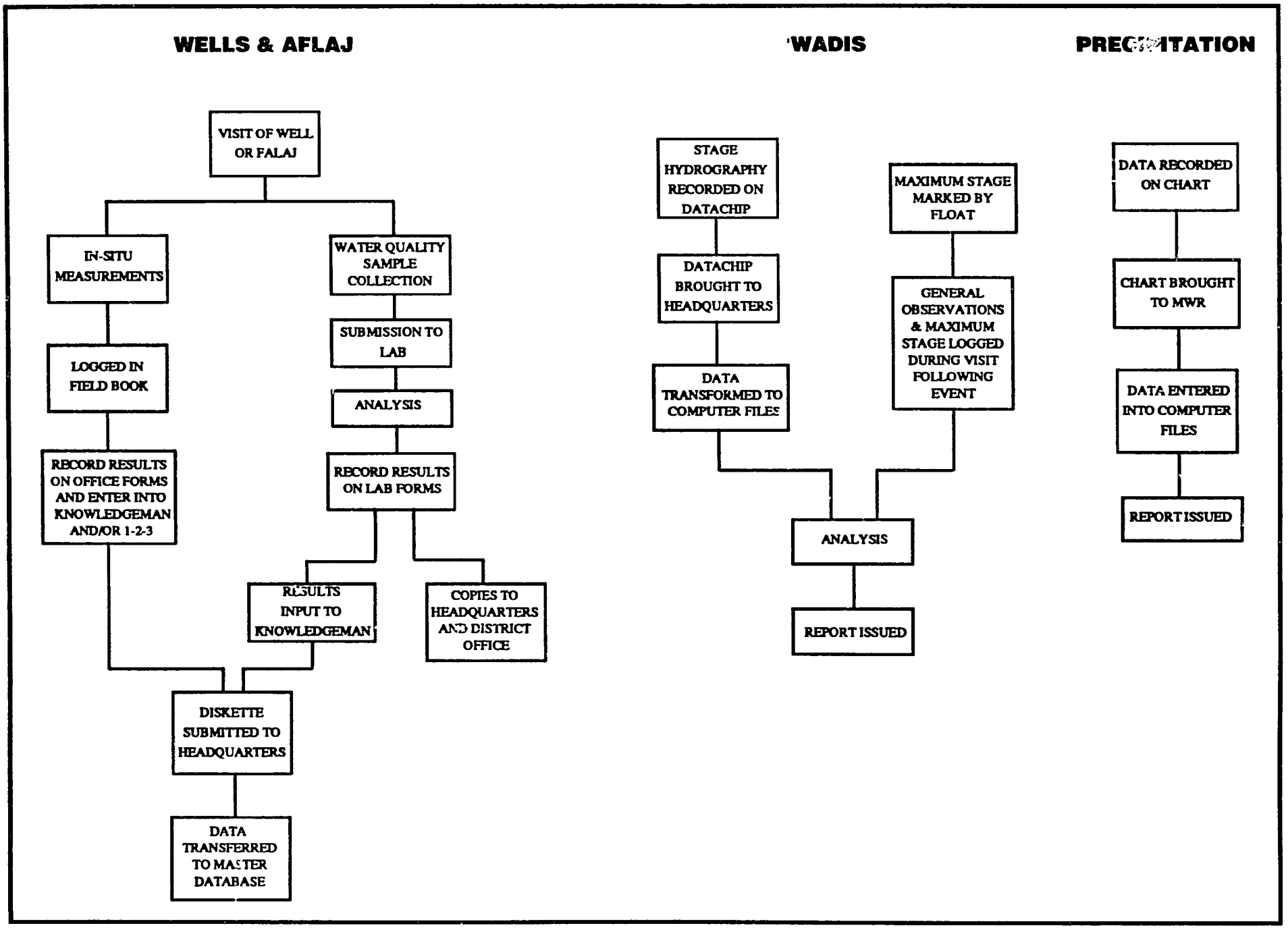
File:	Non-standard water quality analyses
Records:	Up to 4 million active
Contents:	Water quality sample number, constituent name code, value
File:	Water quality parameter IDs
Records:	One per parameter type (ca. 100)
Contents:	Constituent name code, constituent, unit of measurement
File:	Pumping records
Records:	Up to 250,000 active (20,000 wells metered; 3 year's quarterly readings)
Contents:	Well identification number, date, meter reading
File:	Other water resources information available (e.g. logs, pump tests)
Records:	Ca. 1,000
Contents:	Catalog number, waliat, town, feature identification number, date, document title, etc.
File:	Wadi, falaj, precipitation gage, feature locations
Contents:	Identification number, feature type, feature name, latitude, longitude, x coordinate, y coordinate, elevation
File:	Alternative names of wadis, aflaj, etc.
Records:	One entry per alternative name
Contents:	Identification number, feature name
File:	Falaj registration information
Records:	One per falaj (ca. 10,000)
Contents:	Identification number, principal owner, town, waliat
File:	Descriptions of wadi, falaj, precipitation gages
Contents:	Identification number, installation date, instrument type, comments
File:	Wadi flow records
Contents:	Gage identification number,date, interval ending at, depth, flowrate
File:	Wadi cross-section data
File:	Falaj inventory information
File:	Falaj flow records
Contents:	Gage identification number, date, time, depth, velocity, flowrate
File:	Falaj section data
File:	Precipitation records

Appendix D

Charts and Diagrams



ORGANIZATION CHART



INFORMATION FLOW DIAGRAM

Appendix E

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(Documents obtained from Ministry of Water Resources library except as noted.)

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