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PROPOSED HYDROLOGICAL MONITORING AND EVALUATION UNIT FOR THE MINISTRY OF AGRICULTURE AND FISHERIES AQUIFER RECHARGE PROGRAM

SULTANATE OF OMAN

WASH FIELD REPORT NO. 285

FEBRUARY 1990

Prepared for
the Omani - American Joint Commission
for Economic and Technical Cooperation
WASH Task No. 079

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by

Charles E. Fuller
and
John Kent Kane III

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OMAN

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

JORDAN

A Proposed Action Plan for a National Training Program in the Water Sector for the Hashemite Kingdom of Jordan. Field Report No. 34. John H. Austin, Kenneth Woolf, and Walter Pinto-Costa. September 1982.

Water and Wastewater Sector Assessment in Jordan. Field Report No. 244. Philip M. Gary, Peter H. Ware, John R. Lauderbaugh, and James S. Baker. February 1989.

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ACRONYMS

COE	Corps of Engineers
MAF	Ministry of Agriculture and Fisheries
MEW	Ministry of Electricity and Water
MOC	Ministry of Communications
MOE	Ministry of the Environment
NEO	No Environmental Objection
OAJC	Omani-American Joint Commission for Economic and Technical Cooperation
PAWR	Public Authority for Water Resources
TPM	Team Planning Meeting
USAID	United States Agency for International Development
WASH	Water And Sanitation for Health Project

EXECUTIVE SUMMARY

The Omani Ministry of Agriculture and Fisheries (MAF) requested assistance in establishing a hydrological monitoring and evaluation unit within the Department of Irrigation geared toward the MAF program of constructing aquifer recharge structures. USAID provided this assistance under the direction of the Omani-American Joint Commission for Economic and Technical Cooperation (OAJC).

At the request of the OAJC, the Water and Sanitation for Health (WASH) Project sent a two-person team to the Sultanate of Oman in late August 1989 to review the Ministry of Agriculture and Fisheries (MAF) aquifer recharge program in regard to planning, management and evaluation. Specifically, the MAF had requested assistance in establishing a new hydrological monitoring and evaluation unit to assess the effectiveness of aquifer recharge structures.

The purpose of this consultancy was to determine the current capability of MAF to carry out its mandate for agricultural water resources planning, management, evaluation and monitoring, and to develop a plan to strengthen this capability both technically and managerially. Strengthening the institutional plan requires addressing internal program linkages within the MAF as well as related or similar activities which are implemented by the Omani institutions.

The project team interviewed representatives of the MAF and other public sector institutions involved in water resources, and reviewed feasibility study reports and detailed design reports prepared by consultants for the MAF. The team also took field visits to aquifer recharge structures that were complete or under construction, and to sites proposed for future development along the Batinah Coast and in the Interior.

Presently, the MAF monitoring and evaluation unit has only the capability to collect data, with no capability to evaluate the effectiveness of the recharge facility. Based on the present magnitude of the MAF aquifer recharge program and plans for development in the near future, the project team concluded that the current MAF monitoring and evaluation unit should be upgraded to ensure success of the aquifer recharge program.

The WASH team recommends that the MAF employ three technical experts to work within the hydrological monitoring and evaluation unit to organize and direct the activities of the unit. These positions should include a Senior Hydrologist, Staff Hydrologist and a Staff Hydrogeologist. In addition, the current Omani staff should be increased to three (3) Engineer Trainees and ten (10) Field Technicians.

The proposed unit should operate autonomously in terms of staffing, logistics and operating budget. It should be responsible for collecting and interpreting hydrological monitoring data to evaluate the effectiveness of specific aquifer recharge facilities and to develop recommendations for their improvement. Data should be entered into a computer data base system for easy access and

manipulation, and should be made available to other agencies involved in water resources.

Technical training of Omani staff should be a priority of the new monitoring and evaluation unit. This should take a variety of forms, including hands-on experience, seminars, training sessions, and short courses and formal degree programs abroad.

The cost of staffing the proposed unit has been reckoned for both a 4-year period (1990-1994) as well as a longer 10-year term (1990-2000). The Technical Assistance Staff will cost about 40 percent of the total program budget for both the 4- and 10-year terms, while the Trained Technician staff will require 30 percent of the total program cost for the 4-year period and 35 percent for the 10-year period as follows

	4-Year Period		10-Year Period	
	Salaries	Allowances	Salaries	Allowances
Technical Assistance Staff	R.O.268,000	R.O.294,830	R.O.742,000	R.O.802,610
Trainee/Technical	202,800	-----	748,600	----
Technical Training	97,200	-----	291,600	----
Equipment	84,200	-----	199,200	----
	R.O.652,200	R.O.294,830	R.O.1,981,400	R.O.802,610

Formal and informal relationships between the MAF and other agencies such as the Public Authority for Water Resources (PAWR), the Ministry of Communications (MOC), and the Ministry of the Environment (MOE) should be established and maintained. This should provide the bilateral exchange of information and should help to avoid duplication of efforts on behalf of the MAF. Comments should be sought from other agencies concerning the MAF aquifer recharge program, and they should become an integral part of the planning process.

The establishment of an efficient monitoring network as well as a properly staffed and trained Monitoring and Evaluation Unit within the Department of Dams of the Directorate General should be the ultimate goal of this endeavor. Its support and endorsement by other agencies should improve the MAF's Aquifer Recharge Program. Such a program will allow evaluation of the effectiveness of dams already completed by MAF as well as a closer scrutiny of those dams targeted for possible construction, pending favorable feasibility studies.

Chapter 1

INTRODUCTION

1.1 Purpose of Report

This report was funded by the Omani-American Joint Commission for Economic and Technical Cooperation (OAJC) to assess the current capability of the Ministry of Agriculture and Fisheries (MAF) for agricultural water resource planning, management and evaluation, and to develop a plan to strengthen this capability both technically and managerially.

Specific objectives of this USAID/WASH consultancy were to:

(1) Assess the relationship of the MAF's program responsibilities for water resource development with program responsibilities of other public sector institutions; (2) make recommendations for establishing a new hydrological monitoring and evaluation unit within the MAF after reviewing their ongoing and proposed water resource development and construction programs; (3) recommend a phased plan of action for establishing a new monitoring and evaluation unit and linking the unit functionally to the MAF Planning Department.

1.2 Preparation for Assignment

A two-day Team Planning Meeting (TPM) was held at the WASH Operations Center on August 28 and 29, 1989. The project clients in Oman were identified during these sessions, and their interests in the assignment were discussed. The scope of work, as identified by WASH, was reviewed extensively and, based on discussions, a work plan for implementing the assignment was developed. The current scope of this study is presented in Appendix A.

1.3 Conduct of the Study

At the request of the Joint Commission, a study team was assembled by the USAID/WASH Project. The team arrived in Muscat August 31, 1989, and shortly thereafter presented a tentative work plan to representatives from the OAJC and the MAF. This plan was modified slightly and the study was carried out accordingly. During the initial meeting with MAF, this agency explained that definition of the Monitoring and Evaluation Unit was the main issue for this study.

In coordination with the Joint Commission, interviews were conducted with representatives of the Ministry of Agriculture and Fisheries (MAF), the Public Authority for Water Resources (PAWR), the Ministry of Communications (MOC), and the Ministry of the Environment (MOE). In addition, field visits were made to aquifer recharge sites that were either complete, currently under construction, or proposed for future development. A number of available feasibility studies

and detailed design reports for specific aquifer recharge sites were also reviewed.

The team prepared a draft report of its findings in late September. A debriefing with the OAJC and the MAF was held on September 25, 1989, and copies of the draft report were given to key officials for their review and comment. This report presents an overview of the Ministry of Agriculture and Fisheries aquifer recharge program and makes recommendations to strengthen its hydrological monitoring and evaluation unit for assessing the overall effectiveness of the aquifer recharge programs.

Chapter 2

BACKGROUND

2.1 Water Resources for Irrigation

General

The major use of water in Oman is for surface irrigation of crops. The country is very arid, and the extremely limited rainfall occurs mostly in the mountains of the north and south. The primary agricultural demand occurs along the Batinah Cost, in Northern Oman, where over 50 percent of the agricultural land of the country is concentrated, while more than 60 percent of the population resides in this area. Irrigation is considered to account for about 90 percent of the total water use in the Batinah area. Omani laws and customs give precedence to domestic water use but do not authorize transfer of water to another location such as for urban use. Therefore, in practice, rural domestic use followed by agricultural use in fact gains precedence over urban domestic use. There are generally two distinct seasons in a year. The winter season, from November to March, is characterized by a series of storms which can bring heavy rainfall, with occasional flooding in the wadis. The summer months, May to September, are characterized by an extremely hot and dry climate; however, an occasional heavy rain can occur during this season when monsoon winds develop from the southeast. The months of April and October are considered transitional months. The average annual rainfall at Seeb is about 100 mm, while during the period 1976-81, annual rainfall varied from 3.7 to 182.6 mm.

For many centuries water used for the irrigation of crops in Oman has been supplied by shallow dug wells or the falaj systems. Falaj systems were constructed to convey water from its upland source to downstream users by open and closed conduit sections with the rights to these waters granted by ancient laws.

Methods

Current agricultural practices utilize surface irrigation methods, and extraction of water from the falaj systems is not very efficient, ranging from 25 to 40 percent (efficiency is defined as consumptive use divided by total extraction, expressed as a percentage). Much of the "losses" occur as seepage from the conveyance system which, combined with the natural percolation of water in the agricultural areas, help to recharge the underlying alluvial aquifer. Consequently, should attempts be made to reduce seepage "losses" from the conveyance system, thereby increasing the quantity of water available for local agricultural development, a nearly equivalent reduction in water quantity will be experienced by downstream users of the same aquifer.

Studies show that water losses by evaporation appear to be only on the order of 10 to 15 percent. However, evapo-transpiration rates in the area are very high, averaging about 10 times the local rainfall. It has been estimated that the volume of water abstracted for irrigation purposes approximates 260 million m^3/year in the Batinah area and 500 to 800 million m^3/year in the Northern Oman Mountain area. Total water use in the capital area in 1984 was 23 million m^3,

with 6 million m^3 from groundwater, and the remaining 17 million m^3 being desalinated sea water. Total water demand in the capital area is expected to reach 50 to 70 million m^3/year by 1990 with 50 million m^3/year to be derived from the desalination of seawater. Groundwater use in the capital area has generally been limited to garden and lawn irrigation by private users.

The rapid development in Oman since 1970 has seen an increased and largely uncontrolled withdrawal of ground water by pumping from wells to such an extent that the extraction volume frequently exceeds the natural recharge that can be expected of this most valuable resource. This has been accompanied by an overall decline in water quality, the depletion of many aquifers, and rapid salt water intrusion in many areas along the northern coastline. Continued heavy pumping from deep wells, such as occurs in the Batinah area, results in the general inland movement of the fresh water/salt water interface accompanied by an upcoming of the salt water, thereby degrading the quality of the water being pumped from the wells. Reversal of this process requires a reduction in withdrawal of groundwater from the affected area and/or recharge of the aquifer with a fresh water source such as may be enhanced by low-height recharge dams. Due to the intermittent operation of the aquifer recharge basins, which occurs with runoff-producing storms, the monitoring of both surface water flows and ground water levels (as well as water quality) at recharge dams becomes of prime importance. A most costly alternative to aquifer recharge structures is the construction of seawater desalination plants for urban areas.

2.2 Aquifer Recharge Using Low-Height Dams

Background

The U.S. Army Corps of Engineers (COE) completed a study in 1979 entitled "Enhanced Groundwater Recharge of the capital area, Summary of Hydrogeological and Hydrological Needs," which concluded that "recharge structures which will augment the water supply and can be constructed in most of the wadis are the most effective method of water enhancement for Oman." This report recommended eight wadi sites for development and identified four additional sites with potential for consideration. At the time of that report the COE estimated a cost of R.O.14.0 million to construct the eight recommended sites.

Subsequent studies by the COE and the Public Authority for Water Resources (PAWR) confirmed the selection of the first aquifer recharge system at Wadi Al Khawd (about 12 km west of Seeb International Airport), and a feasibility report and summary, including construction plans and bidding documents was submitted by Stanley Consultants, Inc. in December 1981. The project was designed as a pilot project with a principal objective to develop a data base and provide information on the performance of recharge facilities. Construction of the dam was begun in 1984 and completed in April 1985, with a flow measuring flume and monitoring equipment installed in 1986.

Nearly two years passed before the pilot project at Wadi Al Khawd experienced storms which generated flood flows. Subsequently, three major storms occurred between February 20 and April 7, 1987, which produced flood flows into the reservoir. Portions of the flood flow from each of these storms was stored

within the reservoir and infiltrated into the ground within and downstream of the reservoir, with the remainder of the flow lost to the sea. Storage volume calculations for the three storms showed that 5.7 million cubic meters (70 percent) of the flow was prevented from flowing to the sea, while 85-90 percent of the flow from the latter two storms was recharged after adjustments were made to the discharge facilities at the dam.

Subsequent to the construction of the first recharge dam on Wadi Al Khawd, other dams were constructed along the Batinah Coast and in the interior, at Wadi Hilti and Wadi Salahi near Sohar and Quryat on Wadi Sayfam, about 20 km southwest of Bahla. In addition to the three facilities completed and now in service, there are three other recharge dams soon to be placed in service. Construction was recently completed in July 1989 on a detention dam on Wadi Al Jizzi about 25 km west of Sohar. Another detention dam is virtually complete along Wadi Ghul about 6 km west of Al Hamra, while construction is scheduled for completion in December 1989 on a detention dam on Wadi Tanuf. In addition to these facilities, other sites which rank high on the MAF priority list are Barka-Rumais, about 25 km west of Muscat, and on Wadi Al Kabir, about 12 km northeast of Ibri.

2.3 Field Visit to Recharge Dams and Sites

General

On September 4-6, 1989, a field trip was made by the project team accompanied by a representative of OAJC and representatives of MAF. The purpose of the trip was to give the project team an opportunity to inspect recharge dams already completed and in service as well as to visit sites where work is now under construction and, finally, to view sites selected for future projects. The trip was most enlightening and the project team was able to discuss two projects currently under construction with engineers involved in the construction supervision.

Completed Facilities

The recharge dam at Wadi Al Khawd is the oldest facility, soon to be five years in operation. This project is only a short distance from the capital area with high visibility, and with the occurrence of three major storms between February 20 and April 7, 1987, it generated considerable interest with the public. These three storms provided the opportunity to make certain adjustments to the discharge features of the dam to improve recharge of the aquifer.

The second recharge dam was constructed on Wadi Al Hilti and Wadi Salahi about 15 km southwest of Sohar on the Batinah plain. Storms that have been experienced at this site since this facility went into service have resulted in modifications to the spillway structures. The first recharge dam to be constructed inland was Wadi Quryat on Wadi Sayfam about 20 km southwest of Bahla. This facility includes the dam and downstream spreading basin as well as an overflow or relief spillway.

The latest project to be constructed on the Batinah plain is Wadi Jizzi on Wadi Al Jizzi about 25 km west of Sohar. This project was completed in August 1989 and has just been placed in service. Two other projects nearing completion in the interior will be placed in service by the end of 1989. Wadi Ghel was completed in June 1989 with final modifications in August 1989 and will provide recharge to the downstream aquifer that is in the same catchment as Wadi Bahla. Wadi Tanuf will provide recharge to the downgradient aquifer that forms the headwaters of the Wadi Al Abyad downstream.

Proposed Sites

By early 1990, the MAF will have constructed and placed into service six aquifer recharge facilities with three of these completed in 1989. Feasibility studies were also completed during 1989 for 6 Schemes, of which most probably 4 will be recommended for construction;

- Barka-Rumais Scheme
- Ibri/Araqi Scheme (Wadi Kabir)
- Sur Scheme (Wadi Fulayj)
- Wadi Sahalnawt in the Salalah Plain

These 4 Schemes probably comprise the next 4 aquifer recharge projects likely to advance to the construction phase under the MAF program.

Chapter 3

MINISTRY OF AGRICULTURE AND FISHERIES
MANDATE FOR WATER RESOURCES

3.1 Roles and Responsibilities of Public Sector Institutions

In Oman, many ministries and other major government organizations are charged in some way with water resources related responsibilities. Their responsibilities include the disciplines of irrigation, water supply, the collection, reclamation and reuse of wastewater, and meteorological data acquisition to mention but a few. Of those organizations, the following ministries and government entities were found to be especially relevant to any aquifer recharge enhancement program.

- Ministry of Agriculture and Fisheries (MAF)--the agency responsible for planning and overseeing irrigation and agricultural related activities; has taken the lead role in the development of aquifer recharge facilities.

- Public Authority for Water Resources (PAWR)--established to assess and monitor the water resources of the Sultanate of Oman on a regional basis; conduct exploration drilling programs to identify potential groundwater resources; monitor rainfall, surface water and groundwater; administer well permits.

- Ministry of Communications (MOC)--responsible for airports, seaports and roadways; maintains a nationwide meteorological network.

- Ministry of the Environment (MOE)--responsible for conservation of the environment and prevention of pollution; involved in water treatment and wastewater reuse; concerned with environmental issues related to construction.

- Ministry of Electricity and Water (MEW)--primary responsibility is public water supply.

Although the aforementioned public sector institutions were designed to promote coordination and planning of water resources activities within the Sultanate of Oman, there is, at present, a need for greater cooperation among the individual entities. The level of formal and informal communication between these agencies often results in the duplication of efforts and a substantial weakness in the water sector institutional framework which must be overcome if an expanded program of aquifer recharge facilities is to be successful.

3.2 Relationship between the MAF and other Public Sector Institutions

Within the aquifer recharge enhancement programs, the primary objective of the proposed MAF hydrological monitoring and evaluation unit should be to collect and analyze data specifically related to individual aquifer recharge sites. Data collected will be used to assess the operation and effectiveness of the recharge structures and to develop recommendations to improve their performance. Although these activities will be performed by the MAF, namely the Department of Dams, it is important that an open channel of communication and data exchange be established between the MAF and other public sector organizations involved with water resources. Discussions with representatives from other institutions indicate that, at present, the relationships between the MAF Department of Dams and other major entities are as follows:

- Public Authority for Water Resources (PAWR)--MAF has directed consultants who are performing feasibility studies at proposed aquifer recharge sites to collect information from the PAWR. The MAF has submitted copies of completed feasibility reports to PAWR for their review, but comments have reportedly not been given proper consideration. Currently no formal channels exist for the bilateral exchange of information. Informal discussions occasionally take place.

- Ministry of Communications (MOC)--The Directorate of Meteorology submits both monthly and annual data summary reports to the MAF for their information.

- Ministry of the Environment (MOE)--The Environmental Impact Section of the MOE must endorse a Certificate of No Environmental Objection (NEO) in order for a proposed MAF recharge site to proceed to construction. MOE comments concerning the MAF aquifer recharge program have reportedly not been given proper consideration.

- Ministry of Electricity and Water (MEW)--To date the MAF has had no formal relations with the MEW.

It appears that a deficiency exists in the coordination and planning of water sector activities. The MAF aquifer recharge program should incorporate information from other public institutions into their program to provide a more comprehensive assessment of site conditions both before and after emplacement of a recharge structure. It is imperative that official channels of communications and protocol be established between the organizations to ensure the success of the MAF aquifer recharge program.

The MAF's relationship with the PAWR is of utmost importance and must be developed. Discussions should be held with PAWR representatives to discuss the MAF aquifer recharge program prior to a site proceeding to the feasibility phase. This will not only allow the PAWR time to prepare data that will be most relevant to the MAF program, but will also provide the PAWR the opportunity to

make suggestions and/or express their concerns relating to appropriate study site selection. PAWR historical monitoring data should be transferred directly to the MAF at the beginning of a specific program to provide a data base from which the feasibility study may be developed. This should reduce both the time and overall administrative costs involved to provide data to consultants performing the studies. It is important that formal relations between the MAF and other public sector institutions be established for the benefit of the MAF aquifer recharge program. These organizations can provide invaluable data. These institutions must be aware of the MAF aquifer recharge program and, as a unit, reach agreement on appropriate action for the long-term preservation of Oman's water resources.

Chapter 4

MINISTRY OF AGRICULTURE AND FISHERIES WATER RESOURCES PROGRAMS

4.1 Completed Aquifer Recharge Structures

Wadi Al Khawd

The recharge dam at Wadi Al Khawd is the first aquifer recharge project to be constructed in Oman; it was designed as a pilot project with its principal objective to develop a data base and information on its performance that would prove useful in consideration of other recharge facilities. The dam is located about 10 km west of Seeb International Airport in an area of existing and planned development. The dam and storage reservoir is used to detain and store flood flows which originate in the catchment area for Wadi Sumayil and exit in Wadi Al Khawd. The catchment area at the dam is 1800 km^2, while the earthfill dam has a length of 5.1 km and an average height of 7.5 meters. At spillway crest (elevation 38.5 mtr.) the reservoir has a storage capacity of 12.4 million cu. mtr. The dam contains eleven 1.2 m diameter culverts, nine of which are provided with stoplogs; the remaining two are equipped with manually operated sluice gates. The dam is provided with a 3000-m long spillway over the top of dam and the design flood requires a depth of 0.5 m to pass over this spillway. Although the dam does provide a degree of flood protection, it should not be counted on to provide flood relief in a major storm. The dam is provided with monitoring facilities which recheck a concrete river flume upstream of the dam with instrumentation, an automatic water level recorder at the dam, two stream gauging stations on downstream channels and several monitoring wells.

After completion in April 1985, nearly two years passed before the dam was visited by flood flows from three major storms between February 20 and April 7, 1987. These storms provided the first opportunity to observe the aquifer recharge system in operation.

Observations made of the performance of the structure during the first storm indicated that the actual infiltration rate of the existing wadi channels downstream of the dam was less than had been calculated during the design phase for the project. This first storm also indicated a need for better distribution of the flow discharged to the downstream wadi channels. Subsequently,10 stoplogs were installed to block the flow from one of the culverts and to greatly restrict the flow from the remaining five which were initially left open. Reduction of the culvert outflow capacity will now result in greater depths of stored water for a longer duration for any given storm, but will not increase the frequency of spillway overflow significantly, or the ability of this structure to accommodate minor to moderate floods. As constructed, the channels exiting the stilling basin to the east were noted to carry a disproportionately high fraction of the total outflow from the dam. A more uniform flow to the downstream channels was accomplished by raising the stilling basin end wall. Some changes were made when the monitoring equipment experienced some difficulty in accurately defining high flow rates as indicated

by rapidly changing water levels. Consequently, the existing Datapod recorder was supplemented with a bubbler system.

Wadi Hilti/Salahi

The recharge facilities at Wadi Hilti/Salahi were the second to be constructed about 15 km southwest of Sohar on the Batinah plain. The dikes and retention reservoirs interrupt storm runoff from Wadi Al Hilti and Wadi Salahi before its discharge to the ocean 20 to 25 km northwest of Sohar. The reservoirs are used to detain and later release storm flows to the very productive agricultural areas downstream known as Sohar Farms. The catchment area for Wadi Hilti is 256 km^2 and for Wadi Salahi is 106 km^2. The dike for Wadi Hilti has a length of 5.7 km and a maximum height of 3.5 m. The dike has a main spillway 300-m long as well as four auxiliary spillways with lengths of 20 m. At spillway crest, Hilti has a storage capacity of 0.34 Mm^3. The dike for Salahi has a length of 3.0 km and a maximum height of 4.0 m. The dike has two spillways, with lengths of 100 m. and 180 m., respectively. At spillway crest, Salahi has a storage capacity of 0.38 Mm^3. The spillway and overflow weirs are designed to convey the 100-year flood without overtopping the earthfill embankment. Monitoring facilities include observation wells and flow measuring station upstream of the spreading basins. Storm flows which have been experienced at this site have prompted modifications to the downstream apron which distributes water to spreading areas.

Wadi Quryat

The first recharge facilities constructed in the Interior were constructed on Wadi Sayfam for the purpose of replenishing the ground water supplies for Quryat farms. The catchment area at the reservoir is 375 km^2. The storage reservoir is constructed on the eastern branch of Wadi Sayfam and it is formed by an earthfill embankment running north-south at the Government Farms side of the wadi and an overflow gabion weir across the riverbed. The overflow gabion weir contains a spillway 80 m long while flow is conveyed from the reservoir to the spreading grounds through a culvert discharging to an open channel. At spillway crest, the reservoir has a storage capacity of 0.125 Mm^3 while the spreading ground provides additional storage capacity of 0.065 Mm^3. The spillway crest is 3.0 m below the top of embankment and the design flood can be passed with a freeboard of 0.6 m. The monitoring facilities include observation wells and water level recorders in the reservoir, spreading basin and connecting channel.

Wadi Jizzi

The recharge dam recently completed on Wadi Al Jizzi is the third recharge facility to be constructed on the Batinah Coast, in an attempt to provide sufficient recharge to reverse the trend created by overpumping of wells in the seacoast area, and thereby causing salt water intrusion, leading to high salinity of the soils and ground water, and thereby reducing the ability of the adjacent agricultural lands to develop their potential crop output. The dam is located about 24 km west of Sohar village which is about 220 km northwest of the Muscat capital area. Most of the agricultural area around Sohar is irrigated by groundwater furnished from wells. The over- pumping of ground water in this area has affected some of the cultivation due to the high salinity in the

irrigation water. The project consists of a detention dam and storage reservoir with two spillways and dispersion facilities located about 3 km downstream. The catchment area at the dam is 812 km^2, while the earthfill dam is 835 m long (not including spillway lengths), and an average height of 17 m. At spillway crest (elev. 163.9 m) the reservoir has a storage capacity of 5.4 million m^3. The dam is provided with a service type spillway which is 184 m long as well as an emergency type spillway 278 m long which has its crest 1.8 m higher. In addition, the dam is provided with a 1500 mm diameter steel conduit with sluice gate control. The dam is provided with monitoring facilities which include an automatic water level recorder for the reservoir and five monitoring wells (four downstream of the dispersion facility and one upstream of dam). The monitoring wells have been in service during the construction period and will provide not only ground water table information, but information on groundwater quality that could be influenced by salt water intrusion and/or chemical pollution from a copper mine in the westerly part of the catchment.

During the construction phase, supervision was provided by Sir M. MacDonald & Partners, Ltd., who made certain modifications to the design documents as necessitated by design review and field conditions as encountered. Construction cost of this facility was just under R.O.3.0 million, considerably less than the R.O.8.0 million figure carried in the detailed design report. This can largely be attributed to a nearly 50 percent reduction in contractor prices between the time of the detailed design report (June 1986) and commencement of construction (June 1988).

Wadi Ghul

This recharge dam is located about 40 km northwest of Nizwa and about 5 km northwest of the village of Al Hamra on Wadi Ghul. Construction began in July 1988 and should be completed by October 1989. The wadi bed is nearly 400 m. wide at the dam site and moderately steep slopes ascend from each end of the dam. The catchment area at the dam site is 155 km^2 and the wadi channel upstream of the dam has an average slope in excess of 10 percent. Because the catchment has little soil cover and alluvium begins in the wadi less than 12 km upstream, it is considered to have a very high runoff potential. The dam and spillway are made up of gabions such that the spillway is a three-step overflow weir designed to pass the probable maximum flood. The spillway is made from three vertical type weirs with gabion lined stilling basin, with each following the other. The gabions on the upstream face are provided with a sand asphalt mastic while on the downstream face they are capped with concrete. The dam is 330 m long and has an average height of 5 m. At spillway crest (elev. 756.1 m.) the reservoir has a storage capacity of 0.450 MCM. Monitoring facilities include water level recorders in the reservoir and in the wellfield of the recharge site 1.5 km downstream of the dam.

Wadi Tanuf

The area with the most dramatic topographic relief provides the setting for the soon to be completed recharge dam on Wadi Tanuf. This dam is situated about 20 km northwest of Nizwa within a gorge carved in limestone by Wadi Tanuf. Construction began in December 1988 and should be completed by December, 1989. The dam is only 110 m long and the rock abutments at each end rise steeply.

The catchment area at the damsite is 171 km^2 and since it consists of limestone virtually barren of vegetation and soil, with alluvium appearing only immediately upstream of the damsite, it is considered to have a very high runoff potential. The dam structure is a sloped type gabion weir designed to act as an overflow type spillway during flood, with a stilling basin provided with a counter weir downstream and sized so that the hydraulic jump occurs in the stilling basin. The down-stream slope of the gabion weir is protected from scouring by anchored reinforced concrete slabs while the upstream slope is grouted with mastic and then painted with aluminum paint for heat reflection. The overflow section is provided with a 3-m wide crest which will pass the Probable Maximum Flood with a 4.57-m head over the dam. The dam has an average height of 12 m and at spillway crest (elev. 808 m) the reservoir has a storage capacity of 0.680 MCM. The dam is provided with a cutoff wall which goes 5 m below the ground surface and the mastic grouted gabion mattress on the upstream face of the dam reduces the potential for piping and seepage losses. Monitoring facilities include water level recorders in the reservoir and in the well field to be affected by the recharge scheme.

4.2 Planned Water Resource Development Programs

4.2.1 Project Selection

The US Army Corps of Engineers (COE) 1979 study recommended eight wadi sites for development of recharge structures and identified four additional sites for consideration. After further input from the Public Authority for Water Resources (PAWR) and Tetra Tech International, Inc., a plan was recommended for Wadi Al Khawd which agreed with the general impoundment scheme recommended by PAWR. Subsequently, Stanley Consultants was selected and completed their feasibility report in December 1981. Construction began in March 1983 and was completed in April 1985.

The other projects which followed this one were first subjected to a preliminary study, followed by a feasibility study, after which the detailed design report was completed, with the construction plans and specifications sometimes included as part of this phase (see Table 1).

At the end of 1989 there will be six recharge dams constructed and in service as a result of the COE recommendation of a decade ago. These facilities have been constructed and administered by the Ministry of Agriculture and Fisheries.

DIRECTORATE GENERAL FOR IRRIGATION AFFAIRS

DEPARTMENT OF DAMS

Table 1

RECHARGE DAMS FOR WHICH PRIMARY STUDIES WERE COMPLETED IN 1988

No.	Region of Project	Wadi	Name of Consultant	Cost	Date of Actual Start	Date of Completion	Remarks
1.	Al-Dhahirah Al-Kabiir Raka Arbed Abul & Ghurtha Hajar Salef	Dank	Sir MacDonald	21,400	20/2/1988	21/7/1988	8 Dams
2.	Oman Interior	Halfayn Bahla Nizwa Al-Maydin Sayfame Adam	Sir MacDonald	24,700	20/2/1988	21/7/1988	9 Dams
3.	Eastern	Al- Batha Mudaybi Samad	Wakoti	25,000	28/3/1988	29/8/1988	8 Dams
4.	Coastal	Al-Rustaq Al-Hajir Bu-Baghrah Al-Naber Al Mu'amourah	W.S.Atkins	22,500	20/2/1988	21/7/1988	5 Dams

Source : Ministry of Agriculture and Fisheries

4.2.2 Feasibility Study

Sites which are proposed for consideration of recharge dam construction undergo a feasibility study to determine the justification for proceeding with construction. Prior to the feasibility study, proposed projects undergo preliminary or primary studies to determine which projects should proceed to the feasibility study phase. Table 1 lists these sites for which preliminary or primary studies were undertaken in 1988. A total of 30 damsites were considered in the four tabulated regions. Table 2 lists the various project names and wadis on which recharge dams are being considered and studied for their economic and technical feasibility. There are nine projects listed with a total of 23 dams proposed for the identified wadis. The feasibility study focuses on the land and water resources, hydrology and hydrogeology, agriculture, preliminary design of facilities and project justification based on an economic evaluation. Environmental issues are also addressed, especially as they may affect the quality of the water to be recharged.

4.2.3 Detailed Design Report

Projects which receive a favorable recommendation in the feasibility report stage proceed to the detailed design report phase. The detailed design report is an expansion of the preliminary and feasibility reports. In addition to its focus on the background of the project, this report addresses surface and groundwater hydrology, monitoring systems, general design features of the dam and its appurtenances, tender documents and specifications, construction methods and schedule, and the project costs, which enter into a more detailed project evaluation. Frequently, an expanded level of detail is relegated to separate volumes, dealing with such topics as hydrology, groundwater, geology, detailed design, and the cost and economic evaluations. The detailed plans, specifications and tender documents are sometimes made a part of the detailed design report, thereby enabling a project to proceed to construction sooner.

4.3 Construction Programs

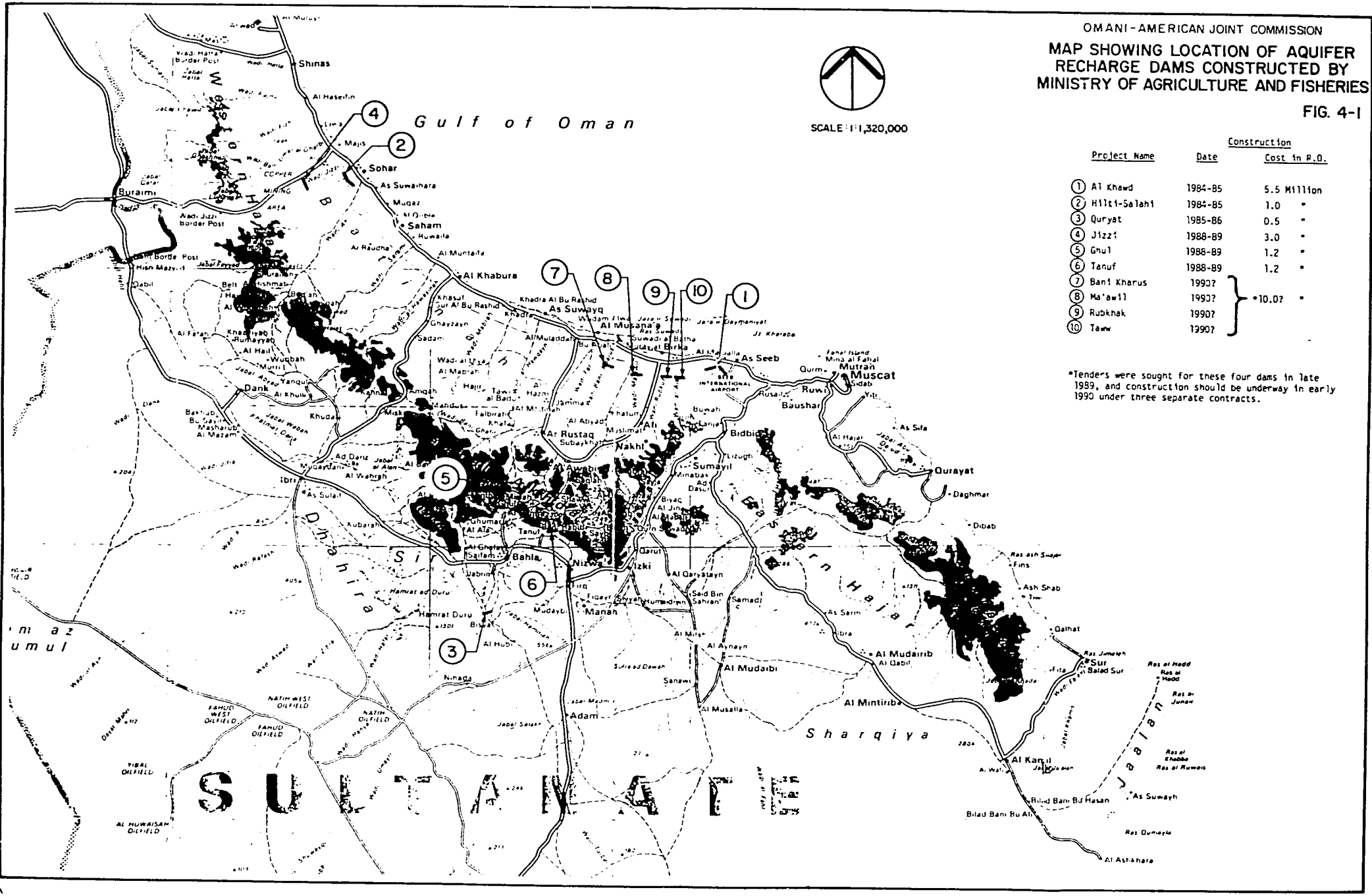
4.3.1 Site Prioritization

The prioritization of sites for possible consideration of construction of recharge dams and facilities is the responsibility of the Ministry of Agriculture and Fisheries (MAF). The MAF retains a staff of in-house consultants who review the work of various consultants involved in preliminary, feasibility and final design studies relating to recharge dam construction. Their input is given considerable weight with regard to recommendations to the Minister as to which projects are most feasible from the standpoint of constructibility and economic feasibility as well as contribution to be made to the present level of agriculture and possible augmentation thereof. The Ministry of Finance approves the budget for construction of the recharge dams based on estimates submitted by MAF as derived from the feasibility reports submitted by the various consultants. There appear to be some instances where projects may be considered

OMANI-AMERICAN JOINT COMMISSION

MAP SHOWING LOCATION OF AQUIFER RECHARGE DAMS CONSTRUCTED BY MINISTRY OF AGRICULTURE AND FISHERIES

FIG. 4-1



	Project Name	Date	Construction Cost in R.O.
(1)	Al Khawd	1984-85	5.5 Million
(2)	Hilti-Salahi	1984-85	1.0 "
(3)	Quryat	1985-86	0.5 "
(4)	Jizzi	1988-89	3.0 "
(5)	Ghul	1988-89	1.2 "
(6)	Tanuf	1988-89	1.2 "
(7)	Bani Kharus	1990?	*10.0? "
(8)	Ma'awil	1990?	
(9)	Rukhkhak	1990?	
(10)	Tawa	1990?	

*Tenders were sought for these four dams in late 1989, and construction should be underway in early 1990 under three separate contracts.

DIRECTORATE GENERAL FOR IRRIGATION AFFAIRS

DEPARTMENT OF DAMS

Table 2

RECHARGE DAMS CONSIDERED FOR ECONOMIC AND TECHNICAL FEASIBILITY STUDIES

No.	Name of Project	Wadi	Name of Consultant	Cost	Date of Actual Start	Date of Completion	Remarks
1.	Barka-Al-Rumays	Bani- Kharous Al Ma'awil Zubkhah Al-Tawin	Sir MacDonald	70,000	19/10/1987	19/1/1989	4 Dams
2.	Nizwa-Bahla	Al-Abyad Bahla	W.S.Atkins	37,000	28/[illegible]/1987	27/9/1988	2 Dams
3.	Wadi Samail	Gani Rajmi Bani Rawaha	WABCO	33,500	12/12/1987		3 Dams
4.	Ibri-Al-Iraqi	Al Kabiir	W.S.Atkins	29,000	12/11/1987		1 Dam
5.	Al-Kamil-Al-Wafi-Sur	Bani Khalid Al-Feleaj	Weid Bellan	44,000	01/01/1988		2 Dams
6.	Salalah	Garzar Naheir Sahnout	Sir MacDonald	60,000			1 Dam
7.	Shinnas	Hatta Fayd					2 Dams
8.	Saham-Sohar	Ahin Sakhin Saremi Shafan					4 Dams
9.	Al-Khaboura/Bani Khalid Al-Bograin	Bani Umar Al-Hawasinah Halhal Mabrah					4 Dams

Source : Ministry of Agriculture and Fisheries 17

and constructed even after the feasibility study does not advance the project for that particular site. There is also evidence that some projects are being advanced to final design phase before completion of the pertinent feasibility study.

4.3.2 Final Design and Construction

As discussed earlier, final design for some projects is made a part of the detailed design report since it is a logical next stop in the implementation of the project. On other projects there may be an interlude between completion of the detailed design report and receipt of authorization to proceed with the final design documents. In the latter case, an implementation period of three years will allow for design and contract documents and their approval (8-12 months), receipt of tenders and award of contract (4-8 months), construction (12-16 months), which provides for a range of 24-36 months dependent on the project. Concerning contractor selection, sometimes the tendering is accomplished in two stages; the first includes prequalification of the contractors while the second includes limited competitive tendering among the prequalified contractors.

During the first four years that recharge dams were constructed, four projects were completed through 1986 as indicated in Table 3. These four projects had a combined total cost of R.O.8,600,000 with Wadi Al Khawd the largest project at R.O.6,000,000. Construction period for this project approached two years while on the three smaller dams it ranged from eight to ten months.

By the end of 1989, work will have been completed on three more projects with a combined total cost of R.O.5,350,000 as detailed in Table 4. This will bring the total cost for the seven dams constructed through 1989 to a value of approximately R.O.14.0 million. When one further considers the fact that feasibility studies for dams on Wadi Bahla, Wadi Al Kabir and Wadi Al Abyad were all completed early this year, it is entirely conceivable that MAF could have no less than 11 recharge dams in operation by 1991. The first four projects were completed and placed into service within a 10-month period in 1985-1986 while the three projects to be completed in 1989 will be placed in service in less than a six month period. Clearly, this second grouping of projects points out the importance of establishing a monitoring and evaluation program that can be used not only to evaluate the effectiveness of projects already completed, but as a baseline for comparison of future sites which will come under consideration. Precipitation records show that it may take seven to ten years in some areas to experience the full range of wet and dry cycles. Therefore, time is of the essence in formulating and establishing an effective recharge monitoring and evaluation program as detailed hereinafter.

DIRECTORATE GENERAL FOR IRRIGATION AFFAIRS
DEPARTMENT OF DAMS

Table 3

RECHARGE DAMS ESTABLISHED THROUGH 1986

No.	Name of Project	Wadi	Name of Contractor	Name of Consultant	Cost in R.O.	Date of Actual Start	Date of Completion
1.	Wadi Al-Khawd	Al-Khawd	C.C.C.	Stanley	6,000,000	Mar. 1983	Dec. 1985
2.	Hylti/Salahi	Hilti Salahi	Al-Harthi-Ekory	Hydro-Consult	900,000	Nov. 1984	Aug. 1985
3.	Wadi Quryat	Sayfam	Tayloruder/ Towel	Hydro-Consult	500,000	Aug. 1985	Feb. 1986
4.	Khour Wadi Al-Rissagh	Rissagh Felaej	Amkat	Hydro-Consult	1,200,000	Sept. 1984	June 1985

Source : Ministry of Agriculture and Fisheries 19

DIRECTORATE GENERAL FOR IRRIGATION AFFAIRS

DEPARTMENT OF DAMS

Table 4

RECHARGE DAMS PROJECTED TO BE CONSTRUCTED THROUGH 1989

No.	Name of Project	Wadi	Name of Contractor	Name of Consultant	Cost in R.O.	Date of Actual Start	Date of Completion
1.	Wadi Al-Gezzi (Northern Batinah)	Al-Gezzi	Sir MacDonald	G and B	2,600,000		24/8/1989
2.	Wadi Al-Ghoul (Oman Interior)	Al-Ghoul			1,250,000		13/6/1989
3.	Wadi Tanauf (Oman Interior)	Tanauf			1,500,000	30/10/1989	

Source : Ministry of Agriculture and Fisheries

4.4 Current Hydrological Monitoring and Evaluation Unit

4.4.1 Staffing

The MAF hydrological monitoring and evaluation unit is comprised entirely of Omani nationals and is currently understaffed and underqualified to fulfill the immediate needs of the MAF aquifer recharge program. At present, it possesses only the capability for the rudimentary collection of monitoring data with no ability to assess the data in regard to determining the effectiveness of the recharge facilities. The following list provides a summary of the current MAF hydrological monitoring and evaluation unit staffing.

Position	No. Persons	Responsibilities
Chief of Operation and Maintenance	1	Section Head of monitoring and evaluation
Geologist	1	Data Collection and review, technical report review, assistant to MAF Engineers.
Senior Technician	1	Review, process, and file monitoring data submitted from Regional Offices. Help train junior employees in monitoring techniques and recorder chart interpretation.
Junior Technician (Regional Offices)	3	Measure water levels in monitoring wells and service graphical recorder stations. Minor administrative duties.
Junior Technician (Capital Area)	3	Receive training in hydrological monitoring techniques and data collection. Assist in recorder chart interpretation.

4.4.2 Equipment

Monitoring equipment currently used by the MAF hydrological monitoring and evaluation unit consists of A.OTT manually operated water level indicators for periodic monitoring well measurement and float/counterweight actuated A.OTT graphical water level recorders for continuous monitoring at each aquifer recharge facility. Water level recorders are generally placed in gauging stations at the dam, in downstream flow channels, and in some cases on the spreading grounds and/or in downgradient monitoring wells. Quality analyses are performed on select water samples at the Ministry using a portable electro-conductivity meter.

4.4.3 Effectiveness

The current MAF hydrological monitoring and evaluation unit has only the capability to collect and store monitoring data from the aquifer recharge sites.

The present staff lacks the qualifications to perform a reliable assessment of this data and has therefore been unable to evaluate the effectiveness of the recharge structures during past flood flow events. Past recommendations for improvement of the structures have been based solely on direct observations.

In addition to staffing inadequacies, there has reportedly been some dissension among the junior field technicians due to extended working hours and the amount of time that must be spent away from home. These two factors are compulsory to the successful completion of field operations,and measures must be implemented to remedy the situation.

At Wadi Al-Khawd, equipment malfunctions created a setback in evaluating the effectiveness of the pilot project for enhanced aquifer recharge. At this site, Omnidata "Datapod" Model 1715 digital water level recorders equipped with pressure transducers were installed at all of the gauging locations. These recorders proved inoperative during the flood flow events and only data collected by local PAWR monitoring stations was acceptable. PAWR data was, however, not sufficient as a base for a comprehensive assessment. Monitoring points at recharge structures constructed thereafter have generally been equipped with A.OTT graphical water level recorders which, although not rigorously tested, appear to function satisfactorily.

Currently, the monitoring schedule includes measuring water levels in monitoring wells on a monthly basis and inspecting the graphical recording stations every two (2) or three (3) weeks. In the case of a flood flow event, the frequency of water level measurement in the monitoring wells is increased to once every two weeks.

Chapter 5

PROPOSED HYDROLOGICAL MONITORING AND EVALUATION UNIT

5.1 Staffing

Personnel

In view of the magnitude of the MAF aquifer recharge program, it will be necessary to upgrade the current hydrological monitoring and evaluation unit both administratively and technically. The new unit must have the capacity to assess the effectiveness of individual recharge facilities and to evaluate and plan the overall direction of the MAF aquifer recharge program. Staffing within the unit should include:

- One (1) Senior Hydrologist
- One (1) Staff Hydrologist
- One (1) Staff Hydrogeologist
- Three (3) Engineering Trainees
- Ten (10) Field Technicians

This technical unit will operate under the guidance of a duly appointed Director of Hydrological Monitoring and Evaluation.

Experience

The Senior Hydrologist position should require 15+ years experience in surface water and groundwater hydrology investigations including data collection and interpretation. Experience should include work in water resources evaluation and planning in arid climates, with some experience in aquifer recharge programs. A minimum of two (2) years experience in the design of hydraulic structures is considered a prerequisite. An understanding of aquifer modeling is desirable. The position requires a high degree of administrative and technical capability. Fluency in either English or Arabic should be considered a must; fluency in the other language a plus.

The positions of Staff Hydrologist and Hydrogeologist should require 5+ years experience in water resources investigations, to include experience in data collection and interpretation. Candidates should possess an M.S. degree or the equivalent in civil engineering specializing in hydrology (Hydrologist) and groundwater geology (Hydrogeologist). Some experience with Aquifer modeling and data base management via computer applications is required. The positions require an interest in field operations, and candidates will be expected to spend time in the field and train other personnel in field techniques. Fluency in either English or Arabic should be considered a must; fluency in the other language a plus.

Engineering trainees should have a strong interest in water resources related disciplines (water resources, hydrology, hydrogeology, civil engineering or the equivalent). Previous experience is suggested, but not required. Candidates

must be willing to participate in field operations and should have an interest in continued education via short courses or a formal degree programs abroad. Fluency in English should be considered a prerequisite.

Field technicians must demonstrate a basic mathematical aptitude and, although not required, completion of a secondary school education will be looked upon favorably. Past experience in water resources data collection is not required but a willingness to learn is considered essential. Technicians must be willing to work long hours in the field and flexibility in working hours is considered a prerequisite. Fluency in English should be considered a plus.

Position Responsibilities

Senior Hydrologist

- Technical and organizational direction of the hydrological monitoring and evaluation unit.
- Organize field operations and establish standard procedures and protocols for the collection and analysis of hydrological data.
- Assess existing monitoring networks and prepare technical specifications and tender documents for their improvement.
- Perform hydrological analyses to evaluate the effectiveness of individual recharge structures and make recommendations for their improvement.
- Evaluate feasibility studies conducted by independent consultants at potential recharge sites.
- Develop and participate in training programs for the Omani staff.
- Establish sound working relationships with, and seek technical input from, the PAWR, MOC and MOE.
- Assess the overall effectiveness of the MAF aquifer recharge program and provide conclusions and recommendations to the MAF Planning Department.

Staff Hydrologist and Hydrogeologist

- Assist Senior Hydrologist in the performance of hydrological evaluations and assessments.
- Prepare a computerized data management system for the input of hydrological monitoring data and train select Omani staff in its use.

- Supervise construction of gauging stations and the installation of monitoring equipment.

- Provide hands-on training in field operations for all Omani staff.

- Teach Omani staff technical subjects applicable to the program through in-house training sessions.

- Coordinate construction of recharge structures with the need for an expanded network of monitoring facilities.

- Visit all monitoring stations periodically to ensure proper operation of the equipment.

Engineering Trainees

- Review and interpret basic monitoring data and chart recordings.

- Assist Staff Hydrologist and Hydrogeologist in the performance of hydrological evaluations.

- Accompany field technicians, on a rotational basis, to ensure proper monitoring procedures.

- Input of monitoring data into the computerized data base system.

- Attend in-house seminars and training sessions.

Field Technicians

- Perform hydrological monitoring operations, including data collection and gauge servicing.

- Assist in data record interpretation.

- Attend in-house seminars and training sessions when appropriate.

Unit Responsibilities

The proposed hydrological monitoring and evaluation unit should fall directly under the auspices of the Directorate General of Irrigation Affairs, Department of Dams, with complete autonomy for staffing, logistics and operating budget. The unit will be responsible for managing monitoring networks of both surface and groundwater in and around the recharge facilities. Data collected will be used to evaluate the effectiveness of the structures and improve on their performance. Based on the results of their investigations, the MAF unit will assess the long-term effects, both positive and negative, of the aquifer

recharge program and provide recommendations for preserving water resources in the Sultanate.

Specific duties of the unit are as follows:

- Establish and maintain formal and informal relationships with the PAWR, the MOC, and the MOE to avoid duplication of efforts and provide for a bilateral exchange of data. Existing information pertinent to the MAF aquifer recharge program should be collected.

- Assess existing monitoring networks and improve them where necessary.

- Collect and interpret monitoring data for surface and groundwater, to evaluate the effectiveness of specific aquifer recharge facilities and to develop recommendations for their improvement.

- Prepare a computerized data base management system for readily accessing surface and groundwater information.

- Prepare reports presenting data summaries, recommendations and conclusions concerning the effectiveness of specific aquifer recharge structures and of the MAF aquifer recharge program in general. These reports should be issued on a quarterly basis to key officials and other government agencies involved in water resources.

5.2 Training

General

The technical training of personnel is essential for the overall success of the proposed monitoring and evaluation unit and for the future Omanization of its staff. Training may take various forms, ranging from on-the- job training to formal education abroad. The type of training available to staff may vary depending on position responsibilities, past performance, and the present goals and aspirations of the individual. Supervisory staff will recommend select personnel for training abroad.

On-the-Job Training

Field technicians and engineering trainees will receive hands-on experience in proper field operation procedures under the tutelage of the staff hydrologist and the hydrogeologist. The professional staff will work with the technicians and trainees in the field, teaching them data collection methods, the use and servicing of graphical data recorders, and appropriate flood flow gauging techniques. As personal interests and skills develop, the technicians and trainees will have the opportunity to participate in basic data interpretation and geotechnical design planning considerations for hydraulic structures.

Seminars and Training Sessions

Seminars and technical training sessions should be held at the MAF on a quarterly basis, with all staff members in attendance. These may take various forms, ranging from short informal meetings to extended technical presentations. Meetings are valuable in that they allow staff the opportunity to exchange experiences, observations, and they provide time to discuss the results of current investigations. At the invitation of the Ministry, guest speakers can present key topics that are relevant to the recharge program, and these discussions may provide a learning experience for all present. Seminars in all forms are important since they often help to develop an individual's interest and strengthen unity within the group.

Short Courses

Technical short courses abroad will be an integral part of the unit's training program. Dependent upon the financial resources, selected staff will have the opportunity to participate in water resources technical training courses which may last in duration from three (3) to six (6) months. Attendees' base salaries should continue to be paid during this time, along with a per diem for extraneous living expenses. Housing, meals and transportation while abroad will be arranged.

Formal Education

Enrollment opportunities abroad in a formal degree program in water resources related disciplines such as hydrology, hydrogeology or civil engineering should be made available to select staff personnel. Candidates should have expressed a strong interest in a particular discipline, a desire for further education, and an academic competency for the successful completion of coursework. These opportunities may take the form of either a two-year Associate degree program, or extended study toward the completion of a four-year Bachelor of Science degree or the equivalent.

5.3 Equipment

If assessment of the hydrological monitoring networks currently maintained by the MAF at specific recharge dam sites, along with those operated by the PAWR and the MOC, reveal deficiencies in the network, it may be necessary to install additional monitoring points. It is suggested that a qualified consulting firm arrange and supervise construction of all gauging stations under the overall direction of the MAF. All gauge sites must be adequately protected from intruders to avoid damage. Currently, all gauges and equipment directly related to the recharge structure have been provided for in the tender specifications.

For new surface water gauging stations and key monitoring wells, it may be reasonable to continue to utilize float/counterweight actuated graphical water level recorders. This type of recorder, although requiring additional man-hours for the manual interpretation and processing of data, appears to have operated successfully for the unit in the past. Currently, A.OTT graphical recorders are in use at a cost of approximately R.O.1200 each. Leapold & Stevens, Inc., based

in the United States, also manufactures a continuous graphical recorder similar to the OTT Model. The Stevens Type A-71 water level recorder was first introduced in 1911 and, fully equipped, lists at approximately R.O.1200.

If studies indicate that additional rainfall gauging stations in the recharge dam catchment areas are required, a number of continuous type graphical recorders are available. Recording gauges currently employed by the PAWR include models manufactured by Leapold & Stevens, Siap and Ikeda, and range in price from approximately R.O.750-1000 each. Gauge selection may be based on the general operating conditions of the site and/or the estimated time duration between servicing.

In addition to hydrological equipment, it is necessary that a four-wheel-drive vehicle be made available to each team of two field technicians to be used exclusively in the performance of monitoring activities. One four-wheel-drive vehicle should also be made available to each engineering trainee for use in site inspection and general construction overview. Acquisition of vehicles in the past has been provided for within tender specifications. However it is unlikely that these vehicles would be available for use exclusively by the proposed monitoring and evaluation unit.

To manage the amount of data that is expected to be generated by the monitoring and evaluation unit, it will be necessary to install an IBM-XT personal computer, or a compatible model, equipped with a user-friendly spreadsheet software such as Lotus 1-2-3 for data entry and retrieval. Lotus 1-2-3 is easy to learn and operate and has various graphing capabilities useful in trend analyses. Data entry into a computer management system will allow for the effective exchange of information with other public sector institutions via the exchange of computer discs.

5.4 Operating Budget

A general operating budget for the proposed monitoring and evaluation unit has been developed based on estimated salaries, training expenditures and equipment costs. The budget has been projected over a period of four (4) years and then (10) years. Many assumptions have been made and actual costs are likely to vary. Salary increases used to develop the 10-year budget represent promotional increases and/or grade changes that may occur over this period. The technical training schemes presented here were used to develop a cost estimate and actual training needs for the monitoring and evaluation unit may differ. Equipment estimates are based on the assumption that for future construction projects, most water level recorders, wadi gauges and rain gauges will be provided within the tender specifications for dam construction.

Four (4) Year Period

Technical Assistance Staff--Salary

Senior Hydrologist at an estimated salary of R.O.27,000/ yr X 4 = R.O.108,000.0
Allowances: R.O.25,560/yr x 4 = R.O. 102,230

Staff Hydrologist at an estimated salary of R.O.20,000/ yr X 4 = R.O.80,000.0
Allowances: R.O.24,075/yr x 4 = R.O. 96,300

Staff Hydrogeologist at an estimated salary of R.O.20,000/ yr X 4 = R.O.80,000
Allowances: R.O.24,075/yr x 4 = R.O. 96,300

	Salaries	Allowances
Senior Hydrologist	= 108,000.000	102,230.000
Staff Hydrologist	= 80,000.000	96,300.000
Staff Hydrogeologist	= 80,000.000	96,300.000
Totals	R.O.268,000.000	R.O.294,830.000

Trainee/Technician--Salary and Allowance

Three (3) Engineer Trainees at an estimated rate of R.O.5700/yr/person X 3 X 4 = R.O.68,400.0

Ten (10) Field Technicians at an estimated rate of R.O.3360/yr/person X 10 X 4 = R.O.134,400.0

Engineer Trainees	= 68,400.000
Field Technicians	= 134,400.000
	R.O.202,800.000 Total

Technical Training

Two (2) Engineer Trainees complete a two (2) year Associate Degree program abroad at an estimated cost of R.O.1350/month/person X 2 X 24 = R.O.64,800.0

Six (6) Field Technicians complete a four (4) month short course abroad at an estimated cost of R.O.1350/ month/person X 6 X 4 = R.O.32,400.0

Associate Degree Program	= 64,800.000
Short Course	= 32,400.000
	R.O.97,200.000 Total

Equipment--monitoring network improvement and expansion

Six (6) wadi gauge stations constructed and equipped with graphical water level recorders at an estimated cost of R.O.1700 each X 6 = R.O.10,200.0

Twenty (20) rain gauge stations constructed and equipped at an estimated cost of R.O.1000.0 each X 20 = R.O.20,000.0

Ten (10) monitoring well graphical water level recorders with housing at an estimated cost of R.O.1200 each X 10 = R.O.12,000.0

Eight (8) four-wheel-drive vehicles for trainees and technicians at an estimated cost of R.O.5000/each X 8 = R.O.40,000.0

One (1) personal computer with printer at an estimated cost of R.O.2000.0

Wadi Gauge Station	=	10,200.000
Rain Gauge Station	=	20,000.000
Monitoring Well Recorders	=	12,000.000
Four-wheel drive vehicles	=	40,000.000
Personal Computer	=	2,000.000
		R.O.84,200,000 Total

Total Cost over Four (4) Year Period

	Salaries	Allowances
Technical Assistance Staff	= 268,000.000	294,830.000
Trainee/Technician	= 202,800.000	-----
Technical Training	= 97,200.000	-----
Equipment	= 84,200.000	-----
Totals	R.O.652,200.000	R.O.294,830.000

Total Salaries and Allowances: R.O. 947,030.000

Ten (10) Year Period

Technical Assistance Staff--Salary

Senior Hydrologist at an estimated increased salary of
R.O.31,000/yr X 6 = R.O.186,000.0
Allowances: R.O.29,350*/yr x 6 = R.O.176,100

Staff Hydrologist at an estimated increased salary of
R.O.24,000/yr X 6 = R.O.144,000.0
Allowances: R.O. 27,640*/yr x 6 = R.O.165,840

Staff Hydrogeologist at an estimated increased salary of
R.O.24,000/yr X 6 = R.O.144,000.0
Allowances: R.O. 27,640*/yr x 6 = R.O.165,840

* Allowances increased 25% for years 5-10 of 10-year programs.

	Salaries	Allowances
Senior Hydrologist	- 186,000.000	R.O.176,100.000
Staff Hydrologist	- 144,000.000	165,840.000
Staff Hydrogeologist	- 144,000.000	165,840.000
	R.O.474,000.000	R.O.507,780,000

	Salaries	Allowances
Initial Four (4) Years	- 268,000.000	R.O.294,830.000
Six (6) Additional Years	- 474,000.000	507,780.000
	R.O.742,000.000	R.O.802,610.000

Total Salaries and Allowances R.O.1,544,610,000

Trainee/Technician--Salary and Allowance

Four (4) Engineer Trainees at an estimated increased rate of R.O.7800/yr/person X 4 X 6 - R.O. 187,200.0

Twelve (12) Field Technicians at an estimated increased rate of R.O.4980/yr/person X 12 X 6 - R.O.358,600.0

Engineer Trainees	- 187,200,000
Field Technicians	- 358,600.000
	R.O.545,800,000 Total

Initial Four (4) Years	- 202,800,000
Six (6) Additional Years	- 545,800.000
	R.O.748,600,000 Total

Technical Training

Two (2) Engineer Trainees with Associate Degrees continue studies abroad for two (2) years to complete a B.S. degree program at an estimated cost of R.O.1350/month/person X 2 X 24 - R.O.64,800.0

One (1) Engineer Trainee and two (2) Field Technicians complete a two (2) year Associate Degree program abroad at an estimated cost of R.O.1350/month/person X 3 X 24 - R.O.97,200.0

Six (6) Field Technicians complete a four (4) month short course abroad at an estimated cost of R.O.1350/month/person X 6 X 4 - R.O.32,400.0

B.S Degree Program	-	64,800.000
Associate Degree Program	-	97,200.000
Short Course	-	32,400.000
		R.O.194,400.000 Total

Initial Four (4) Years	-	97,200.000
Six (6) Additional Years	-	194,400.000
		R.O.291,600.000 Total

Equipment

Eight (8) new 4-wheel-drive vehicles for trainees and technicians acquired as necessary at an estimated cost of R.O. 5500/each x 8 - R/P/ 44,000.0

Ten (10) wadi gauge stations constructed and equipped with graphical water level recorders at an estimated cost of R.O.1700 each X 10 - R.O.17,000.0

Thirty (30) rain gauge stations at an estimated cost of R.O.1000 each X 30 - R.O.30,000.0

Twenty (20) monitoring well graphical water level recorders with housing at an estimated cost of R.O.1200 each X 20 - R.O.24,000.0

Four-Wheel-Drive Vehicles	-	44,000.000
Wadi Gauge Stations	-	17,000.000
Rain Gauge Stations	-	30,000.000
Monitoring Well Recorder	-	24,000.000
		R.O.115,000.000 Total

Initial Four (4) Years	-	84,200.000
Six (6) Additional Years	-	115,000.000
		R.O.199,200.000 Total

Total Cost over Ten (10) Year Period

		Salaries	Allowances
Technical Assistance Staff	-	742,000.000	R.O.802,610.000
Trainee/Technician	-	748,600.000	-------
Technical Training	-	291,600.000	-------
Equipment	-	199,200.000	-------
Totals		R.O.1,981,400.000	R.O.802,610.000

Total Salaries and Allowances: R.O.2,784,010.000

A comparison of costs of operating an extensive recorder network as opposed to the cost of an extensive manual monitoring network scattered all over the country with technical staff based in the capital to service this network results in the following. The recorder network would consist of the following equipment:

20 Wadi gauge stations	@ R.O.1,700 ea. -	R.O.34,000
40 rain gauge stations	@ R.O.1,000 ea. -	R.O.40,000
20 monitoring well graphical water level recorders	@ R.O.1,200 ea. -	R.O.24,000
	Total	R.O.98,000

Such a program of recording devices could be serviced one week out of every five weeks or approximately 20 percent of the time. This means that the cost of a vehicle (R.O.5,000) could be shared with another endeavor or cost to this project would be R.O.1,000; when spread over a five-year period, this results in an annual cost of R.O.200. In addition to a share in the capital cost of the vehicle, the cost of operation is estimated at R.O.1150 per year based on travel of 1,600 km per month at R.O.0.060 per km. Labor is based on a total of four days per month for a technician and a driver with a combined salary of R.O.5,200 per year, which results in a labor cost of R.O.1,000 per year. Based on a 10-year life for the recording equipment, the capital cost for the project is R.O.9,800 per year, while the vehicle cost is R.O.1,350 per year. Combined with a labor cost of 1,000 per year, this results in a total cost for the recorder network of R.O.12,150 per year.

The manual monitoring network would be handled by two teams with each consisting of a technician and driver. One of these teams would make stream flow measurements at 20 wadi stations with each wadi being visited once each week for six months of the year (October through March) with the frequency of visits halved to once every other week for the remaining months of the year (April through September). The second team would be responsible for the 40 rain gauge stations (plastic wedge type) and necessary observations for 20 monitoring wells. The wadi gauge team would incur a capital cost of approximately R.O.2,000 per year for stream gauging equipment while they would need a vehicle full time for travel of up to 2,250 km per week during the six-month period of October through March with approximately 1,125 km per week necessary for the

remaining months of the year, thus resulting in a total operational cost of R.O.5,250 per year. Labor costs would amount to 22 days per month for the remaining six months of the year with 11 days per month for the remaining six months, thus resulting in a total cost of R.O.4,120 per year. The vehicle cost of R.O.5000 would be spread over a 5-year period, thus resulting in R.O.1,000 per year being assessed to the project. The foregoing would result in capital costs of R.O.3,000 per year while O&M costs of vehicle operation would be R.O.5,250 per year with labor estimated at R.O.4,120, thus resulting in a total of R.O.12,370 per year.

The second manual monitoring team would be responsible for operation of the rain gauge stations and the monitoring wells and would spend 22 days per month in the field for 6 months of the year with only 11 days per month the remaining 6 months of the year, thereby resulting in a total labor cost of R.O. 4,120. The cost to operate and maintain the vehicle for this team would be based on travel of nearly 2,900 km per week for six months of the year with approximately 50 percent of this value for the remaining six months, thereby resulting in a total cost of R.O.6,750 per year. When these values are added to an estimated capital cost of R.O.2,000 per year, they result in a total of R.O.12,870 per year which, when coupled with R.O.11,370 per year for the water gauge team, results in a total cost per year of R.O. 24,000, nearly double that of the recorder network.

5.5 Action Plan

5.5.1 Water Resources Information Requirements

Ministry of Agriculture and Fisheries

This study has provided most enlightening information about the status of the recharge dam program undertaken by the MAF. By the end of 1989 there will be seven recharge dams complete and in service with construction underway on four more facilities on the Batinah Coast (three contracts for four dams are currently out for tenders), with yet other facilities being considered for construction in 1990. The need to develop a hydrological monitoring and evaluation unit at MAF to focus on the aquifer recharge program cannot be overstated. Furthermore, because the MAF has undertaker the aquifer recharge program at such an accelerated pace, it must also expand its role in data collection and interpretation as necessary at each dam site, since the other logical agency which could undertake this challenge, the PAWR, has recently proposed an ambitious program for the upgrade and expansion of its wadi flow and rainfall gauging network in Oman (Ref. 1). A program to serve just the needs of the aquifer recharge program by MAF will require an increase in staff as well as on-the-job and formal training. The need for an increase in staff, above and beyond that which comprises the current monitoring and evaluation unit, has been expressed throughout the report and is also reflected in the Operating Budget section.

The MAF should be responsible for establishing and operating any rainfall gauges necessary to provide data for the catchment areas in which recharge dams are planned or constructed. Most existing rainfall gauges have periods of record

less than 10 years, thereby requiring considerable extrapolation of the data. Although the PAWR proposes to upgrade and extend its rain gauge network from approximately 140 to 200 stations, it cannot be expected to tailor its program to meet the needs of the MAF recharge program. Likewise, the MAF should provide wadi flow gauges at each of its dam sites, with water level recorders installed for reservoir and spreading basin levels as well as at measuring flumes, to permit flow rates and volumes to be calculated. In as much as PAWR also proposes to upgrade and expand its wadi gauge network from approximately 120 to 170 stations, there may be a few locations where the proposed PAWR wadi gauge could also serve the needs of the MAF recharge program. The MAF should inform PAWR at least annually of those areas in which feasibility studies will be undertaken for potential construction of recharge dams.

The increase in staff at MAF which will be required to undertake this program, together with input and training by the technical assistance staff as proposed, should enable the MAF to become much more self-sufficient in its handling of the recharge program. Hopefully, with the training and guidance envisaged for the new monitoring and evaluation unit, it will be possible for this unit to undertake the responsibility for performing the preliminary studies necessary for each proposed recharge site. In this respect, the staff would demonstrate capability in the following areas:

Rainfall--install and operate gauges and use data obtained to make station correlation and mass curve analyses, frequency analyses for various durations, and estimates of probable maximum precipitation.

Runoff and Flood Flows--install and operate wadi gauges and use data obtained to predict annual runoff, number of flood events in average year, peak flow values for various storm frequencies, unit hydrograph and mass curve development.

Ground Water Monitoring--install and operate monitoring wells and conduct surveys of ground water use and quality, conductivity measurements--evaluate crop water requirements, evapotranspiration--make surveys of irrigation methods and efficiency.

The monitoring and evaluation unit will be responsible for the complete evaluation of all recharge dams constructed and placed in service. This will include determination of volumes of water recharged after each storm, sedimentation and siltation studies (to determine rate of decrease in recharge rate with time, including program for silt removal), and a periodic update of the benefit cost ratio for each facility. It is expected that with the lower contractor costs that prevail today over costs incurred with facilities constructed in 1984-85 that benefit-cost ratios would improve for a number of projects, if updated. Further, with improved irrigation methods, more land could be put under cultivation per unit volume of water, thereby increasing crop output and, consequently, further improving the benefit-cost ratio.

Public Authority for Water Resources

The PAWR will be extensively involved in its proposed program of upgrade and expansion of the current rainfall and wadi flow gauge network. In addition, its programs of ground water well monitoring, well permits and possibly water exploration and drilling programs (discontinued three years ago), will comprise its major effort. The PAWR should continue with its own programs but also be made the responsible agency for collecting and disseminating water resources data obtained by others. The PAWR should also continue to serve as a reviewer for feasibility studies and final design conducted for MAF, and its review comments considered with those from other cooperating agencies, as described hereinafter.

Ministry of the Environment

The MOE should continue in its role as reviewer for proposed recharge projects. This involvement should include not only the required review necessary to issue the required Certificate of No Environmental Objection (NEO) for a recharge facility to proceed to construction, but continued review of feasibility studies conducted for MAF, with its review comments also considered with those from other cooperating agencies, as described hereinafter.

Ministry of Electricity and Water

The MEW should continue to monitor the output of its well water supply systems, including records of groundwater levels, with this information provided quarterly to MAF and PAWR. Formal communications should be established by MAF with MEW, with meetings held semi-annually to discuss progress of the program and areas of common interest.

Ministry of Communication

The Directorate of Meteorology for MOC should continue to submit both monthly and annual data summary reports to the MAF (with copy to PAWR) and should be included in proposed semi-annual meetings with MAF, MOE and PAWR.

5.5.2 Data Collection and Analysis Systems

After completion, existing recharge structures have generally been provided with water level gauging stations located within the reservoir area, within the discharge flow channels, and when appropriate, within the downstream spreading grounds. All gauges, including those replacing the Datapod data loggers at Wadi Al Khawd, are equipped with float/counterweight actuated graphical water level recorders. Although the structural design and geographical setting at individual recharge sites will vary, the aforementioned monitoring stations are considered essential to the program as they provide basic data necessary to evaluate the operational efficiency of the recharge structure. Gauge equipment should be install immediately after completion.

At Wadi Al Khawd, a flume upgradient of the dam was constructed in the wadi to monitor the flood flow rate and water volume entering the reservoir. In many

cases, it is not practical to construct a flume, and upgradient wadi gauges must suffice. Installation of wadi gauges should be coordinated with the PAWR to obtain direction concerning strategic placement and design of the gauge and to avoid duplication of efforts. In some cases, existing PAWR wadi gauges may be adequate and additional gauges will not be necessary.

Installation of additional rainfall gauges in pertinent catchment areas is another item that must be considered, to help establish relative rainfall/runoff relationships. In Oman, these relationships are currently an area of uncertainty due, in part, to an inadequate number of monitoring stations and the lack of continuous long-term monitoring data. It is important for the benefit of the MAF program that the placement of additional rain gauges be coordinated with the PAWR and the MOC to provide for the most effective coverage of a particular catchment area.

An evaluation of the monitoring network downgradient of each recharge structure should be performed whereby key monitoring wells are identified. It may be advantageous thereafter to equip one or more of these wells with a continuous graphical water level recorder. This will provide a comprehensive record of water level fluctuations in the well, as well as act as a means of reference for periodic measurements in other wells. In addition to monitoring the boreholes that were installed at a site during the feasibility study, it is important to monitor a number of wells further downgradient to help define the range of influence the recharge structure may be having on the local groundwater system. This could be achieved in a number of ways, including the transfer of available PAWR well monitoring data for the area and periodic monitoring of local dug and drilled wells by the MAF hydrological monitoring and evaluation unit. In certain cases, it may be necessary to install additional downgradient monitoring wells. However, considering the cost of drilling, this alternative should only be considered after exhausting all other possibilities.

5.5.3 Technical Assistance and Manpower Development

In view of the present scale of the MAF aquifer recharge program, and future plans for its expansion, it is imperative that the hydrological monitoring and evaluation unit be upgraded as soon as possible. Initially it would be important to fill the proposed technical assistance staff positions (Senior Hydrologist, Staff Hydrologist, Staff Hydrogeologist) and employ a number of additional field technicians. The Engineer Trainee positions could likely be filled most advantageously by staff members currently working for the unit, with the possible recruitment of one additional person.

Technical assistance staff should start by evaluating the existing monitoring networks and, if necessary, make arrangements for their expansion and/or improvement. Existing monitoring data could be collected and reviewed, making preliminary interpretations of the hydrological conditions at both completed and proposed recharge sites.

Training of field technicians and engineering trainees in proper field operations and methods of data interpretation should be regarded as a high priority of the technical assistance staff. Hands-on training, seminars and

training sessions are important and should be developed early in the program, and scheduled on a regular basis. The technical responsibilities of the field technicians and engineering trainees should be increased through time as their individual strengths and capabilities are recognized. As the program develops, technical assistance staff should recommend select personnel for training abroad, both in short courses and formal degree programs, based on job performance and their overall interest in the work.

The eventual Omanization of the technical assistance staff by qualified individuals should be considered as one of the ultimate goals of the monitoring and evaluation program. It is important, however, that technical assistance staff remain in their positions until a number of comprehensive hydrological assessments concerning the effectiveness of particular recharge facilities have been completed. This will allow qualified Omani staff to participate in evaluations, both under supervision and independently, with technical review from the technical assistance staff.

The time period required before technical assistance staff can be phased out is difficult to estimate. Both surface water and ground water hydrology are complex subjects, requiring years of study and experience to develop a good understanding of mechanisms involved. This, accompanied by the often lengthy time interval between sizable rainfall/flood events, makes it uncertain when the technical assistance staff may be effectively replaced by their Omani counterparts. The technical assistance staff could be phased out in a staggered manner, with the Senior Hydrologist remaining active in the program for some time thereafter to provide a degree of continuity and coordination.

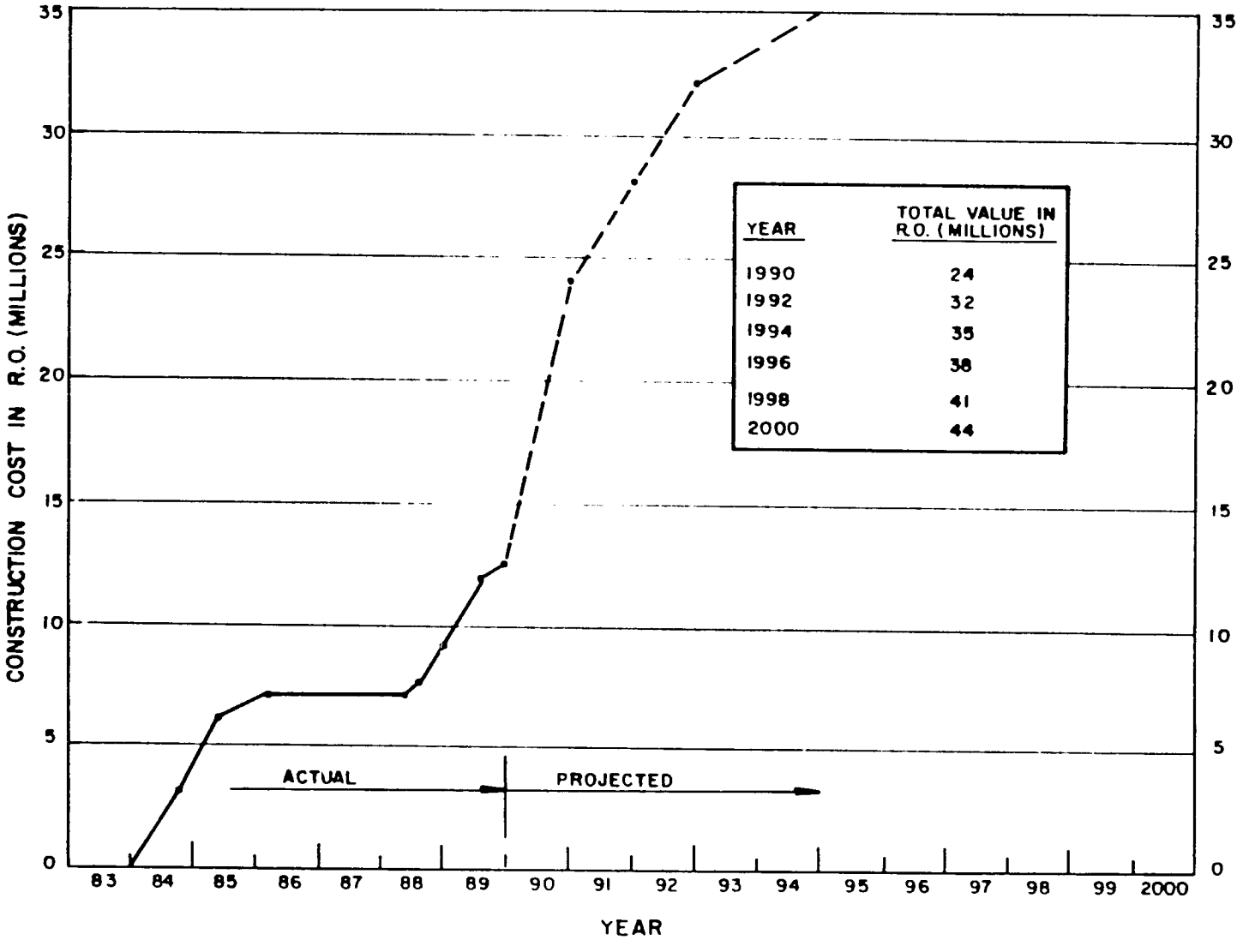
Chapter 6

FUTURE OF THE PROJECT

6.1 Findings

The current investigation has revealed a most ambitious program of recharge facilities to be underway by the MAF in both the study and construction phases. By the end of 1989 six recharge dams will have been constructed and placed into service since 1984 with three of the six completed in 1989; the total construction cost of the six facilities is R.O.14.0 M. At the present time, the MAF is soliciting tenders for the construction of four dams on the Batinah Plain in the Barka-Rumais area with an estimated construction cost of R.O.10.0 M. These include Wadi Bani Kharus, Wadi Ma'awil, Wadi Rubkhak and Wadi Taww. Also, during 1989 feasibility studies were completed for three dams in the Interior: Wadi Bahla, Wadi Al Kabir and Wadi Al Abyad. This suggests that by the end of 1990 the MAF will have ten dams constructed and in service with a total construction cost of R.O.24.0 M, while it is further possible that with construction of two of the three above named dams in the Interior, the total would increase to twelve dams with a total construction cost of R.O.28.0 M by 1991. The addition of the Sur Scheme (with dam on Wadi Fulayj) as well as a dam on Wadi Sahalnawt on the Salalah Plan would then swell this total to fourteen dams with a total construction cost of R.O.32 M by 1992! Projection of future construction costs after 1992 at a reduced rate of R.O.3.0. M per two-year period brings total construction cost to R.O. 44 M by the year 2000! This suggests an average annual expenditure of R.O.8.0 M for the next two years, much greater than the R.O.5.35 M spent for three dams during the past year. It will also be noted that the facilities constructed through 1989 as well as those contemplated for the next two years are pretty well divided evenly between the Coastal Plain and the Interior. The total construction cost expended to date by MAF, as well as possible projected costs through the year 2000, are depicted in Figure 2.

The conduct of feasibility studies and the subsequent construction of aquifer recharge dams seem to be consistent with the "prioritization and ranking of recharge schemes" as set forth in the February 1985 reconnaissance study by Hydroconsult Co. Ltd., entitled "Catchment Water Conservation and Recharge Schemes for Irrigation." This report identified 58 schemes and separated them into two categories : (a) "Approved Schemes for Design and/or Construction" and (b) "New Priority Schemes Recommended." Of the eight schemes identified in "a," the first six schemes represent the six facilities which have been constructed to date, while the two remaining schemes (Al Kamil and Bilad As Sur) are currently under contract for feasibility study. Of the 15 schemes identified in "b," the first scheme (Barka Rumais) is currently out for tender (4 dams--3 contracts), while eight of the remaining 14 schemes are scheduled for feasibility study, with six under contract. Table 5 represents a copy of Tables 7-11 through 7-14, "Prioritization of Proposed Recharge Schemes" from the February 1985 report by Hydroconsult Co. Ltd. (See Appendix C).



OMANI-AMERICAN JOINT COMMISSION

CONSTRUCTION INVESTMENT BY MINISTRY OF AGRICULTURE AND FISHERIES IN AQUIFER RECHARGE DAMS

Figure 2

DIRECTORATE GENERAL FOR IRRIGATION AFFAIRS

DEPARTMENT OF DAMS

Table 5

EXISTING RECHARGE DAMS - MAINTENANCE WORK

No.	Name of Dam	Type of Maintenance	Name of Contractor	Cost	Date of Actual Start	Date of Completion	Remarks
1.	Wadi Ouvrayat	1-removal of alluvium 2-maintenance 3-improvement	Desert Line Enterprises	27,048.550	16/08/1987	15/10/1987	
2.	Wadi Al-Khoudh	1-removal of alluvium 2-maintenance 3-Improvement	Arab Construction Establishment Desert Line Enterprises	59,400 77,499.950	26/01/1988 23/11/1987	25/03/1988 23/03/1988	
3.	Wadi Al-Haltif Salahi	1-removal of alluvium 2-maintenance 3-improvement	Target Target	26,400 61,600	20/12/1987 26/01/1988	17/02/1988 24/04/1988	
4.	Khour Rasagh	1-removal of alluvium 2-iron works painting 3-installation of metallic net at pavement 4-repairing and painting of the inaugural board	Luse Trading & Contracting Establishment	3,300	20/12/1988	10/02/1989	

Source : Ministry of Agriculture and Fisheries

Inasmuch as work constructed to date represents, for the most part, the most viable projects, those currently under study will likely be less viable, with some not feasible from a benefit-cost analysis. This points out the importance of organizing, staffing and training the personnel that will become part of the monitoring and evaluation unit. This unit should be staffed and in operation no later than January 1991, if it is to keep pace with the aquifer recharge program now well underway by MAF. The work to be accomplished will increase as the number of recharge facilities in service increase. Therefore, the monitoring and evaluation becomes critical not only to determine the relative success of projects completed and in service, but also to be used as a baseline for comparison for future projects.

Comments

There were many interviews held during the three and a half weeks that the project team spent in Oman (ref. Appendix B). The comments expressed gave us insights to the aquifer recharge program that became clearer with time. Probably of greatest concern was the pace at which MAF seemed to be proceeding with a program with so many questions unanswered--many of which could be answered were there a monitoring and evaluation program in place.

The following comments represent impressions from our discussions with persons concerned with the program as well as responses to these comments provided by MAF and their review of the draft report. The original comments have been modified to reflect the input from MAF and are included here for consideration.

1. Program pace needs to be reduced to allow for monitoring and evaluation unit to be established and conduct adequate evaluations. Need to establish monitoring facilities sometime before the dam is constructed, preferably during the feasibility study stage. Otherwise, it is very difficult to prove benefits. The monitoring and evaluation program needs to be in place for 4 to 5 years before the results can be interpreted and interpolated to provide data for a baseline of comparisons

2. The internal review given by MAF to recharge projects under consideration should be more rigorous. There is a definite need for an external review by an independent qualified consultant. The results of the internal review by MAF as well as the external review by consultant could then be reviewed by other agencies involved with water resources. The gaining of a consensus at this stage could facilitate the construction phase.

3. Although it has been suggested that a savings of time and money could occur by combining the preliminary and feasibility studies, comments by MAF suggest that the preliminary study should be retained since the cost of a preliminary study is, by far, less than the cost of the feasibility study in which sometimes considerable and expensive field work (such as drilling) takes place. Preliminary studies can examine several proposed schemes, grouped on a regional basis, which are screened more carefully for viability at a technical level than studies of a reconnaissance nature. A preliminary level study can eliminate schemes prior to a feasibility study.

4. Proper consideration should be given to environmental concerns at each site in order to ensure a long term sustainable development. The MAF presently follows known recommendation and requirements of the MOE. The MAF also investigates the impact on natural and geomorphological and hydrological processes brought about by a proposed project as well as the impact on flora and fauna as a result of the project. For each study conducted on the feasibility level, MAF includes an ecologist or an environmentalist on the study team. The MOE has proposed that funding or financing of <u>any</u> project not proceed unless accompanied by an environmental impact report.

5. The evaluation of a project should include monitoring changes in types and extent of vegetation over a period of time extending from prior to construction to many year after the facility has been placed in operation.

6. The construction of recharge dams in catchments where one already exists will require the determination of impact of the upstream recharge facility on the downstream facility, particularly with regard to recharge volumes and depth and extent of siltation.

Studies carried out by the MAF have led to a breakthrough in the understanding of the hydrology of OMAN where it has long been the considered opinion that mountain rainfall was the major contributor to the recharge of the aquifers with little if any input from rainfall falling on the plain. It has been demonstrated that floods generated by local rainfall on the plains may play a major role in that rarely, except in rare synoptic events, is all the catchment area (plain and mountain) affected by the flood. It is possible that the concept of a flood originating from the mountain and flowing down the catchment area, replenishing the successive aquifers as it progresses downstream and possibly causing a loss of recharge downstream, may not be true.

There was a general consensus that the MAF had proceeded with such alacrity with the recharge program construction that evaluation of the program would be difficult, and in many instances the lack of baseline information would preclude some sites from ever receiving a meaningful evaluation. There were instances where more than one agency provided review comments to MAF as requested, only to have the project proceed to construction without heed to the comments. Also in one instance a consultant was requested to provide a proposal for design services and, upon submitting same, was provided a contract for final design before completion of the feasibility study for the same project. From these and other instances we conclude that communications between MAF and other agencies involved in water resources could be much improved.

We recommend that a new post in the MAF Planning Department be created. The individual filling this post should be responsible for soliciting input from other ministries and departments (PAWR, MOE, MEW and MOC) relating to the review of feasibility reports and final designs for proposed recharge projects, and for responding in writing to all comments received before the project proceeds to construction. He should also be responsible for submitting an environmental impact report to the MOE for each project intended for construction (in anticipation of receipt of NEO), and for scheduling the quarterly or semi-annual meetings with the PAWR, MOE, MEW and MOC, while maintaining close liaison with

his planning counterpart at the MOE. Hopefully, this would meet the need for improved communications and someone responsible for obtaining the necessary approvals before a project is submitted to the Development Council for consideration for financing by the Ministry of Finance.

Considerations

Discussions held with MAF at a meeting on September 25, 1989, indicated a consensus of unanimity for proceeding with the monitoring and evaluation program with due haste. The MAF acknowledged that much stands to be learned from such a program, not only with regard to dams already completed, but information that will affect the scope of study for dams yet to be selected for feasibility studies. The MAF also acknowledged that they were already experiencing a decrease in the number of projects which could still be classified viable, as they now focus on projects which rank lower on the priority list established by Hydroconsult. Accordingly, they foresee a slowing in the pace of construction of recharge dams as projects become less viable and the benefit-cost ratio diminishes. Still, other factors to be revealed as part of the monitoring and evaluation program could help the benefit-cost ratio of certain projects.

We offer the following suggestions for consideration when the recharge program is enhanced by a monitoring and evaluation unit.

1. The recharge program needs to focus on the entire watershed, considering comparative benefits from smaller structures in the headwaters of certain catchments to serve agricultural needs there. Studies by the MAF have shown the headwater structures are often demonstrated to be not feasible due to the steep slopes reducing the capacity of the reservoir as well as the heavy bed load causing reservoirs to fill up fast with silt, and thereby making maintenance costly; as well as high water tables reducing storage capacity of the aquifer downstream of the structures among other unfavorable factors.

2. The program should also focus on alternative methods such as deep well injection and infiltration galleries to promote recharge. Consideration should also be given to use of sub-surface and sand storage dams (Ref. 2) for supply to small villages and agricultural settlements. These have been used in the arid southwestern part of the United State as well as in Iran, Afghanistan and Japan. Although some of these alternative methods have been studied in feasibility studies completed to date and then generally disregarded as being extremely costly or technically difficult to implement, they should not be dropped completely from consideration on certain future projects.

3. The well monitoring program needs to be expanded, particularly in the Batinah Coast area. New wells need to be established along transients (perpendicular to coastline) to enable better definition of the saline wedge, as well as upcoming. There is also a need to study the influence of tides (as affected by the lunar phases) on the salt water wedge. Monitoring of the evolution of the saline wedge in the Batinah Coast is of a regional nature and should receive the attention of the PAWR which has already carried out considerable work on the subject. Generally, the

problem has been considered by the MAF and drilling of observation wells at the coast for the monitoring of the interface has been performed for the relevant schemes.

4. The water resources of each catchment need to be examined with the realization that not all water-sheds should be developed to serve agriculture. The resources of some watersheds should be allocated for municipal and possibly industrial water supply as well as agriculture. Recharge along the Batinah Coast is likely to reduce an existing deficit rather than expanding water resources for development of additional agricultural land. This fact is well illustrated for the Al Khawd Scheme where the recharged water, estimated at 5 mcm, has likely been used by the MEW well fields downstream of the dam without providing any direct benefit for agriculture.

5. The projects which have been constructed as well as others on which feasibility studies have been completed generally conclude that recharge dams are effective at a local level. Examination of their effectiveness on larger scale frequently leads to considerable differences of opinion. Consequently, the cost-benefit analysis presented may be optimistic when viewed from a larger or regional scale.

6. The viability of installing disposable structures (e.g. inflatable dam) in certain upstream portions of catchment to provide recharge to wadis in small villages for local water supply or agriculture should be investigated.

6.2 Recharge Structures

Coastal Plain

The program to construct aquifer recharge structures along the coastal plain of the Batinah is one which evokes very little controversy. The continued and uncontrolled pumping of groundwater from production wells in the area is responsible for intrusion of the salt water wedge, thereby resulting in high salinity of both the soils and groundwater with upconing very common. This situation lowers the fertility of the existing arable lands as farmers tend to overpump the water, thereby further aggravating a critical situation.

Because most of the agricultural land lies within a band only 15 to 20 km wide along the coast, any recharge facility constructed within 20 to 25 km of the coastline has an excellent chance of detaining, storing, and recharging major portion of the aquifer with water from storm systems in the catchment before it is carried to the sea and lost. Because the dams which have been proposed or constructed are usually lost at the most downstream location in the catchment where the recharge process can utilize the permeable sands and gravels in the alluvial fans, they represent the last location where fresh water can be captured before it is lost to the sea. These dams do not even have to be proven economically feasible for their construction to proceed.

Interior

The program to construct aquifer recharge structures at reasonably wide sections of the wadis where permeable deposits of sands and gravels prevail has provoked a number of questions. There is a claim that recharge dams can dislocate the natural recharge area and, thereby, affect the quantity of water available downstream. Although recharge dams are usually sited just upstream of the portion of the wadi containing the most permeable sands or gravels (or adjacent spreading grounds), the temporary storage of the water behind the recharge dam generally leads to siltation and clogging of the area upstream, with some clogging and loss of recharge capacity even downstream of the dam. Should recharge of an area immediately downstream of a recharge dam result in a substantial increase of the groundwater table in that area, it can be argued that that water is no longer available for downstream irrigation of agriculture, especially if the increase in groundwater levels near the recharge dam results in increased agricultural activity and irrigation. Further, with increased agricultural activity in the vicinity, there will be an undue stress on the groundwater table during drought periods. Some contend that the barriers which make up the recharge dams will disturb the equilibrium for recharge which now takes place under natural conditions, thereby taking water from downstream users for the benefit of the recharge area upstream. Consequently, there is a concern for the adverse environmental impact. For this reason there is a need to monitor changes in vegetation over a period of time as part of the evaluation. In short, many questions remain to be answered and, hopefully, the monitoring and evaluation program will provide that opportunity.

Chapter 7

RECOMMENDATIONS

In view of the magnitude of the MAF aquifer recharge program, it is imperative that the proposed hydrological monitoring and evaluation unit be implemented as soon as possible. It is recommended that the new unit work toward the following:

- Make preliminary evaluations concerning the effectiveness of completed aquifer recharge facilities using existing data.
- Provide recommendations to the MAF Planning Department concerning the overall direction of the aquifer recharge program.
- Establish and maintain relations with other public sector institutions to provide data exchange and to avoid duplication of efforts.
- Review and assess current monitoring networks and make improvements where necessary.
- Collect and interpret hydrological data from completed recharge facilities.
- Establish baseline hydrological conditions at proposed aquifer recharge sites.
- Develop technical training programs for Omani staff.

REFERENCES

REFERENCES

1. "Proposal for the Upgrade and Expansion of the Wadi Flow and Rainfall Gauging Network of Oman," by Wayne C. Curry, Head Surface Water Department, Public Authority for Water Resources; Report : PAWR, DFR 89-1; April 1989.

2. "Ground-Water Dams for Rural Water Supplies in Developing Countries," by Goran Hanson, Ph.D., Quaternary Geology, VIAK AB Consulting Engineers, Stockholm, Sweden, and Abe Nilsson, Research Engineer, Department of Land Improvement and Drainage, Royal Institute of Technology, Stockholm, Sweden; 1984.

APPENDIX A

Statement of Work

APPENDIX A

Statement of Work

Background

USAID is interested in assisting the Omani Ministry of Agriculture and Fisheries (MAF) in its institutional development for agricultural water resources planning, management and evaluation. They have requested assistance in establishing a hydrological monitoring and evaluation unit within the Department of Irrigation geared toward the Ministry's program of constructing aquifer recharge structures. They have also requested a senior technical water resources planner to work in the Ministry's Department of Planning.

Objective

The objective of this consultancy is to analyze the current capability of the Ministry to carry out its mandate for agricultural water resources planning, management and evaluation and to develop a plan to strengthen this capability both technically and managerially. The institutional strengthening plan needs to address internal program linkages within the MAF and on-going and planned activities related to or of a similar nature which are implemented by other Omani institutions.

Tasks

1. Review and assess the functional responsibility of the proposed hydrological monitoring and evaluation unit in relationship to the mandate of the Ministry of Agriculture and Fisheries for water resources and the on-going and planned programs of the ministry. The consultants will review relevant Royal Decrees and other pertinent documentation concerning the roles and responsibilities of public sector institutions involved in water resources development and management and will describe and assess the relationship of the MAF's program responsibilities for water resources development with the mandate and program responsibilities of other organizations such as the Public Authority for Water Resources, Ministry of Communications and the Ministry of the Environment.

2. Review and assess on-going programs and planned water resources development and construction programs of the Ministry of Agriculture and Fisheries. The team will review and assess the major on-going and planned water resources data collection and analysis activities (undertaken by MAF and other public authorities) as they impact on the proposed hydrological monitoring and evaluation unit and the responsibilities of the senior water resources planner in the MAF Planning Department. The consultants will assess and recommend manpower, equipment and 47 operating budget requirements for establishing the new hydrological monitoring and evaluation unit. The WASH team is expected to interview concerned officials in the Ministry of Agriculture and Fisheries, the Public Authority for Water Resources, Ministries of Communications and

Environment and undertake site visits within Oman as appropriate (Sohar, Nizwa and Salalah).

3. The consultants will recommend a phased plan of action for establishing the proposed hydrology monitoring and evaluation unit and linking the unit functionally to the MAF Planning Department. The proposed action plan should include, inter alia : an outline of the major types of information on water resources planning and development which need to be produced by the proposed hydrological monitoring unit; the proposed water resources data collection and analysis systems to be operated by the unit; equipment networks, configurations and specifications for the phased acquisition of such equipment needed by the unit; technical assistance and manpower development plans. Within the action plan, the consultants will prepare position descriptions, qualifications and required experience for key personnel to staff the unit and position in the Planning Department of the MAF. This will include both key management and technical staff of the host country or expatriate staff.

NB: In the preparation of the Action Plan, care must be taken to link planned activities and organizational capabilities of the hydrological monitoring and evaluation unit and senior planning staff within the MAF and to link MAF activities to and not duplicate similar functions and capabilities performed by PAWR. The consultants' final report is expected to show major organizational linkages for the collection and analysis of water resources data.

APPENDIX B

Schedule of Meetings and Field Visits

APPENDIX B

Schedule of Meetings and Field Visits

* 31 August 1989

1030	Arrival at Seeb International Airport
1200	Check into hotel
1400	Check location of Ministries

* 01 September 1989 Public Holiday

* 02 September 1989

0900-1100 Meeting with Ministry of Agriculture and Fisheries

List of Attendees

Name	Agency
Dr. Naim Abdul Rehman	Ministry of Agriculture and Fisheries
Zakaria Yahya Al-Riyami	Ministry of Agriculture and Fisheries
Paul Barriere	Ministry of Agriculture and Fisheries
Bernard Blasco	Hydrogeologist — DOD — Ministry of Agriculture and Fisheries
Saif Mubarak Al-Hanai	Geologist — Ministry of Agriculture and Fisheries
Hilal Malik Batashi	Ministry of Agriculture and Fisheries
I.K.Ali Khan	Ministry of Agriculture and Fisheries
Musa Al-Mazroui	Omani-American Joint Commission
Charles E. Fuller	Camp Dresser McKee — Water and Sanitation for Health Project
John Kent Kane III	Camp Dresser McKee — Water and Sanitation for Health Project

1115-1500 Review reports and documents provided by MAF pertaining to ground water recharge using low- height dams

* 03 September 1989

0730-1215	Discussions at Joint Commission Offices and review of reports and documents
1300-1445	Meeting with Wayne C. Curry, Chief, Surface Water Branch of Public Authority for Water Resources

* 04 September 1989 Field visit to Batinah Coastal Plain

0700-1000	Travel Ruwi to Sohar
1000-1115	Inspect Wadi Jizzi Dam
1130-1200	Visit Observation Wells near Wadi Jizzi Dam
1215-1300	Inspect Wadi Al Hilti and Wadi Salahi Dam

1400-1630 Travel Saham to Seeb
1630-1730 Inspect Wadi Al Khawd Dam
1730-1800 Inspect measuring flume
1800-1845 Return to Ruwi

* 05 September 1989 Field visit to Nizwa-Bahla area

0715-1000 Travel Ruwi to Nizwa
1000-1100 Visit Nizwa office of PAWR
1100-1200 Travel Nizwa to Tanuf
1200-1330 Inspect Tanuf Dam under construction
1400-1445 Travel Tanuf to Al Hamra
1445-1515 Inspect Wadi Ghul Dam nearing completion
1515-1615 Travel to Wadi Sayfam
1615-1645 Inspect Wadi Quryat Dam and spreading grounds
1645-1730 Travel to Bahla
1730-1745 Visit Wadi Bahla damsite
1745-1900 Return to Nizwa via Tanuf Overnight at Nizwa

* 06 September 1989 Field visit to Ibri area

0800-0930 Travel Nizwa to Tanuf
0945-1115 Travel Tanuf to Ibri
1115-1145 Visit Wadi Al Kabir
1200-1400 Travel Ibri to Nizwa
1445-1715 Travel Nizwa to Ruwi

* 07 September 1989 Work at hotel

1000-1400 Revisions to report outline and review of reports and documents

* 08 September 1989 Public Holiday

* 09 September 1989 Work at Joint Commission Offices

0730-1400 Review of reports and documents; begin report draft
1400-1530 Meet with Murl Baker — OAJC

* 10 September 1989 Work at Joint Commission Offices

0730-1200 Review of reports and documents; continue report draft
1300-1415 Meeting with John Kay @ PAWR
1420-1550 Meeting with Wayne Curry @ PAWR

* 11 September 1989 Work at Joint Commission Offices

0730-0800 Preparation for meeting
0830-1215 Meeting with Ministry of Agriculture and Fisheries

List of Attendees

Name	Representing
Majid Bilarab Al-Batashi	Ministry of Agriculture and Fisheries
Dr. Naim Abdul Rehman	Ministry of Agriculture and Fisheries
Bernard R. Blasco	Hydrogeologist — DOD- Ministry of Agriculture and Fisheries
Saleem-Uddin Ansari	Hydrogeologist — DOD — Ministry of Agriculture and Fisheries
Paul Barriere	Ministry of Agriculture and Fisheries
Saif Mubarak Al-Hanai	Geologist — Ministry of Agriculture and Fisheries
Hilal Malik Mohamed Batashi	Ministry of Agriculture and Fisheries
Musa Al-Mazroui	Omani-American Joint Commission
Charles E. Fuller	Camp Dresser McKee — Water and Sanitation for Health Project
John Kent Kane III	Camp Dresser McKee — Water and Sanitation for Health Project

1300-1600 Review of reports and documents; continue report draft

* 12 September 1989 Work at Joint Commission Offices

0730-1600 Review of reports and documents; continue report draft

* 13 September 1989 Work at Joint Commission Offices

0730-1430 Review of reports and documents; continue report draft
1430-1600 Present status report to OAJC staff- Meeting at OAJC

List of Attendees

Name	Organization
Duncan Miller	US Representative — OAJC
Murl Baker	Deputy US Representative — OAJC
Roger L. Russell	General Engineer — OAJC
Musa Al Mazroui	Project Officer — OAJC
Anjab Sajwani	Project Officer — OAJC
Charles E. Fuller	Camp Dresser McKee — Water and Sanitation for Health Project
John Kent Kane III	Camp Dresser McKee — Water and Sanitation for Health Project

* 14 September 1989 Work at hotel

1000-1400 Review of reports and documents; continue report draft.

* September 1989 Public Holiday

* 16 September 1989

0730-0845 Work at Joint Commission Offices
0910-0955 Meeting with Muhamid Redha, Director of Planning Unit, MAF
1015-1130 Meeting with Nasser Seif Al- Riyami, Director of Meteorology and Ahmed Hamoud Al-Harthy, Chief of Operation & Technical Services, MOC.
1200-1300 Meeting with Mr. Subramanium of MEW
1315-1440 Meeting with David G Lees and Paul Winston of MOE
1520-1600 Work at Joint Commission Offices

* 17 September 1989 Work at Joint Commission Offices

0730-1600 Review of reports and documents; continue report draft.

* 18 September 1989 Work at Joint Commission Offices

0730-1600 Review of reports and documents; continue report draft.

* 19 September 1989 Work at Joint Commission Offices

0730-0820 Work on report draft
0840-1010 Meeting at Sir M. MacDonald & Partners, Ltd. with Malcolm Ashworth and Andrew Keiller
1030-1230 Work on report draft at office
1315-1445 Meeting with David G. Lees at MOE; also meeting at MAF
1515-1600 Work on report draft at office

* 20 September 1989 Work at Joint Commission Offices

0730-1245 Work on report draft
1330-1430 Meeting with Majid Bilarab Al-Batashi at MAF
1500-1600 Work on report draft

* 21 September 1989 Work at Hotel
1000-1400 Work on report draft

* 22 September 1989 Public Holiday

0930-1230 Work on report draft
1430-1630

* 23 September 1989 Work at Joint Commission Offices

0730-1400 Work on report draft
1400-1520 Present status report to OAJC staff
1520-1600 Work on report draft

* 24 September 1989 Work at Joint Commission Offices

0730-1630 Work on report draft

* 25 September 1989 Work at Joint Commission Offices

0830-1120 Meeting with Ministry of Agriculture and Fisheries

List of Attendees

Name	Organization
Dr. N. Abdul Rahman	Ministry of Agriculture & Fisheries
Zakaria Yahya Al-Riyami	Act. Director of Dams Department
Majid Bilarab Al-Batashi	Ministry of Agriculture & Fisheries
Saif Mubarak Al-Hanai	Geologist — Ministry of Agriculture & Fisheries
Hilal Malik Al-Batashi	Ministry of Agriculture & Fisheries
Dr. Aly Afifi	Ministry of Agriculture & Fisheries
Bernard Blasco	Ministry of Agriculture & Fisheries
Paul Barriere	Ministry of Agriculture & Fisheries
Musa Al-Mazroui	Project Officer — OAJC
Charles E. Fuller	Camp Dresser McKee — Water and Sanitation for Health Project
John Kent Kane III	Camp Dresser McKee — Water and Sanitation for Health Project

1315-1630 Work on report draft

* 26 September 1989 Work at Joint Commission Offices

0730-1600 Work on report draft

* 27 September 1989 Work at Joint Commission Offices

Complete report draft

APPENDIX C

Prioritization of Proposed Recharge Schemes

PRIORITIZATION OF PROPOSED RECHARGE SCHEMES - Adapted from Feb.1985 Report by Hydroconsult Co. Ltd. (Table 7-11)

Villages to be benefited	Wadis to be utilized	Region	Prioritization		Remarks by CDM-WASH
			Marking out of 480	Ranking Order	
Al Khawd Sib	Samail	Batinah	450	1	In Service
Sallan-Majis Sohar	Jizi Suq Yanbu	Batinah	430	2A	Constructed
Bu Abali Barka-Rumays	Bani Kharus Maawil Taww	Batinah	430	2B	Out for Tenders
Sohar	Hilti Salahi	Batinah	420	3	In Service
Saham Muqay'if Dil Yal Burayk	Ahin Sakhin Sarami Shafan	Batinah	410	4	Feasibility Study
Shinas	Al Hatta Fayd	Batinah	360	5	Feasibility Study authorized
Bani Khalid Al Bu Qurayn	Mabrah	Batinah	340	6A	Feasibility Study authorized
Wadi Quryat	Sayfam	Interior	340	6B	In Service
Al Kamil Al Wafi	Bani Khalid (Al Batha)	Sharqiyah	320	7A	Feasibility Study underway
Al Musanaa	Far	Batinah	320	7B	
Husayfin Sur Bani Luzaymat	Rajmi Zabin Bid	Batinah	310	8A	
Al Liwa	Bani Umar Al Gharbi	Batinah	310	8B	
As Suwayq	Bani Ghafir	Batinah	310	8C	
Al Hamra	Ghul	Interior	310	8D	Constructed
Bilad As Sur	Fulayj	Quryat/Sur	310	8E	Feasibility Study authorized

TABLE C-1 PRIORITIZATION OF PROPOSED RECHARGE SCHEMES - Adapted from Feb.1985 Report by Hydroconsult Co. Ltd. (Table 7-12)

Villages to be benefited	Wadis to be utilized	Region	Prioritization		Remarks by CDM-WASH
			Marking out of 480	Ranking Order	
Al Khaburah	Hawasina Bani Umar	Batinah	300	9A	Feasibility Study authorized
Ibri-Araqi	Al Kabir	Interior	300	9B	Feasibility Study complete - 1989
Nizwa	Nizwa	Interior	300	9C	Feasibility Study complete - 1989
Bahla	Bahla	Interior	290	10A	Feasibility Study complete - 1989
Quryat	Dayqah Qatimah Mijlas	Quryat	290	10B	
Al Bu Rashid	Hajir	Batinah	290	10C	
Al Asra Bani Umar Nabr	Fizh	Batinah	280	11A	
Salalah	Jarsis Sahalnawt	Salalah	280	11B	Feasibility Study complete
Bu Baqarah	Al Qawr	Batinah	270	12A	
Wadi Quryat Lower Farms Jabrin	Sayfam Bahla	Interior	270	12B	
Tanuf	Tanuf	Interior	270	12C	Constructed
Dank	Dank	Interior	270	12D	
Rusayl Azaiba Al Amarat	Rusayl Lansab Aday	Batinah Capital Area	260	13	
Izki	Halfayn	Interior	250	14	
Ibra	Al Batha	Sharqiyah	240	15A	

TABLE C-1 PRIORITIZATION OF PROPOSED RECHARGE SCHEMES - Taken from Feb.1985 Report by Hydroconsult Co. Ltd. (Table 7-13)

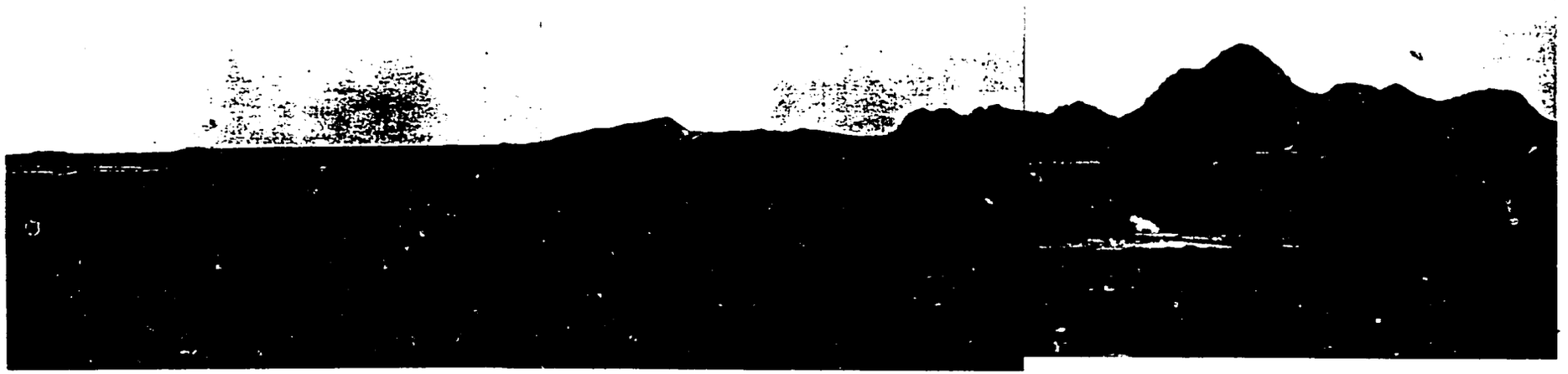
Villages to be benefited	Wadis to be utilized	Region	Prioritization		Remarks
			Marking out of 480	Ranking Order	
Buraymi	Zarub Maqdah	Interior	240	15B	
Dariz	Al Kabir	Interior	220	16A	
Mamurah	Arzat	Salalah	220	16B	
Karshah Mannah	Nizwa	Interior	110	17A	
Bisyah	Bahla	Interior	210	17B	
Rustaq	Far	Batinah Inland	210	17C	
Yangul	Rakah	Interior	200	18A	
Al Arid	Al Arid	Interior	200	18B	
Mudaybi	Mudaybi	Interior	200	18C	
Al Ghafat	Sayfam	Interior	190	19A	
Samad	Samad	Interior	190	19B	
Hayyal	Al Kabir	Interior	190	19C	
Maqabil	Hijr	Interior	190	19D	
Sulayf	Shibaminah	Interior	190	19E	
Luzuq	Ugq	Samail	190	19F	

TABLE C-1 PRIORITIZATION OF PROPOSED RECHARGE SCHEMES - Taken from Feb.1985 Report by Hydroconsult Co. Ltd. (Table 7-14)

Villages to be benefited	Wadis to be utilized	Region	Prioritization		Remarks
			Marking out of 480	Ranking Order	
Al Mintrib	Az Zahir (Al Batha)	Sharqiyah	190	19G	
Birkat al Mawz	Maydin	Interior	180	20A	
Muti Qarut	Halfayn	Interior	180	20B	
Said Wabal	Kuri	Samail	180	20C	
Hajir	Mayh	Quryat	180	20D	
Suq Qadim Shafa	Halfayn	Interior	170	21A	
Sanaw	Andam Samad	Interior	170	21B	
Al Ulya	Samad	Interior	170	21C	
Lizq	Samad	Interior	170	21D	
Adam	Bahla Sayfam	Interior	170	21E	
Mudayrib Gullay	Al Kabil (Al Batha)	Sharqiyah	170	21F	
Al Ayn Jinah	Rajim	Samail	170	21G	
Mughbariyah Rissah	Ruwahah	Samail	170	21H	

APPENDIX D

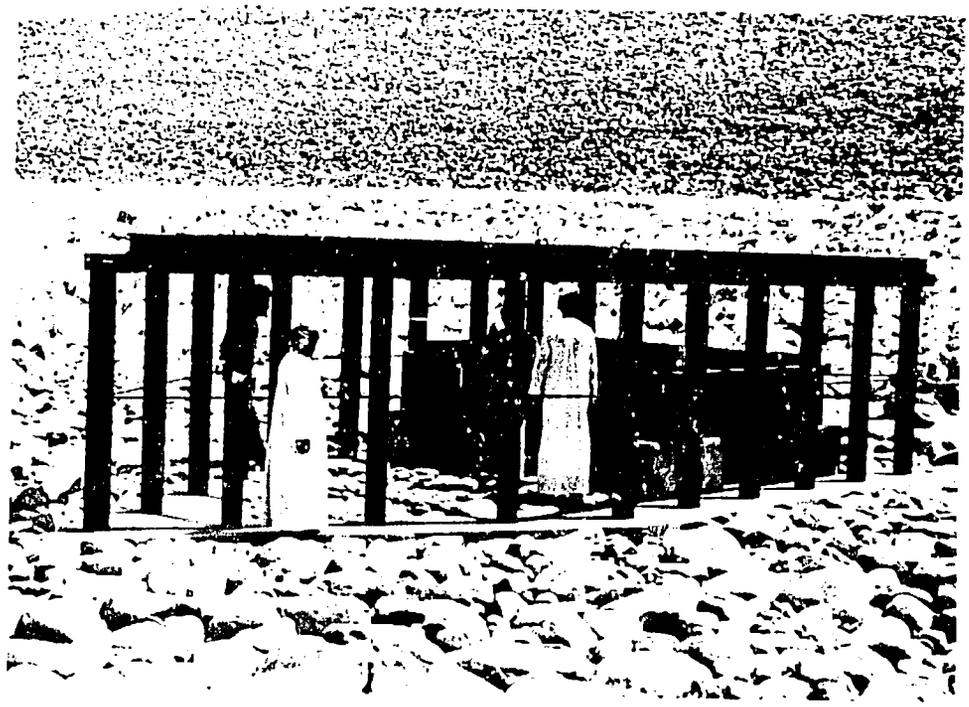
Photographs



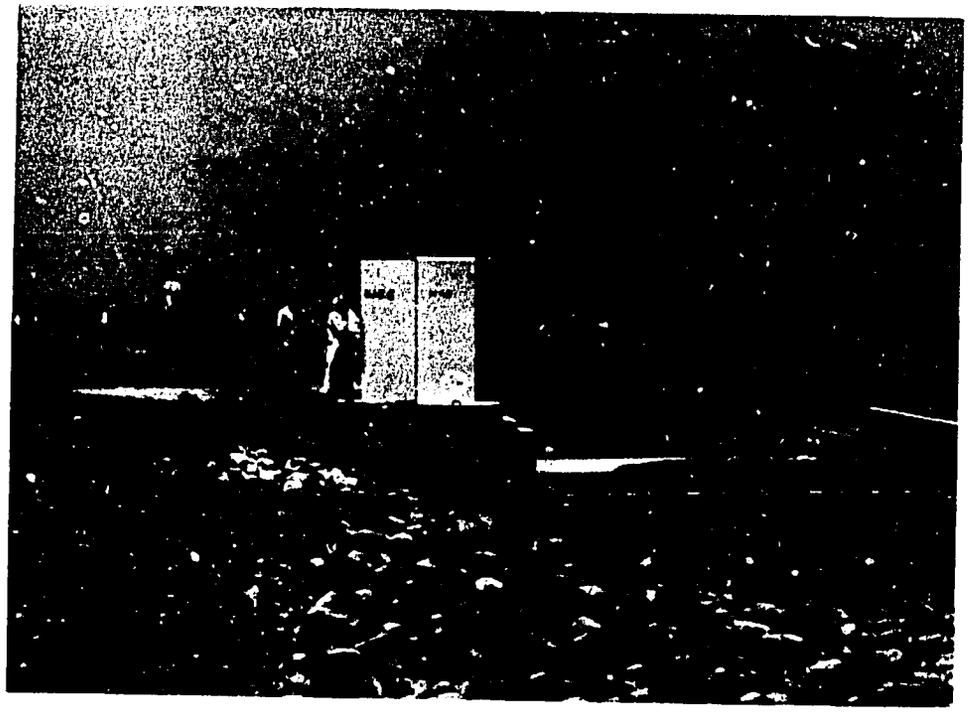
D-1 Jizzi Dam looking downstream with main spillway on right and auxiliary spillway on left.

D-2 Jizzi Dam looking downsteam from main spillway.

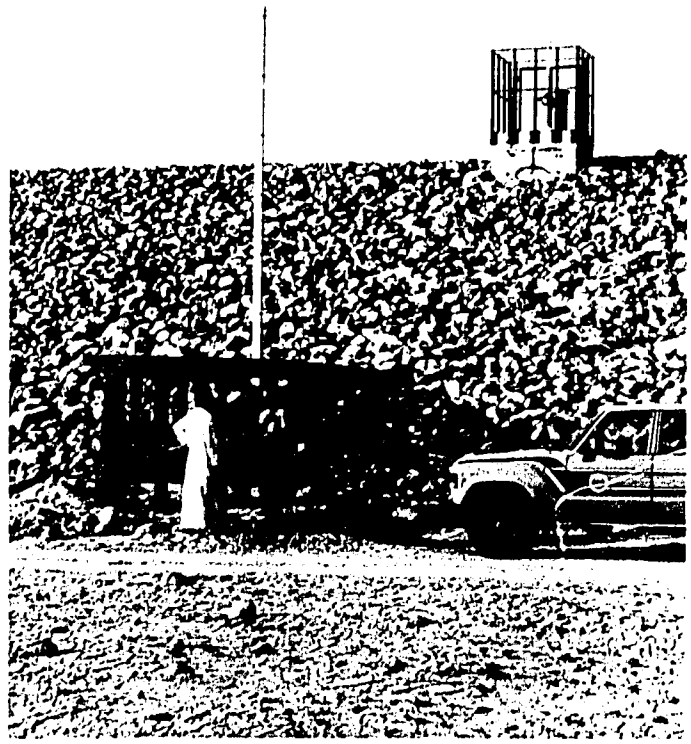
D-3 Jizzi Dam looking upstream at staff gauge and water level recorder.



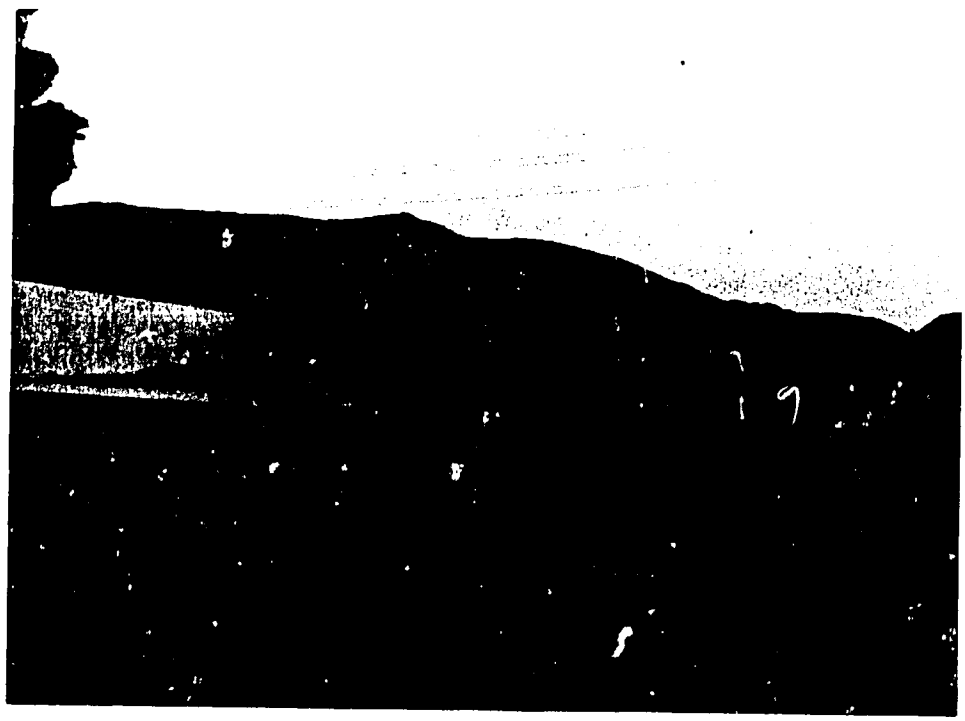
D-4 Jizzi Dam at entrance to 1500 mm steel conduit.



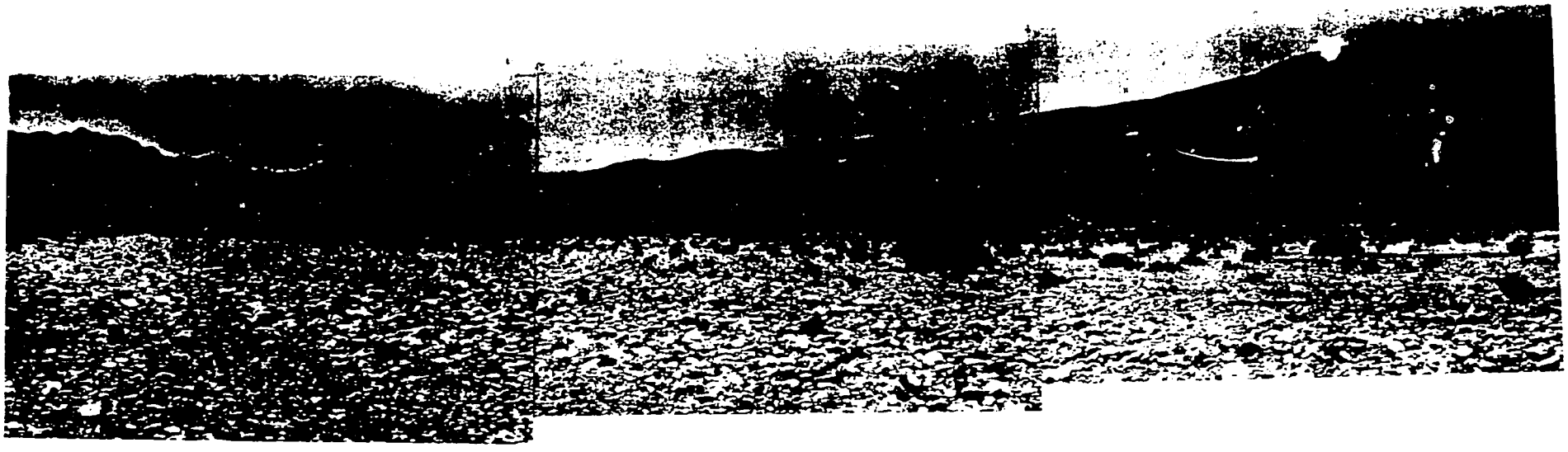
D-5 Measuring flume and water level recorder at spreading basin downstream of Hilti-Salahi.



D-6 Wadi Al Khawd at entrance to 1200 mm conduit with sluice gate control.

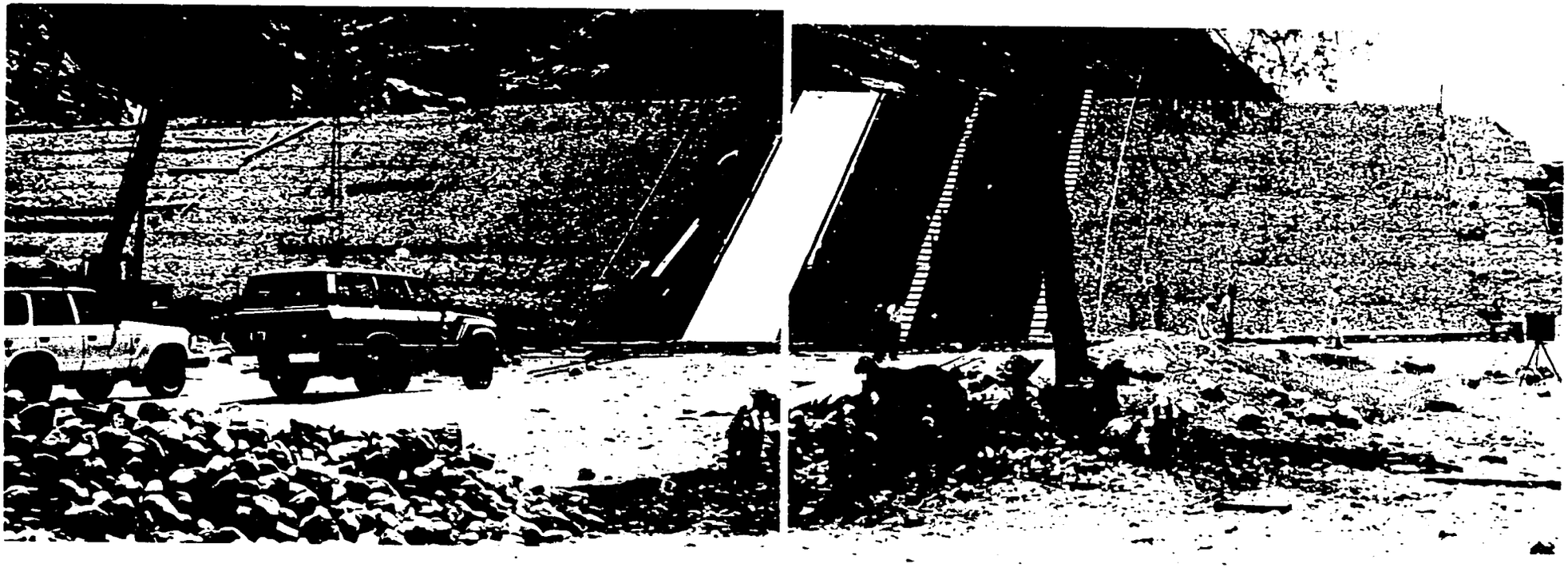


D-7 Measuring flume upstream of Wadi Al Khawd dam

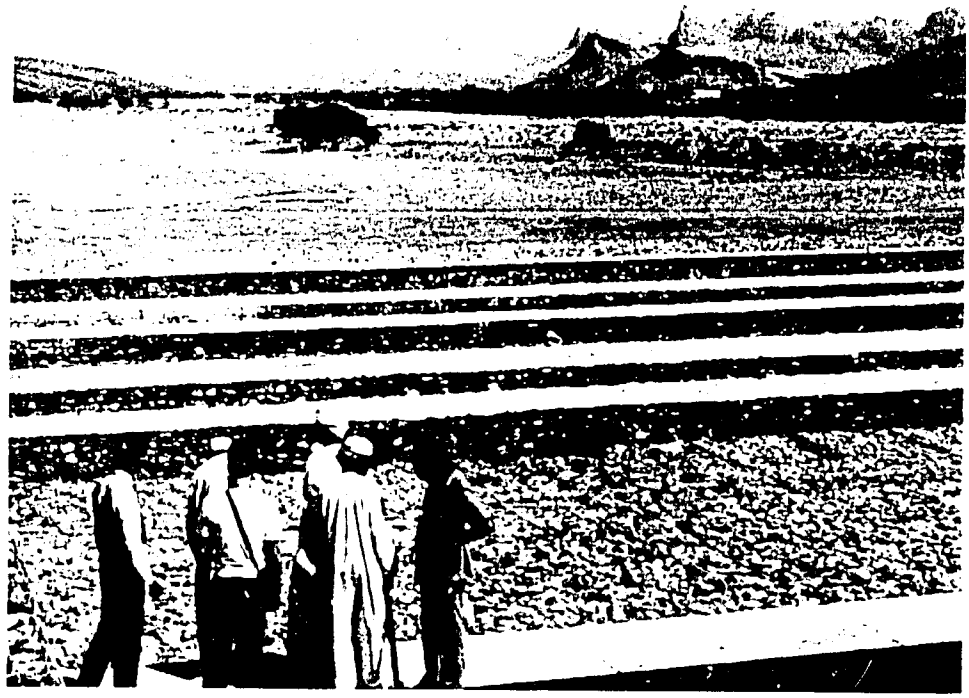


D-8 Proposed dam site on Wadi Al Abyad upstream of Nizwa.

D-9 & 10 Water level recorders at Wadi Tanuf dam.



D-11 Wadi Tanuf dam looking at upstream face.

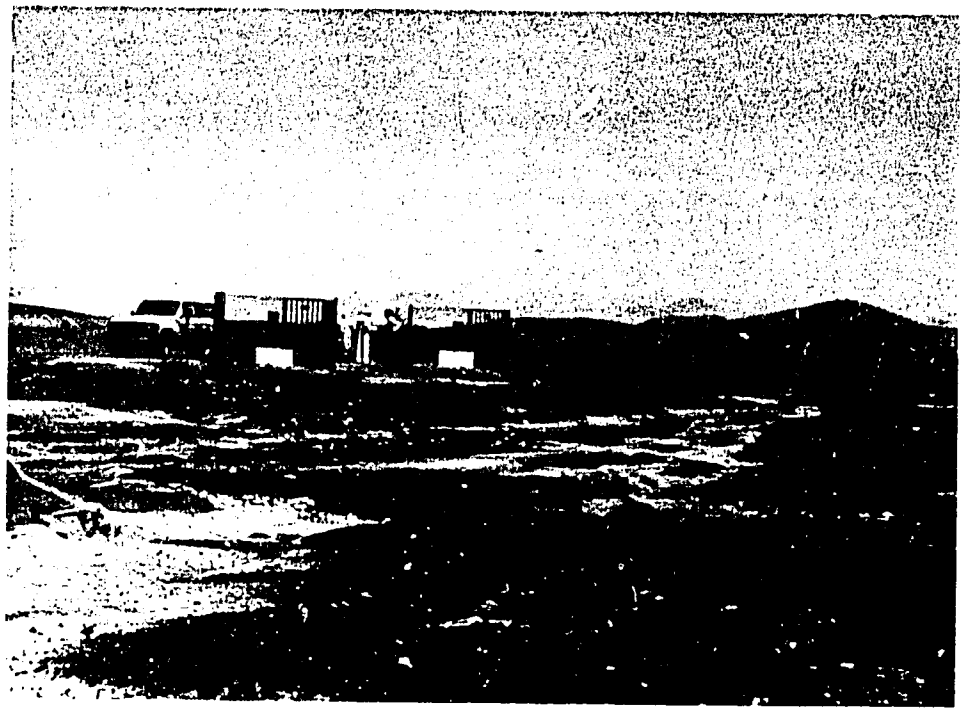


D-12 Wadi Ghul dam looking downstream over stepped spillway.

D-13 Wadi Ghul dam looking south across stepped spillway.

D-14 Wadi Quryat dam looking north to discharge culvert and water level recorder.

D-15 Wadi Quryat dam looking downstream at spreading basin and connecting channel.



D-16 Proposed dam site on Wadi Al Kabir at Ibri-Araqi.

APPENDIX E

Reports reviewed

APPENDIX E

Reports reviewed

1. Experimental Groundwater Recharge Schemes Reconnaissance Phase, Main Report by Hydroconsult Co. Ltd. April, 1982

2. Experimental Groundwater Recharge Schemes Design Phase, Volume I, Sohar Groundwater Recharge Schemes by Hydroconsult Co. Ltd. May, 1983

3. Experimental Groundwater Recharge Schemes Design Phase, Volume 2, Quriyat Groundwater Recharge Schemes Final Report by Hydroconsult Co. Ltd. May 1984

4. Wadi Al Khawd Aquifer Recharge Project – Feasibility Report, by Stanley Consultants Dec., 1981

5. Wadi Al Khawd Aquifer Recharge Project – Aquifer Test and Observation Wells Technical Specifications, by Stanley Consultants Oct., 1985

6. Wadi Al Khawd Aquifer Recharge Project – Final Report on Operation of Aquifer Recharge Project by Stanley Consultants May, 1987

7. Wadi Ghul and Wadi Tanuf Feasibility and Detailed Study Investigation Report & Maps by Hydroconsult Co. Ltd. March 1986

8. Wadi Ghul and Wadi Tanuf Specialized Engineering and Geotechnical Investigation, Final Report by Hydroconsult Co. Ltd. May, 1986

9. Wadi Ghul and Wadi Tanuf Feasibility and Detailed Design Study Draft Feasibility Report Ud.1 Wadi Tanuf Ud.2 Wadi Ghul by Hydroconsult Co. Ltd. July, 1986

10. Wadi Ghul and Wadi Tanuf Feasibility and Detailed Design Study, Final Feasibility Report
    Volume 2, Wadi Ghul Feb., 1987
    Volume 2, Wadi Ghul Annexure Oct., 1987

11. Wadi Ghul and Wadi Tanuf Feasibility and Detailed Design Study, Final Feasibility Report Volume 1 Wadi Tanuf Annexure by Hydroconsult Co. Ltd. Dec., 1987

12. Wadi Ghul and Wadi Tanuf Feasibility and Detailed Design Study, Final Detailed Design Report for Wadi Ghul
by Hydroconsult Co. Ltd. Dec., 1987

13. Catchment Water Conservation and Recharge Schemes for Irrigation-Reconnaissance Study — Ud.1- Main Report
by Hydroconsult Co. Ltd. Feb., 1985

14. Wadi Jizzi Agricultural Development Project — Feasibility Study
Main Report Japan International Cooperation Agency
Appendix I Jan., 1983
Appendix II

15. Groundwater Recharge Scheme for Nizwa/Bahla Areas — Feasibility Study Data Analysis Report — Volume 1 (Nizwa)
by W. S. Atkins April, 1989

16. Groundwater Recharge Scheme for Nizwa/Bahla Areas — Feasibility Study Data Analysis Report — Volume 2 (Bahla)
by W. S. Atkins April, 1989

17. Groundwater Recharge Scheme for Ibri/Araqi Area — Feasibility Study Engineering Assessment Report (Draft)
by W. S. Atkins Jan., 1989