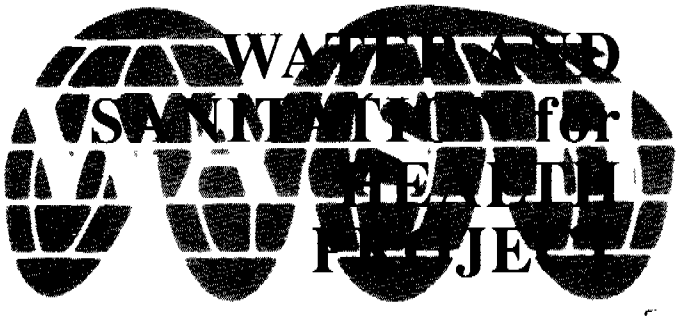
F I E L D R E P O R T

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

TASK 5: WATER MANAGEMENT
TASK 6: TECHNOLOGY DEVELOPMENT

SMALL BASIN MANAGEMENT
Part 6

WASH Field Report No. 353
December 1991



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WASH Field Report No. 353

Part 6

SMALL BASIN MANAGEMENT

Prepared for the Omani-American Joint Commission
under WASH Tasks Nos. 254 and 255

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ACRONYMS

ASR	aquifer storage and recovery
cm	centimeter
CSR	center sampling rotary
EC	electrical conductivity
FAO	United Nations Food and Agriculture Organization
GIS	geographic information system
GPS	ground positioning system
H.E.	His Excellency
H.H.	His Highness
H.M.	His Majesty
in	inch(es)
JICA	Japanese International Cooperation Agency
km	kilometer(s)
l	liter(s)
l/s	liters per second
L.S.	lump sum
m	meter(s)
m^2/d	square meters per day
m^3/d	cubic meters per day
m^3	cubic meters

MAF	Ministry of Agriculture and Fisheries
mcm	million cubic meters
mcm/yr	million cubic meters per year
MEW	Ministry of Electricity and Water
mm	millimeter
MM/WH	Mott MacDonald International, Limited in association with Watson Hawksley
MMP	Sir Mott MacDonald and Partners, Limited
MOC	Ministry of Communications
MOD	Ministry of Defense
MOH	Ministry of Housing
MOI	Ministry of Interior
MSS	multispectral scanner sensor
MWR	Ministry of Water Resources
NASA	National Aeronautics and Space Administration
NSA	National Survey Authority
OAJC	Omani-American Joint Commission for Economic and Technical Cooperation
pop	population
PAWR	Public Authority for Water Resources
PVC	polyvinyl chloride
R.O.	Omani Rials
SCTP	Supreme Committee for Town Planning
SFWMD	South Florida Water Management District

tm	trademark
TEM	transient electromagnetics
TM	thematic mapper sensor
TPM	team planning meeting
uS/cm	micro Siemens per centimeter
USAID	United States Agency for International Development
UTM	universal transverse mercator
WASH	Water and Sanitation for Health Project

EXECUTIVE SUMMARY

The Omani-American Joint Commission (OAJC) and the newly established Ministry of Water Resources (MWR) of the Sultanate of Oman have a common interest in the water resources of the nation. Early in 1990, OAJC requested the Water and Sanitation for Health Project (WASH) to assist the fledgling Ministry in:

- Strengthening all aspects of its operations
- Establishing a strong technical base
- Developing policy and procedures

The WASH team worked in Oman and in the United States from May through August 1991 to complete Tasks 5 and 6 of the scope of work and also work under Tasks 3 and 4 that was interrupted by the Gulf War.

Following Parts 1 and 2, which provide a general introduction and background, each of the six parts of the report on Tasks 5 and 6 covers a different area of study and contains a summary of conclusions and recommendations to which the reader can refer for a quick review.

MAJOR FINDINGS AND RECOMMENDATIONS

Part 3 ... Wadi Gauging Network Rationalization and Upgrade

More surface water gauging stations are needed in MWR's wadi gauging network to provide information on the process of groundwater recharge and the effectiveness of recharge enhancement schemes. But the expansion of the network should not delay the processing and publication of the large volume of data already in hand.

Surface water data collection is limited by various physical and practical constraints, and all users of these data would greatly benefit from an understanding of these limitations and of the methods employed by the Surface Water Department.

The department's effective relations with other agencies and private sector groups interested in surface water and floods should be cited as a model for other MWR departments.

Part 4 ... Salt Water Intrusion Monitoring and Remediation

MWR faces a serious problem of saline intrusion and upconing in the Batinah coast region. Past efforts at control have lacked a focus and a defined policy. Emphasis must now change from observation of the advancing intrusion to a detailed program designed to find a solution. This can begin with concentrated efforts to protect municipal and public water supply systems from upconing and lateral intrusion in areas where severe impacts and economic dislocations are expected.

MWR should set up a section to undertake this work urgently after reviewing and, if necessary, modifying the policy and goals recommended. Unless this is done, the saline intrusion program will continue to lack direction and purpose.

Part 5 ... Alternative Well Technologies for Use in Saline Groundwater Systems

The WASH team investigated several alternative well technologies to pump fresh water from saline aquifers. The separation of fresh water from saline groundwater is called skimming by some hydrologists. Of the methods investigated, three show the most promise in Oman:

- Conventional low-drawdown wellfields
- Scavenger wells
- Water collection galleries

Existing conventional wells with high drawdowns are prone to upconing and sea water intrusion, whereas low-drawdown wells can extract a similar amount of water without inducing salt upconing. MWR should enhance its capacity to advise others on the use of this technology.

Scavenger wells separate salt water and fresh water into two discharge streams. More work needs to be done to define their potential for specific sites in Oman.

Collection galleries may find some application in coastal areas to provide agricultural or potable water supplies. They must be operated with care and, to be most effective, should be pumped continuously at very low drawdowns.

MWR should work on these methods to provide a leadership role in their use. There are many opportunities for applying them as part of a broad regional water management strategy rather than to improve water quality in a few wells while the regional groundwater system deteriorates.

Part 6 ... Small Basin Management

The WASH team quickly discovered that the inhabitants of the upper basins and small catchments have a thorough understanding of the water resources that sustain them. Much of this knowledge has neither been recorded nor considered of any value in water resources management in these areas.

MWR should set up a Small Basins Reconnaissance Section to draw upon this knowledge in a collaborative plan for water resources development that would take the villagers' ideas into account.

Cultural, political, and human considerations are no less important than technical concerns in the planning and implementation of water related work. Although the guidelines provided relate to small basins, they can be profitably applied to many other MWR projects.

Part 7 ... Applications of Geophysics

There are several methods of geophysical exploration that could help MWR in its assessment work. However, many of these are expensive and, experience suggests, could lead to poor results unless they are properly utilized. Recommendations are offered on staff organization to develop the necessary skills and on appropriate training, equipment, and computer software.

The author of this part, Dr. Kendrick Taylor of the University of Nevada, is willing to sponsor one or more Omani students for graduate studies in the application of geophysics in Oman. The OAJC would finance these studies.

Part 8 ... Applications of Remote Sensing

Remote sensing has many useful applications but its products are expensive and MWR must be sure that they would advance its work. The range of available products, their costs, and their uses are dicussed. A pilot project to test the technology in defining water use along the Batinah coast and an incremental process that moves ahead as useful results are obtained are suggested.

Working Paper ... Discussion Paper for a Staff Orientation Document

The WASH team worked with almost the entire MWR staff from August 1990 to August 1991. Although it noted much progress in that short time, it also observed that many new staff members knew very little about Oman and its water resources and had poorly formed ideas about the nature of MWR's work. In spite of the fact that most policies and goals have been defined, the information has not yet filtered down to the rank and file of the organization. Given its rapid growth this is not surprising.

The discussion paper is an attempt to summarize important information that senior staff members should have as they begin their work. It reviews MWR's policies and approaches and explains what the Ministry is and why it was formed, what they should know about working in Oman, and how they can help the Ministry to reach the important goals ahead.

The paper is intended to fill an immediate need and should be followed by a similar document that is enlarged and refined as MWR gains knowledge and experience.

In Conclusion

To assist decision makers, the report on Tasks 5 and 6 provides the approximate capital and recurrent costs of the programs recommended. The earlier reports on Tasks 1 through 4 contain similar data.

OAJC and WASH hope that the information provided here will be useful to MWR in its important work in Oman. The OAJC staff and its managing director, H.E. Hamoud Halil al Habsi, are anxious to be of continuing support.

Chapter 1

INTRODUCTION

1.1 Background

Water is a scarce and precious commodity in the mountain communities of Oman, for whom the aflaj system is still the predominant source of supply. This system has maintained a delicate balance between availability and demand. But increasing population pressure and the widespread use of mechanical pumps have altered this balance in many areas and led to a realization that management of water resources was urgently required. In October 1989, the Ministry of Water Resources (MWR) was formed with a mandate to formulate policies and regulations for monitoring hydrologic systems, evaluating long-term sustainable supplies, and generally managing and preserving the nation's water resources.

Government policy recognizes the importance of maintaining rural aflaj villages and discouraging urbanization. About 4,000 aflaj are in use, many in the upper mountain basins where dug and drilled wells are not as prevalent as in the lowlands. The catchments of these aflaj range from 15-20 to several hundred square kilometers. The upper basin areas, those watersheds within the mountain zone, may contain several villages, each with at least one falaj. The integrity of these systems is central to the traditional rural culture of Oman.

The mountain communities could profit from three types of project assistance: artificial recharge, water storage, and conservation. Artificial recharge is the process of inducing recharge at specific locations during rainfall or a flood event by means of dams or basins or water spreading. Water storage is the capture of water for future use by dams, both surface and subsurface, and cisterns. Both artificial recharge and water storage increase the volume of water available locally. Conservation stresses economy in water use by introducing drip irrigation systems, crops with lower water requirements, and improved water management.

This report focuses on water needs in the upper mountain basins and how MWR should approach problems related to water management in these areas.

1.2 Scope of Work

The scope of work included:

- Visiting the Batinah and interior regions of northern Oman to become familiar with hydrologic, social, and political conditions

- Identifying appropriate small-scale water management and conservation interventions which, to the maximum extent possible, would involve local communities

- Assisting in the preparation of a program for water management interventions for small basins that would tie in with traditional water management systems.

1.3 Program Planning Criteria

The criteria for program planning stipulated that projects should:

- Consider national water resource priorities

- Address the needs of upper basin communities

- Focus on technically sound interventions of appropriate scale

- Be realistic and practical

The selection of projects should be governed by the following considerations:

- They should address the expressed needs of the beneficiaries

- They should concentrate on providing potable water supplies

- Their downstream effects should be minimal

- They should be on a scale small enough to invite community participation in planning

- They should stress water conservation and an awareness of its importance

This report outlines a course of action for MWR to establish links with mountain communities, collect information for an assessment of needs and resources, and foster water management in a manner acceptable to the communities and consistent with technical constraints and broader policies.

Chapter 2

SUMMARY OF CONCLUSIONS

MWR must be aware of the cultural, social, and political environment in which it proposes to intervene, without losing sight of its obligation to take national priorities and goals into account.

Field visits confirmed that the communities are well aware of the need for water management and are willing to discuss local conditions that affect their supplies. They have their own ideas about what would be beneficial, and although these may lack technical sophistication, they offer MWR a starting point for investigations.

The cultural, social, and political environment is the product of centuries of struggle to survive. Alternating periods of conflict and coexistence have marked this history, which can be disregarded only at the risk of inviting renewed resistance and condemning projects to failure. MWR's mandate to regulate the nation's water resources according to national priorities will only be strengthened by a sensitivity to local sentiments and concerns.

It is recommended that MWR set up a Small Basin Reconnaissance Section to:

- Bring issues such as resource limitations and conservation directly to local communities
- Obtain information about local hydrologic conditions from knowledgeable villagers
- Identify and evaluate potential water management interventions that have local interest and support

This will benefit both MWR and the local communities and make it a leader in addressing local needs within the context of national priorities.

Chapter 3

VISITS TO VILLAGES

Four major observations were made in the course of several visits to upper basin communities:

- These communities have developed water systems and water management practices that have become part of the culture and fabric of rural life.
- Each village has different physical, geological, and hydrological characteristics.
- Villagers are acutely aware of everything that affects their water supply.
- Water issues are deeply rooted in the cultural composition of village life, and disagreements can become contentious and highly politicized.

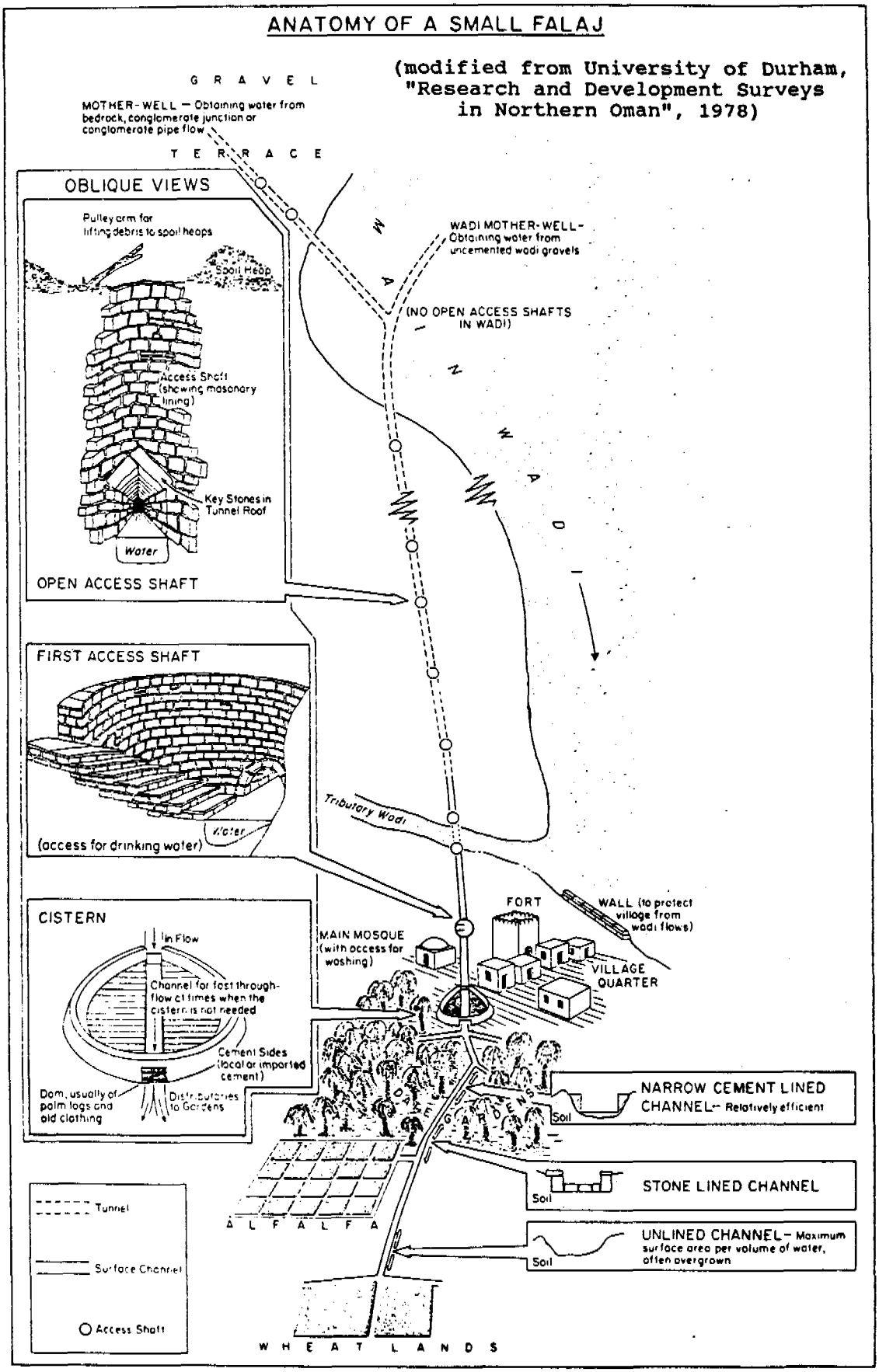
The interplay among these factors establishes both the limitations and opportunities for action in these areas.

3.1 Water Delivery in Rural Communities

Each village has its own falaj system, which captures, conveys, and delivers water for drinking, washing, and irrigation. A complex procedure developed over many centuries governs financing, maintenance, and management. There are three types of aflaj: *daudi*, *ghayl*, and *ayn*. A *daudi* falaj is a subterranean tunnel driven upstream at a gentler gradient than the land surface so as to intercept the water table (Figure 6-1). It is generally constructed to intersect the wadi alluvial gravels where they are relatively transmissive and the aquifer yields are highest. The headwaters of this type of falaj are referred to as the mother well, or *umm*. A *ghayl* falaj, most common in mountainous areas, draws on surface water flow in wadi channels. It is usually constructed as an open or cut-and-cover channel that may be several kilometers long. The flow is variable both seasonally and annually. An *ayn* falaj obtains water from seeps and springs issuing from bedrock and is a reliable, if small, source of supply in mountainous areas. (Wilkinson, 1977, presents a comprehensive discussion of the aflaj of Oman).

Many upper catchment villages with no wells or aflaj further up the wadi channel are served by *ayn* aflaj. Villages are usually built in a line along the wadis, whose alluvial aquifers supply

Figure 6-1


ANATOMY OF A SMALL FALAJ
(modified from University of Durham, "Research and Development Surveys in Northern Oman", 1978)
GRAVEL
MOTHER-WELL — Obtaining water from bedrock, conglomerate junction or conglomerate pipe flow
TERRACE
OBLIQUE VIEWS
Pulley arm for lifting debris to spoil heaps
Spoil Heap
Access Shaft (showing masonary lining)
Key Stones in Tunnel Roof
Water
OPEN ACCESS SHAFT
WADI MOTHER-WELL - Obtaining water from uncemented wadi gravels
(NO OPEN ACCESS SHAFTS IN WADI)
WADI
FIRST ACCESS SHAFT
Water
(access for drinking water)
Tributary Wadi
CISTERN
In Flow
Channel for fast through-flow at times when the cistern is not needed
Cement Sides (local or imported cement)
Dam, usually of palm logs and old clothing
Distributaries to Gardens
FORT
WALL (to protect village from wadi flows)
MAIN MOSQUE (with access for washing)
VILLAGE QUARTER
DATE GARDENS
NARROW CEMENT LINED CHANNEL — Relatively efficient
Soil
STONE LINED CHANNEL
Soil
UNLINED CHANNEL — Maximum surface area per volume of water, often overgrown
Soil
ALFALFA
Tunnel
Surface Channel
Access Shaft
WHEAT LANDS

most of the water. Villages farther down the wadi, in the central part of the catchment, are usually served by *ghayl* aflaj. At the lowest end of the catchment, as the wadi opens out onto the piedmont area, *daudi* aflaj are most common. Figure 6-2 shows how villages are located in an upper basin.

3.2 Water Management Practices

A community organization manages water use, maintains the primary channels, and is responsible for major repairs. Falaj water is considered community property when used for drinking, washing, and religious ablutions. It is often taken above the main irrigated gardens for these purposes (Figure 6-3). Once the falaj enters the main irrigated area, the primary channel splits to serve the whole village. A complex web of ownership and water use scheduling then comes into play. Since the flow of a falaj is continuous but not at a constant volume, water shares are apportioned on a prescribed cycle, traditionally based on the sun and stars but now generally on watches. The complexity of the system and the depth of understanding of water management are born of concern for equity. Time allocations have been worked out to take into account the location of gardens, the slopes of the falaj channels, the water lost in the channel, and variations in the length of the day and night.

Long-term minimum flows dictate the area that can be planted to tree crops. Any additional water is used for annual or seasonal crops. In areas with low flows, cisterns capture water for periodic release to ensure that water reaches the ends of the falaj channels. Determining how the falaj will be managed, whether to use cisterns, when to make releases, and how to guarantee everyone a fair share of water has been worked out over more than a thousand years.

The full scope of these management practices cannot be described in this report, but their complexity and importance are very clear. For example, a small settlement just above the village of Sayyah in the upper part of Wadi Dank has no other source of water for its palm gardens than a small falaj. Three cisterns are part of the system. Which one is used and how depends on several factors, including how strong the source is and which part of the garden is to be irrigated. Water from the lowest cistern had been released just before the field visit. Sluice gates were being hurriedly opened and closed up and down the channel to ensure that each tree got a share of the water, which was released twice a day. It was explained that the cisterns were used constantly, except for brief periods after the rains when the falaj flow was adequate. It was clear that water use was very carefully controlled and waste kept to an absolute minimum.

Misfah Al Shurayqiyin (Wadi Bani Kharus) is an example of communities in the upper wadi reaches that depend on seeps and springs above the village proper. Water runs down the upper portion of the *ayn* falaj channel at a steep angle of 45 degrees to a splash basin where a cistern captures the trickle. The water is then released quickly down irrigation channels.

Figure 6-2

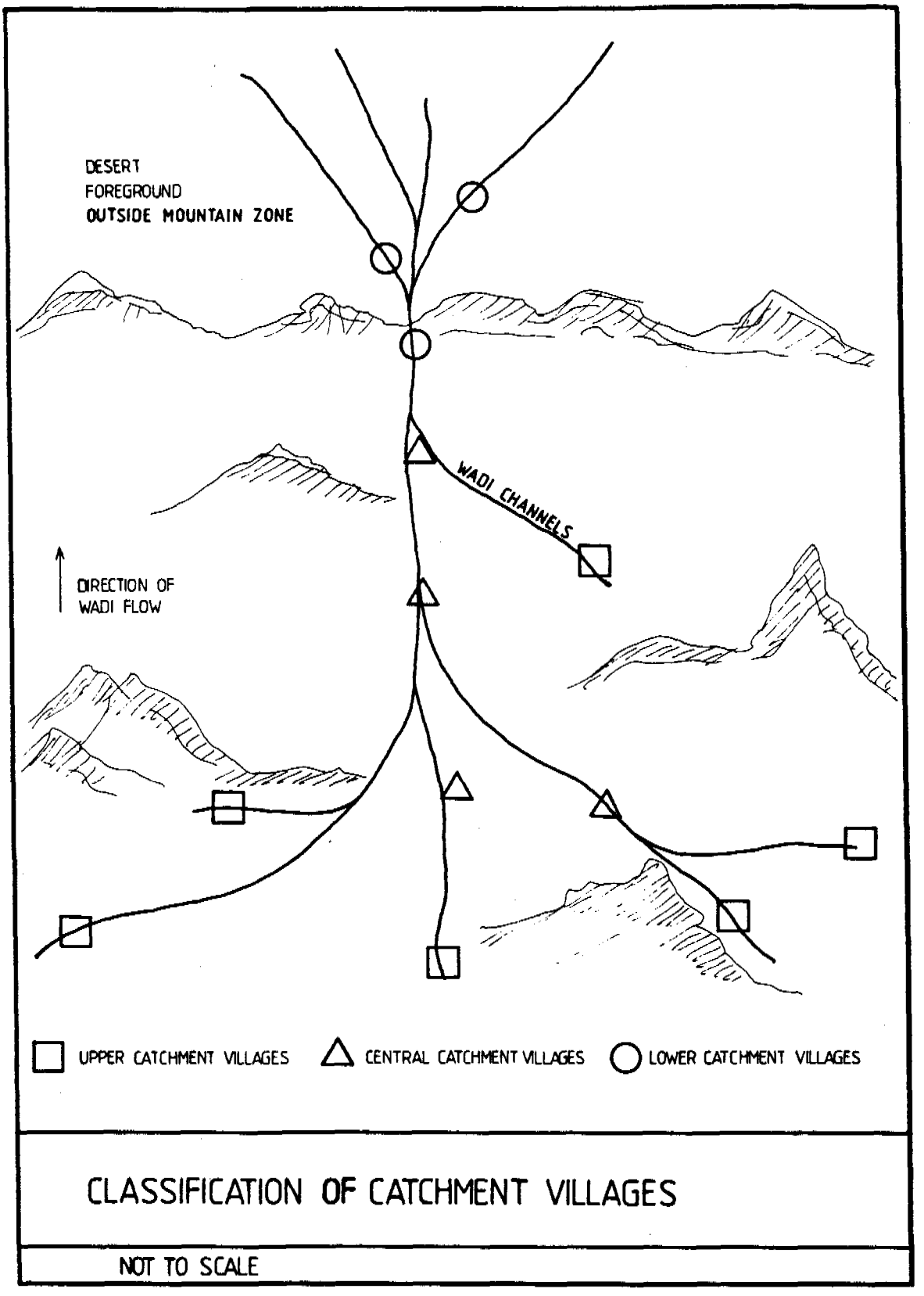
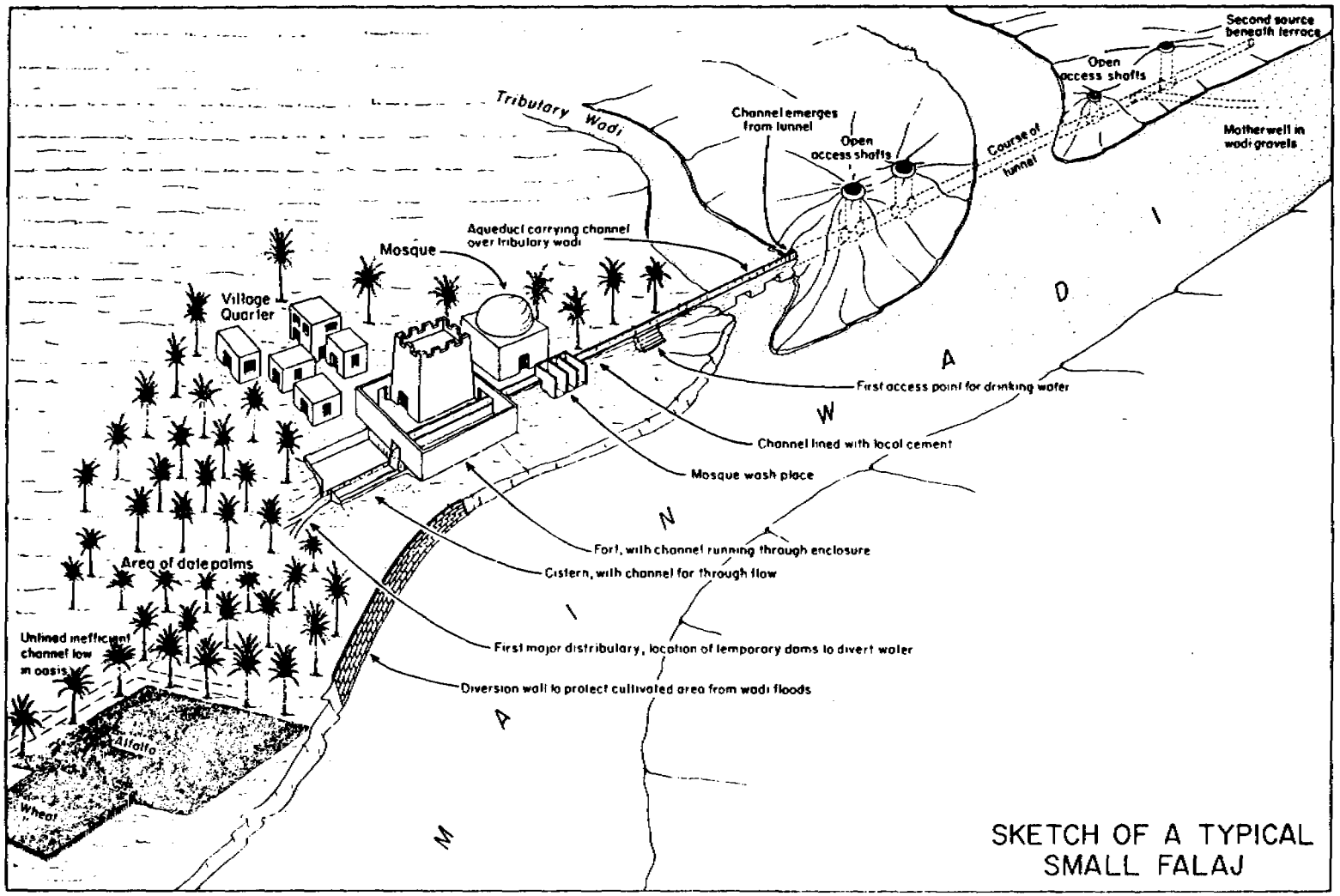

DESERT
FOREGROUND
OUTSIDE MOUNTAIN ZONE
WADI CHANNELS
DIRECTION OF
WADI FLOW
UPPER CATCHMENT VILLAGES
CENTRAL CATCHMENT VILLAGES
LOWER CATCHMENT VILLAGES
CLASSIFICATION OF CATCHMENT VILLAGES
NOT TO SCALE

Figure 6-3



(from University of Durham, "Research and Development Surveys in Northern Oman", 1978)

Shares of the flow from the cistern are measured by means of a marked stick placed on a rock at the bottom of the cistern. During the visit, water was being temporarily diverted around the cistern because the women were doing their washing.

These are two examples of water management practices developed over the years. Although there are dug wells in parts of the upper basin, the falaj is still the mainstay of water supply and the clearest illustration of community involvement.

3.3 Community Diversity

Since the alluvial aquifers of wadi channels are the main source of water, mountain villages tend to form a line along the wadi. But the characteristics of each village are defined by its location along the wadi and by the local geography, geology, and hydrology. The upper catchment villages capture water from seeps or springs (*ayn* aflaj) before it enters the alluvial gravels of the wadi bed, often depending entirely on falaj flow to meet their needs.

Farther down in the central part of the basins, *ghayl* aflaj generally collect and divert water from a zone where cemented alluvium has driven the wadi base flow to the surface. In these areas, villages may be close together or far apart, depending on the location of arable land and the amount of water available from the alluvial aquifer. In parts of Wadi Bani Khalid they are very close together, whereas in Wadi Ahin they are several kilometers apart. The geography of the mountain zone is also very variable, with wide open basins in some areas and narrow canyons in others. All that can be said reliably is that where there is a village, there will be at least one falaj.

Visits to two villages highlighted this variation. Mu'aydin is about 10 km above the point where Wadi Mu'aydin exits the mountains at Birkat Al Mauz. The wadi is about 200 m wide in a deep limestone canyon. A *ghayl* falaj originates several kilometers above the village in the Bani Habib tributary of Wadi Mu'aydin. The nearest major upstream village is at least 12 km away. Falaj flow is clearly greater than in the upper catchment, as might be expected from the larger watershed area above the village. Falaj repairs, which included construction of a tanker fill point, were in progress at the time of the visit. The falaj capture area is in a cemented alluvium section of the wadi above the village. There appeared to be little need for additional water, since gardens at the confluence of Wadi Mu'aydin and Wadi Bani Habib cannot be expanded without being subject to flood flows. In areas near the village, uncemented sands and gravels predominate to a depth of perhaps 20 m. Logs of nearby monitoring wells indicated an upper and lower aquifer. Local limestone formations are extensively faulted and dip strongly in the direction of wadi flow. If any recharge structure was built in this area (for the benefit of Birkat Al Mauz downstream from Mu'aydin), some of the water might be lost to deeper aquifers.

The village of Haybi is in Wadi Haybi, a tributary of Wadi Ahin, above a well-defined wadi channel on a wide terrace of loosely cemented alluvium underlain by crustal sequence ophiolite. A *daudi* falaj serves an extensive irrigated area, which could probably be expanded were water available. A number of dug wells provide additional water for irrigation. There are several villages within 4-5 km of Haybi both upstream and downstream. The crustal sequence ophiolite has low permeability and, in the area near Haybi, water resources are limited.

In addition to the general variability of upper basin watersheds, there are specific local features that could affect the types of interventions being considered. For example, at Sayyah, in Wadi Dank, a single falaj with two sources serves the irrigated gardens. One source issues from baseflow in the wadi gravels and the other from an exceptionally alkaline spring originating in mantle sequence ophiolites. The result is the dramatic appearance of carbonate precipitates at the point where these two flows mix within the falaj channel. Potable water is supplied to the village from a borehole in a different wadi.

These kinds of variations in village location, size, and physical, geologic, and hydrologic features make it difficult to prescribe a single intervention that would be widely effective. The idiosyncracies of communities will determine the technical and economic feasibility of each project.

3.4 Community Knowledge

Discussions with villagers and community leaders revealed their understanding of the concept of aquifer storage, the relationship between rainfall and falaj flow, and the general characteristics of baseflow recession. This knowledge is not scientific nor can they quantify variables exactly. But they can offer MWR valuable information for planning specific interventions and understanding the hydrology of particular regions.

The extent of local knowledge was dramatically demonstrated during a meeting with the wali and sheikhs of Wadi Bani Khalid, who described the hydrologic contact between two wadis at a place called Juffar. There they explained that when surface flows reach Juffar, the wadi to the east experiences increased flow and the spring at Aynsarooj benefits from higher flows at Muqal, several kilometers away. When asked what projects could be useful, they agreed that a surface storage dam on Wadi Sharq would protect downstream villages from damaging floods and benefit all downstream users by storing water for release during dry periods. They said the timing of these releases should be decided by MWR and the wali, in effect asking MWR to assist in water management. They also expressed interest in check dams for flood protection on Wadi Bani Khalid above Muqal. Wadi Bani Khalid has few water problems, and projects might better focus on areas with greater need. However, the interest they showed and the information and ideas they shared indicated a broad understanding of local conditions and a willingness to share this information with MWR.

The upper catchment villages in a wadi basin are often dependent on aflaj to meet all their water needs. Al Hajir, a community of approximately 200 inhabitants in Wadi Sahtan, is an example. At least one of the springs that feed its falaj can be seen as it issues from the limestone just above the falaj source within a section of the wadi alluvium that has accumulated behind a blockage in the channel. The villagers explained that the flow is constant but is stronger after rains, and that they must adjust water use to prevailing conditions. At the time of the visit, irrigation was on a nine-day cycle and some of the lower agricultural areas were fallow. When water is more plentiful, irrigation is on a four-day cycle and larger areas are cultivated. When asked what could be done to improve the falaj flow, the villagers showed they were clearly aware that the alluvium that has accumulated above the falaj provides water storage and that their falaj would go dry if any attempt were made to improve it. They explained that it had last rained six months ago and that the low flow of their falaj would likely decrease to half unless it rained again before next year.

In all the areas visited, villagers were willing to share their experiences and local knowledge. Some suggested possible interventions. Although projects cannot be based entirely on community suggestions, these can provide a starting point for beneficial discussion of the local situation.

3.5 Potential for Conflict

A knowledge of hydrologic conditions and their importance in local water use can also cause disagreements. Historically, before mechanically pumped wells became common, the falaj organization played a part in the resolution of disagreements over water issues not easily settled among villages and tribes. The proliferation of wells, which will affect aflaj sources, can be expected to increase tensions and require political or legal intervention. MWR has already become embroiled in some of these disputes. For example, Al Ghafat (in Wadi Kawr) is already supplementing its major falaj with water pumped from several dug wells in the village. The reconnaissance survey completed for MAF (Sir Mott MacDonald International Ltd. 1989) confirms that there is a water shortage in Al Ghafat. The village is now interested in extending its underground falaj (already about 6 km long). Well owners and the smaller villages of Al Ayshah and Al Ala (who belong to different tribes) in the area of the mother well oppose the extension. They believe that it will affect water availability in their wells. In fact, an earlier agreement between the villagers and the well owners called for abandonment of several wells in exchange for an agreement not to extend the falaj. The well owners now feel that this agreement may be abridged. When the wali of Bahla and the MWR district officer visited the site to mediate the dispute, emotions ran high. The dispute has not yet been resolved, but any settlement must be worked out within the context of the agreement among the parties involved. MAF is completing a design study for a small recharge dam in this area. But there is no indication that plans for this project recognize the tensions that prevail.

Conflicts have also arisen in the Wadi Haybi basin (in Wadi Ahin). The village of Hijjal is served by a *ghayl* falaj just above the village where a diversion dam sends water to aflaj on both banks of the wadi. Several villagers expressed concern to the MWR district officer about a well in one of the side wadis near the falaj channel. This concern may have been motivated by internal community conflict, as investigations revealed several other illegal wells nearby. Villagers contend that the illegal wells are necessary because the people of Haybi upstream also have illegal wells that affect their falaj supply. Haybi is situated several kilometers above Hijjal in an alluvial deposit at the confluence of three smaller wadis (Wadi Haybi, Wadi Qufsa, and Wadi Sham), and is served by a *daudi* falaj that draws upon both Wadi Haybi and Wadi Sham. When their illegal wells were questioned, the villagers of Haybi pointed the finger upstream to Aktam and Sham, which they claimed were just as guilty. Aktam and the villages below have never been on the best of terms.

These two examples show that equitable water management in these areas may be complicated by local agreements and disagreements rooted in tribal affiliations as well as by water resource issues.

Chapter 4

CURRENT UPPER BASIN MANAGEMENT PROGRAMS

Since Oman's renaissance and the coming to power of Sultan Qaboos, there has been an overwhelming change in rural life marked by the widespread introduction of engine driven pumps. In addition, a series of research and development projects undertaken by the Government have sought to provide services and opportunities to people in the mountain regions of northern Oman. Although many of these projects recognize that water is a limiting factor for development, few adequately address issues related to improving water availability within the context of national priorities.

4.1 Background

Historically, the aflaj system has provided water in the northern Oman mountains. The complexity of community structure, social life, land tenure, and water utilization in aflaj villages was documented by J.C. Wilkinson (Wilkinson 1977) in the early 1970s. More recently, extensive research on agriculture and water has been completed by the University of Durham (Wilkinson 1978). These reports provide a comprehensive introduction to the changes that have overtaken mountain communities and offer a socio-political backdrop to water use and the potential for action in the traditional setting.

A number of documents shed light on the hydrology and hydrogeology of the Oman mountains. These include a report on the geology (Glennie et al. 1974) in 1972 and on the hydrology (Stanger 1985) in 1983, and monographs on regional issues of hydrogeologic importance by PAWR and other consultants. Examples of these studies are groundwater resource surveys of the Saiq-Mahil formations, groundwater resource studies in Wadi Safwan, and drilling studies in northeast Sharqiyah. Together these provide an overall understanding of the mountain regions and a detailed understanding of specific areas.

One of the first comprehensive surveys of water resources and water use to identify the need for development was conducted for the Ministry of Communications in 1973-74 (Sir Alexander Gibb and Partners 1975). The current MAF aflaj and well repair and maintenance program is the result of this work, which was an important step in developing clearly defined programs for the upper basins.

Large-scale artificial recharge was initiated by the U.S. Corps of Engineers with a study of enhanced recharge for the capital area (Brown and Root Mid-East LLC 1984). This work eventually led to building the recharge dam at Wadi Al Khawd in 1985. Further investigations of groundwater recharge using the same recharge dam concept were laid out in a report delivered to the Ministry of Agriculture and Fisheries by Hydroconsult Co. Ltd in 1985

(Hydroconsult 1975). This report identified 56 appropriate locations for recharge dam sites and has provided the basis for much of the subsequent work in aquifer recharge. Eight dams are now complete and at least a dozen more are in some stage of feasibility, planning, or construction. This work has been done under the auspices of MAF.

4.2 National Involvement in Small Basin Management

The allocation of budgets for economic development is the responsibility of the Development Council, a national body that includes all the Ministers. It has outlined national priorities and approved projects in a series of five-year plans. The fourth plan runs from 1991 through 1995.

The Supreme Committee for Town Planning (SCTP) is a ministerial level committee served by a technical secretariat. It has responsibility for directing the physical development of the country. Various town and regional plans have been completed under its auspices.

All projects and activities undertaken at the ministerial level conform to the policies and plans approved by these organizations.

4.2.1 Ministry of Water Resources (MWR)

Current MWR activities that affect upper basin areas are well permitting, public awareness campaigns, the planned national well inventory, rainfall and aflaj monitoring, and regional water resource assessments. To date much of this work has been technical, focusing on resource assessment. The public awareness program and the well permitting program are first steps in informing the public about resource issues and encouraging a more active stance in water resource management. MWR has not yet initiated any artificial recharge, water storage, or conservation programs in upper basin areas.

The most visible MWR activity is the well permitting program, which seeks to limit extractions and conserve the water resource. Criteria for new wells and the deepening of existing wells have been laid out and as a result more than 80 percent of new well permit applications are being denied. In addition, violations are being brought to MWR attention and orders to backfill some wells have been issued. This has created considerable antagonism and generated more work for the staff in attending to the appeal process.

Less controversial activities are monitoring aflaj flows, flood events in wadis, and water levels at selected sites in the mountains and in the piedmont for a better understanding of the hydrology of northern Oman. The assessment of the Wadi Al Batha drainage basin is the first of several regional assessments planned for completion during the current five-year plan to provide a basis for comprehensive management of the resource.

As a relatively new organization, MWR is still engaged in building up staff levels and setting priorities. The Research Department, responsible for drainage basin evaluation and recharge, has not yet made any significant contributions. But the commissioning of the National Water Master Plan and work on the OAJC-assisted Water Resources Technical Assistance Program are evidence that MWR is forging ahead. It has no projects as yet directed exclusively to the upper basins, nor any ideas for village involvement in project planning and implementation.

4.2.2 Ministry of Agriculture and Fisheries (MAF)

MAF's Directorate of Irrigation has two programs that impact on water resources in mountain zones: the ongoing well and aflaj maintenance and repair program, and the design and construction of artificial recharge dams.

The aflaj repair and maintenance program has been in operation for more than 10 years and has had an annual budget of R.O. 1.5 million. It has reached many mountain villages, upgrading civil works associated with the main aflaj channels. There appears to have been little effort to introduce improved water use by lining secondary channels, improving water allocation, or introducing other crops. These changes may be difficult to make within the framework of existing aflaj management because of constraints of land ownership patterns and the way water shares are allocated.

The previously mentioned Hydroconsult report is the basis for the artificial recharge dam program. Six schemes have been completed, three are nearing completion, and 10 are in the feasibility stage. Most of these structures are beyond the mountain front and do not benefit upper basin communities. They are justified by anticipated increases in agricultural development and the fact that the water captured would otherwise have flowed to the sea or to the uninhabited interior. They have not necessarily taken into account community concerns or the potential impacts of water resource relocation.

Recent interest in the Jebel Akhdar region has resulted in an MAF-funded study of water resources for agricultural development. Recommendations include six small groundwater recharge dams and 64 small hydraulic structures, mainly detention dams, in the upper areas (Sir Mott MacDonald 1989). Feasibility studies for the recharge dams are nearly completed. The design calls for the capture of 10 percent of the 10-year flood and the storage of this water by the aquifer. There is no indication of the basis for this design or whether local villages were consulted about site selection. The six sites do not include any of the seven villages identified in the study as having an acute water shortage.

The feasibility study for the small hydraulic structures recognizes that interventions should not disrupt traditional ways of life, and that the knowledge, skills, and resourcefulness of these mountain people are a valuable resource. A sociological study of the impacts on agriculture, livestock, migration patterns, the role of women, and changing settlement patterns formed the basis for the selection of sites. This is a sensible approach to a complex problem.

4.2.3 Ministry of Electricity and Water (MEW)

The Ministry of Electricity and Water, which is responsible for supplying potable water to major towns and some rural villages, has four technical departments related to water: Water Projects (developing and implementing new water projects); Muscat Distribution (operation and maintenance of capital area water systems); Wilayat Distribution (operation and maintenance of systems in larger towns); and Wilayat Interior (dealing with rural towns and villages). In rural areas, water usually is delivered from a single borehole through a standpipe system or by private tankers under contract to MEW.

4.2.4 Ministry of Housing (MOH)

MOH recently has been given responsibility for drawing up a plan for development of the Jebel Akhdar area (Travers Morgan 1991). Land tenure and land use, local and transient labor, water resources availability and use, and ecological factors are among the topics covered. The plan expresses a need to consider enhancement of catchment yields while reconciling competing demands for water among communities in the Jebel area, the foothills, and the lowlands. It recommends building retention structures, improving the capture of rain water, and reducing water losses, but no detailed evaluation of the impact of these measures on the nation's water resources has been made as yet.

4.2.5 Ministry of Defense (MOD)

Ministry of Defense activities in the mountain zone are connected with the camp on the Saiq plateau at the head of Wadi Mu'aydin. MOD has taken responsibility for the water supply of the camp and of the surrounding villages that provide support services. Drilled wells and water delivery by tanker have already significantly altered the traditional lifestyle of the Saiq plateau communities.

4.3 The Role of Regional Institutions in Upper Basins

The Ministry of Interior (MOI) has overall responsibility for the wilayats and the walis (district officers) serve as its employees. They are the link between local communities and the central government and are normally posted away from their home villages to minimize political considerations in their handling of local affairs. Each of MWR's eight district offices (five more are planned) is responsible for activities in a number of wilayats. Regional office work mainly is administering the well permitting program and attending to the appeals and violations incident to it, and monitoring aflaj and water levels. Contact with the local communities and the walis for the most part is limited to work associated with the well permitting process.

4.4 Community Organization

The local institutional structure is strictly traditional. The sheikh, who is a respected elder of the village, speaks for the community. Although individuals may have occasion to approach government agencies, as in the case of well permit applications, most formal contact on village affairs takes place between the sheikhs and the wali. Villages within a geographical area are linked by family and tribal background. These affiliations still influence much of rural life.

Chapter 5

PROSPECTS AND PROBLEMS IN SMALL BASIN MANAGEMENT

Several ministries and agencies have active programs to improve the lives of upper basin communities. Some are well conceived, others lack the depth of thought necessary to fashion workable long-term solutions. MWR has the technical capacity to provide valuable guidance on water resource issues and should be a leader in addressing local needs within the context of national priorities. Augmentation of small basin water supply by artificial recharge, water storage techniques, or improved water use and conservation requires careful water resource management. The need for intervention, the impact of the intervention on beneficiaries and downstream populations, the economic and equity issues at stake, and the technical viability of the intervention are all important considerations.

5.1 Potential for Intervention

There are a number of interventions that could help meet local needs (Bienchi and Muckel 1970, Luxton et al. 1991), depending on village location in the basin, the size of the community, and geologic and hydrologic conditions.

Water use in upper catchment areas has been balanced with availability by practices developed over many centuries. This factor, together with the constraints of variable hydrogeologic conditions and the cost of extensive evaluation of projects often not even wanted or needed, militates against work in these areas. Ideas for conservation are likely to be well received where the water supply is limited, but suggestions affecting falaj management will probably be less welcome.

In the central catchments, opportunities for worthwhile intervention are more promising. Even though alluvial storage is limited, projects could have a significant impact on the local water supply, which often is more erratic than in the upper catchments and would benefit from artificial recharge or subsurface storage. However, the scale of such projects would be larger because of the need to control flood flows. Feasibility would have to consider the costs to downstream users as well as the benefits to the communities directly affected. As in the upper catchment areas, conservation initiatives may also be beneficial.

5.2 Sociopolitical Considerations

Water is a critical element in Omani life, and people understand that any activity in an upstream area is likely to affect their water supply. Increased extraction from wells nearby or in areas above the falaj causes concern. When upstream recharge or storage projects are

planned, downstream communities know without doubt who will and will not benefit. Any intervention will have to withstand the scrutiny of a number of interested parties. The challenge is convince them that their needs can be met within the context of the wadi system, its hydrogeologic limitations, and the concerns of those who will jealously guard their right to water.

5.3 Institutional Considerations

MWR is not yet ready to implement water management programs, believing that the assessment of water resources must precede any action to alleviate such problems as aquifer overdraft and saline intrusion. There are no clearly defined criteria for action nor mechanisms for addressing the social, political, and technical complications that could arise.

The district offices, which have the most contact with regional and local institutions, are heavily involved in a well permitting process. They are newly established and staff members have limited experience with the technical aspects of water resource assessment and management. Nevertheless they will be an important component of any MWR program in the upper basins, providing an important link between the Ministry and the communities involved.

Aflaj are the predominant source of irrigation supplies in the mountains, but wells also provide irrigation and potable water. The management of water serving multiple needs requires the close collaboration of the ministries and agencies involved, particularly MAF and MEW. The current impasse between MWR and MAF must be resolved before effective conservation, storage, and recharge programs for the upper basins can be developed.

Chapter 6

A PLAN FOR MWR INVOLVEMENT

6.1 Introduction

MWR was established less than two years ago and is still growing. Water management programs are still in their infancy, but it is not too early to prepare for the planned program in the upper basins. The most important first step is to recognize that upper basin communities are clearly interested in water-related issues and can offer information in project planning. A phased program for the establishment of a Small Basin Reconnaissance Section within the Ministry is recommended.

6.2 The Basis of the Plan

MWR is divided into the Directorates of Water Resource Assessment, Water Resource Management, Regional Affairs, Training, and Administration/Finance. It has no experience in artificial recharge enhancement, water conservation, or water storage. Although it may have the technical ability to evaluate and initiate small-scale projects, it has made no effort to develop the capability to address the sociopolitical concerns that will inevitably arise. Its focus is on resource assessment, with the eventual goal of broad-scale management of Oman's water resources. Since it does not believe it is ready to take responsibility for water management—and any intervention that alters hydrologic conditions implies management with specific criteria and goals—it is not reasonable to expect it to introduce these interventions at present.

However, its large well permitting program should lay the groundwork for control of extractions and eventually lead to more active water management. Although the Department of Public Awareness has an action plan for informing the public about the scarcity of water and the need for conservation, this message has yet to be delivered convincingly.

MWR is expanding its program to measure rainfall, gauge floods, and calculate aflaj flows. However, much important information has never been recorded. Older residents in upper basin villages, which depend on the rains and floods and the way the water flows in the region, can supply some of this valuable information.

6.2 The Proposed Plan

A Small Basin Reconnaissance Section should be established to:

- Bring water resource issues directly to the people
- Obtain hydrologic, water use, and hydrogeologic information to supplement quantitative data now being collected
- Identify and evaluate potential water management interventions that have local interest and support

The MWR role in the water sector, the water resource issues that face Oman now and in the future, and the role of all citizens in using the resource wisely must be stressed. Problems cannot be solved by MWR alone. The well permitting process provides the opportunity to explain the need for limiting extractions and the contribution the villagers in these communities can make in meeting both local and national objectives.

One such contribution is to share information on local hydrology and hydrogeology with MWR. Many older residents have a vast storehouse of knowledge on these issues that could be a valuable addition to the quantitative data now being collected.

Villagers often know clearly what would benefit them. Their ideas and their approval should be sought in planning any intervention intended to meet local needs. But they should be made to understand that the intervention must be technically feasible and consistent with regional and national water planning goals. Although MWR has the regulatory authority to enforce water management, the cooperation of communities in creating a consensus before any project is undertaken will greatly enhance the probability of its success.

The Small Basin Reconnaissance Section will help direct investigations to areas of need, assemble important information on local conditions, and build a cooperative environment for future work, so that when artificial recharge, water storage, and conservation projects begin in earnest, MWR will be prepared to lead the way.

Chapter 7

IMPLEMENTATION OF THE PLAN

The Small Basin Reconnaissance Section will supply information to the district offices and the Research, Groundwater, and Surface Water Departments and assemble a list of projects acceptable to upper basin communities. Its function must be established by clearly defined guidelines. This could be complicated by the fact that its activities will be multi-dimensional, taking on aspects of public awareness, resource assessment, and eventually, water management. Its logical place is in the Research Department of the Water Resources Assessment Directorate. It should be linked to the Drainage Basin and Recharge Sections of the Research Department and the Public Awareness and Drainage Basin Management Departments of the Directorate of Water Resource Management. Later, as its work focuses on intervention, it could be moved to a program implementation department. Given the importance of rural linkages, the district offices must be involved at all levels of village interaction.

7.1 Activities of the Small Basin Reconnaissance Section

The proposed activities of the Small Basin Reconnaissance Section can be divided into three areas: field surveys, technical evaluations, and management.

7.1.1 Field Surveys

Field surveys will be the key to the success of the Small Basin Reconnaissance Section. Survey teams should be technically capable but also sensitive to rural customs and traditions. They should be able to explain MWR's role in water resource assessment and management and ask how MWR can help, without making promises that MWR cannot fulfill. They should also be able to elicit information on local hydrologic and geologic conditions, much of which can come from casual remarks followed up in greater detail.

Initial contacts for a field survey should be made through the district office and the wali's office. This approach may be time consuming but it formalizes the process and keeps all concerned parties informed. It was most successful in arranging field visits. Explaining the purpose of the survey to the wali will help him to set up meetings with village leaders to discuss regional problems, the solutions they have in mind, and the team's suggestions for potential interventions (diversion channels, subsurface dams, etc.). These meetings should be followed by visits to specific villages where more focused discussions can be held with village leaders and particularly the older members of the community. By raising questions about the local situation, the team should be able to discern the level of agreement or uncertainty

prevailing. This question period should be followed by informal exchanges that may uncover pearls of local wisdom.

Follow-up with villagers is important and may involve explaining that further evaluation will be made or that the interventions they have proposed are not feasible. It is important that something of benefit be transmitted to villagers. At a minimum, this should include recommendations on water conservation practices and how to protect the quality of water sources.

7.1.2 Technical Evaluations

Technical evaluations will examine the artificial recharge/water storage options identified during the survey in the context of national water management objectives and the needs of the local communities. The first step should be a feasibility study encompassing village needs, a project to meet them, and a cost estimate. The technical evaluation staff should be creative in suggesting alternatives or modifications if necessary.

The second step is an assessment of the impact of a proposed project on water for human and animal consumption, agricultural development (maintaining agricultural production versus expanding it), employment opportunities, and the cultural life of the community. The impact on downstream users must also be considered.

7.1.3 Management

Management covers the organization of the work of the field teams and the technical evaluation group. It will require identification of areas of interest to MWR and setting schedules for the field staff, and should be completed in collaboration with the departments that will benefit from the information collected. These departments should also be consulted in the preparation of the survey, which might include questions on the number of rain events in previous years, the number of flood events, the magnitude and duration of large floods recalled from memory, the maximum or minimum extent of land previously irrigated, and the date of introduction of mechanical pumps. Upon completion of the survey, the manager must debrief the team, evaluate the results, plan any follow-up work, and compile relevant information for future MWR use.

The manager of the technical evaluation unit will steer the unit to interventions with the most promise. In collaboration with other MWR officials, he must determine which interventions merit further assessment and which should be selected for implementation.

7.2 Schedule

The Small Basin Reconnaissance Section should be established in phases over a three-year period. The first year of the project will focus on setting up procedures and initiating the reconnaissance surveys. Project objectives and the approaches taken to reach them should be evaluated at the end of this phase. The second year will see an orderly expansion of the first year's activities. By the end of the third year, the survey section should be in a position to respond to MWR's diverse needs in interacting at the community level. A suggested time line for the first year's activities is shown in Figure 6-4.

7.3 Project Requirements

7.3.1 Staff

MWR, through the well permitting program, is just beginning to gain experience in working at the community level. The staff it hires for the new section must understand the value of information supplied by local people and how it can assist MWR not only in a technical sense but also in promoting project objectives.

Staff will be needed for the three major groups: management, field survey/assessment, and technical evaluation.

Management

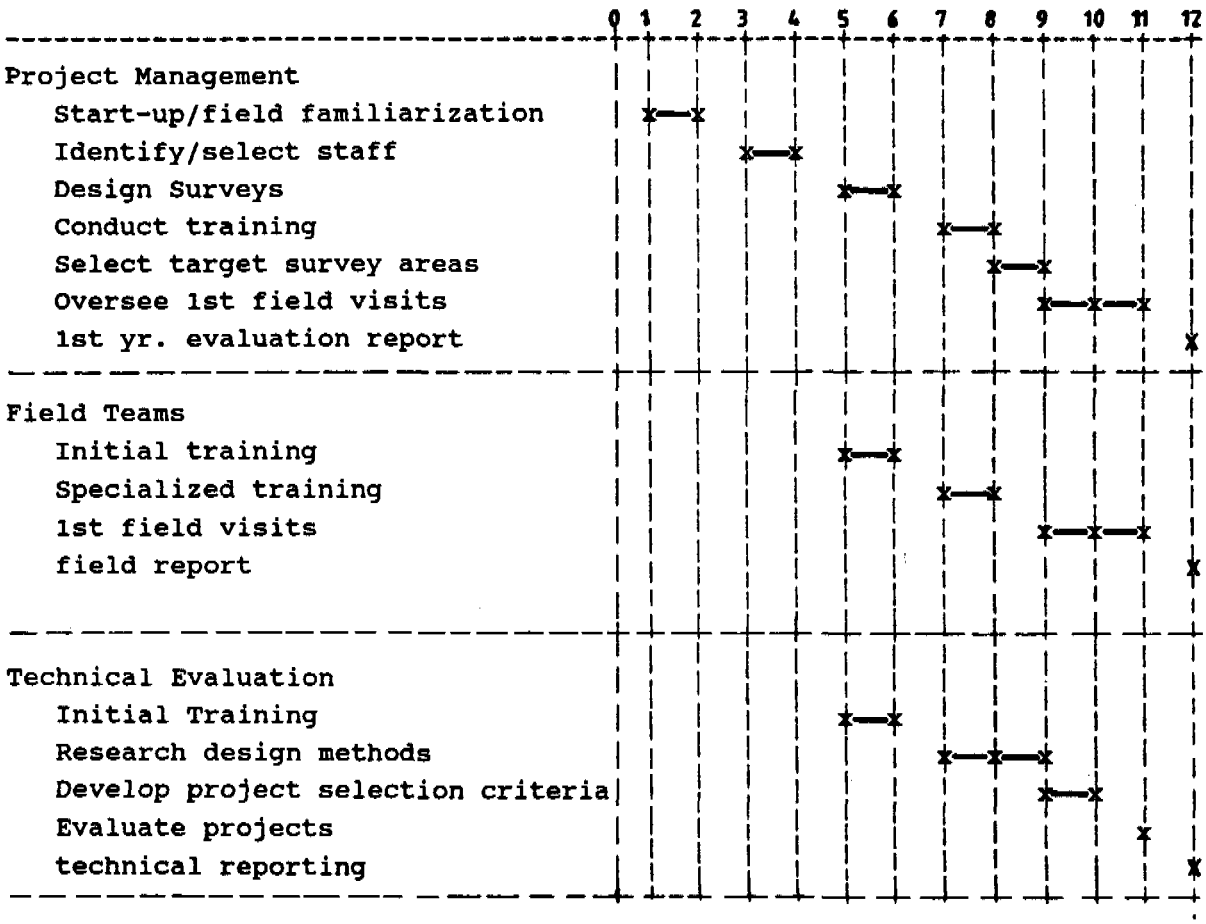
The key tasks of this group will be:

- Drawing up an initial list of study areas with officials of other ministries
- Finalizing this list and assigning priorities
- Designing surveys in collaboration with other MWR departments
- Overseeing staff training
- Compiling survey results in a suitable format

The staff will consist of two people. The section manager should be an Arabic-speaking water resources engineer with a keen sensitivity to the needs of rural communities. His assistant should be an Omani hydrologist familiar with the hydrology of the mountain zone.

Figure 6-4

First Year Schedule
for the establishment of the
Small Basin Reconnaissance Section



Field Survey/Assessment

The survey teams will be responsible for:

- Meeting with walis, sheikhs, and community leaders
- Discussing MWR's role in water resource assessment and management
- Collecting useful information on local hydrogeologic conditions
- Eliciting villagers' suggestions on local water projects and identifying sociocultural factors that could influence their success
- Collecting information on water use and need and on the suggested projects
- Informing district office personnel of all visits and the results of these visits

A field survey/assessment team will consist of three people, preferably all Omani: a water resources engineer, a hydrologist, and a public awareness expert. The engineer should be familiar with small-scale water management and be able to discuss nontechnical issues relating to water resources in rural areas. The hydrologist should have a good grasp of Oman's hydrology and be sensitive to the importance of local knowledge, even when it is not fully quantifiable. The public awareness specialist should be familiar with MWR programs and priorities and their effect on communities in the upper basins, and also with the possible technical interventions in these areas. Leadership of the team will depend on the experience of the team members.

Initially only one team will be required; two will be added later.

Technical Evaluation

The technical evaluation group will be responsible for:

- Developing an exhaustive list of small-scale artificial recharge and storage options along with their advantages, disadvantages, and unit costs
- Evaluating the technical feasibility of interventions proposed by villagers and suggesting alternatives as appropriate

- Developing proposals for detailed investigations of selected interventions

- Conducting impact assessments of these interventions in the context of management of water resources for the national benefit

The group will be composed of two engineers and a draftsman. The senior engineer should have experience in the design and impact of small hydraulic structures. The junior engineer should have a background in water resources engineering. This group could eventually become part of a different section as work grows in importance for other MWR activities. Initially, however, it should be part of the Small Basin Reconnaissance Section.

7.3.2 Equipment

The section will need office space, furniture, filing space, computers, and photocopy facilities. It will also need several four-wheel-drive vehicles, one for the management group and one for each field team. Funds for the operation, maintenance, and repair of these vehicles must be included in the budget.

Miscellaneous equipment for the field team will include, but not necessarily be limited to, tape measures, binoculars, cameras, and sighting levels.

7.4 Cost

As outlined in Table 6-1, the five-year cost for the proposed project is R.O. 880,000. This allows for the orderly introduction of staff and vehicles during the phased program. The initial year's costs are roughly R.O. 120,000, rising to just over R.O. 202,000 in the third year when the section is fully staffed.

Table 6-1

Cost Estimate for Small Basin Reconnaissance Section

	Unit Cost	Year 1	Year 2	Year 3	Year 4	Year 5
Personnel						
Management						
Project Manager	35000	35000	35000	35000	35000	35000
Counterpart Manager	15000	15000	15000	15000	15000	15000
Technical Staff						
Engineer	24000	12000	24000	24000	24000	24000
Jr. Engineer	12000	6000	12000	12000	12000	12000
Draftsman	7000	3500	7000	7000	7000	7000
Field Teams						
Engineer	12000	9000	24000	36000	36000	36000
Hydrologist	12000	9000	24000	36000	36000	36000
Public Awareness	8000	6000	16000	24000	24000	24000
Equipment						
Vehicles	9000	18000	8000	8000	0	0
Vehicle O&M	900	1800	2700	3600	3600	3600
Office and computers	2000	4000	2000	1000	500	500
Misc. field equipment	1000	1000	1000	1000	500	500
Annual Totals		120300	170700	202600	193600	193600
Program Total				Rials Omani		880800

Chapter 8

TRAINING NEEDS

The section will require many skills that MWR does not have in abundance at present: rural survey techniques including rapid assessment, engineering for small-scale project feasibility and design, impact assessment, and basin management. If possible, experienced MWR staff who understand the nature of the task should be assigned to the section, but for the most part the employees will be new and, in the case of the field team, should be sought for their ability to communicate.

8.1 Basic Skills

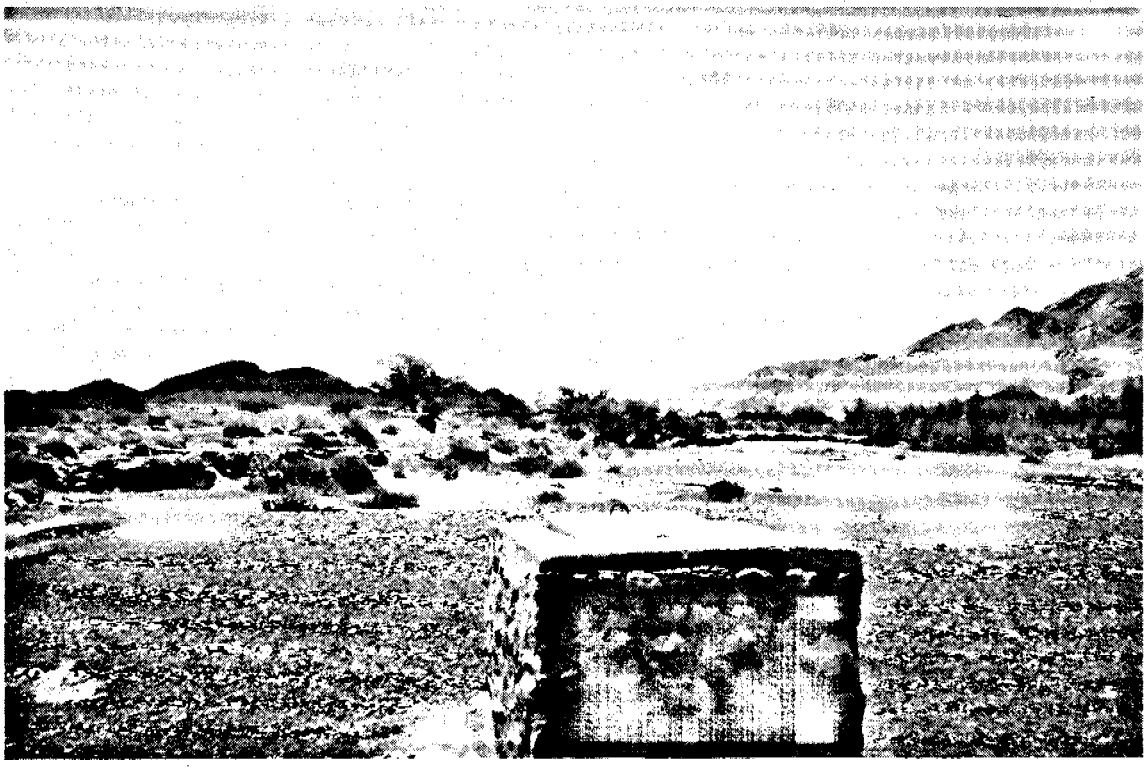
There should be courses in basic hydrology and water resource planning, like the present six-week course for unskilled employees. Follow-up training both on the job and overseas should come later.

8.2 Specialized Skills

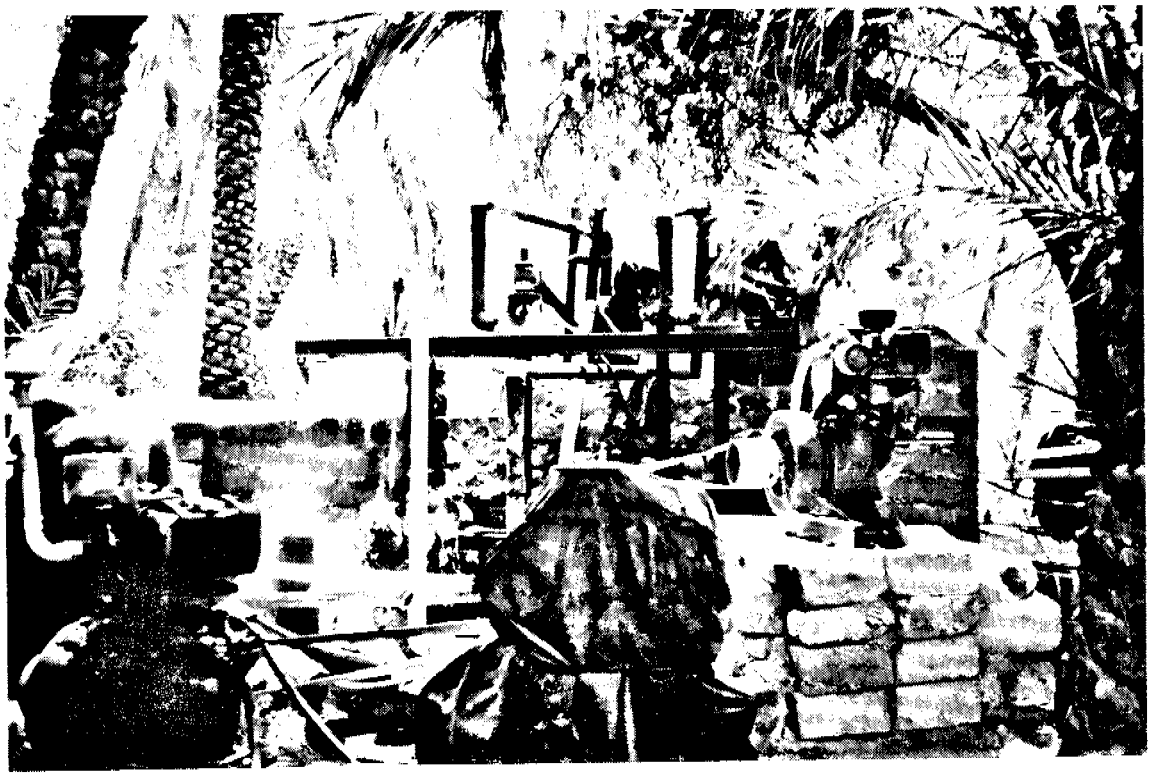
Short courses on survey techniques could be arranged at Sultan Qaboos University or abroad. Special emphasis should be placed on the rapid appraisal used in agricultural surveys in other countries. The technical staff should be trained in site evaluation and technical design and in economic, environmental, and cultural impact assessment, perhaps through short courses overseas. A group of skilled professionals able to work closely with upper basin communities provides the best assurance that projects in these areas will be successful.

PHOTOGRAPHS

A typical Ghayl Falaj Intake Structure at Mugal



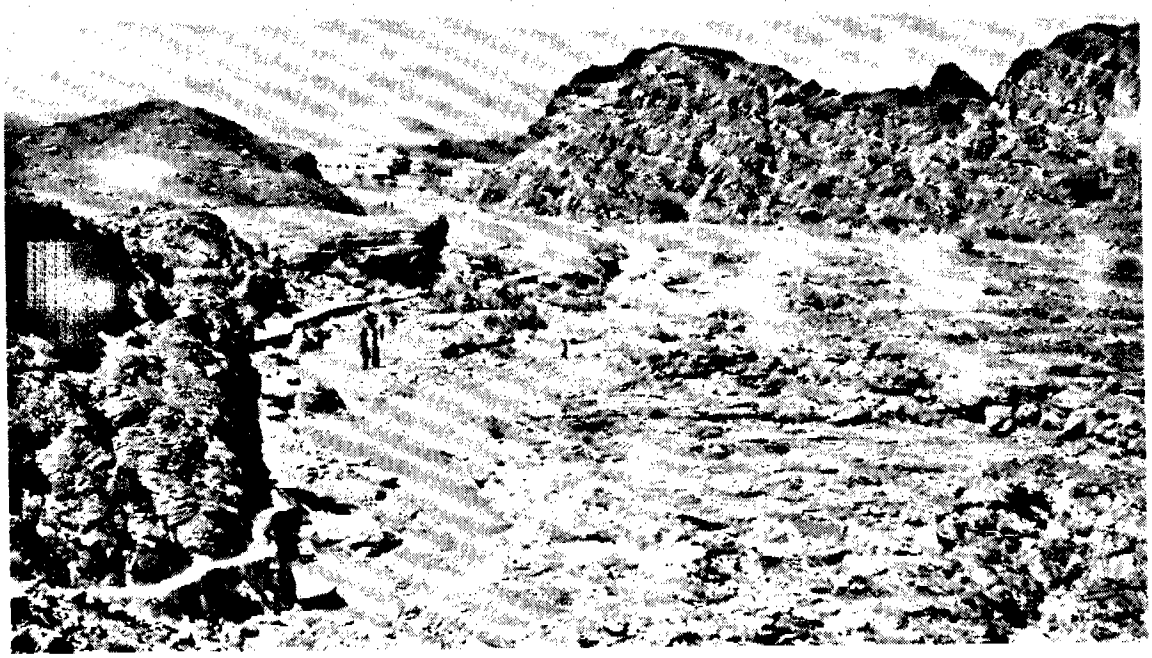
Ghafal



Ghaf Wells

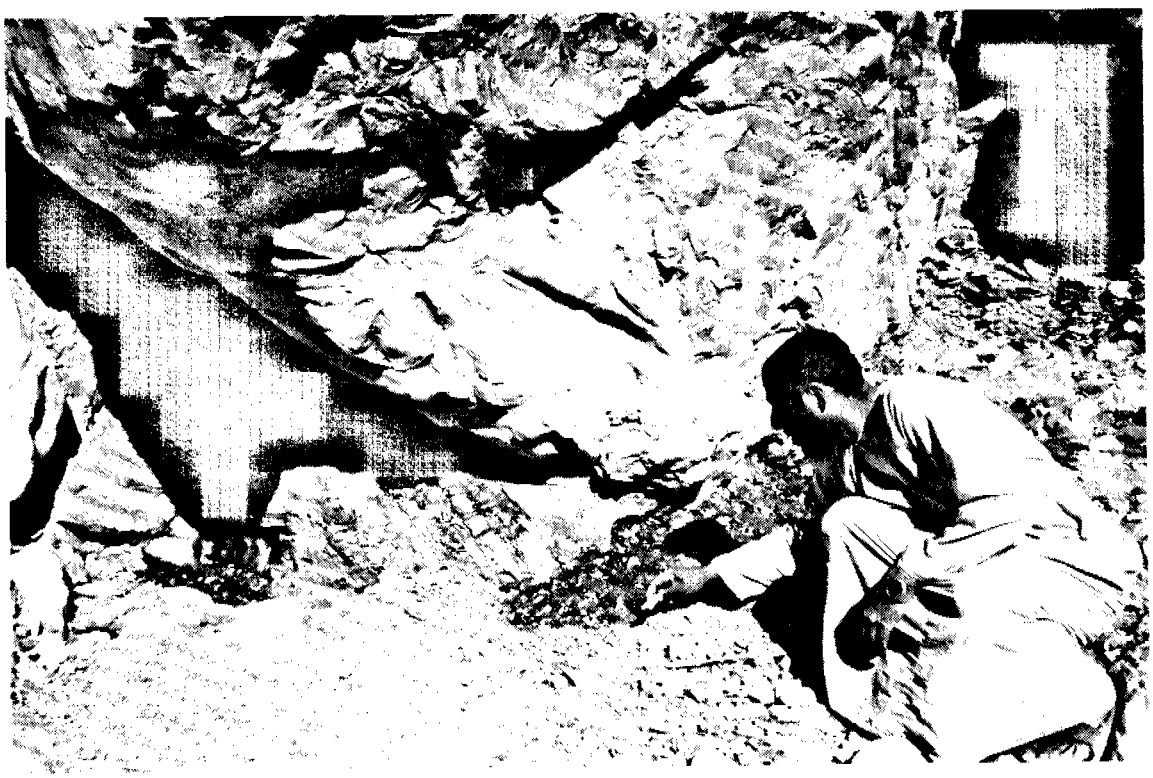
Falaj keeper and village boy

Yuqal

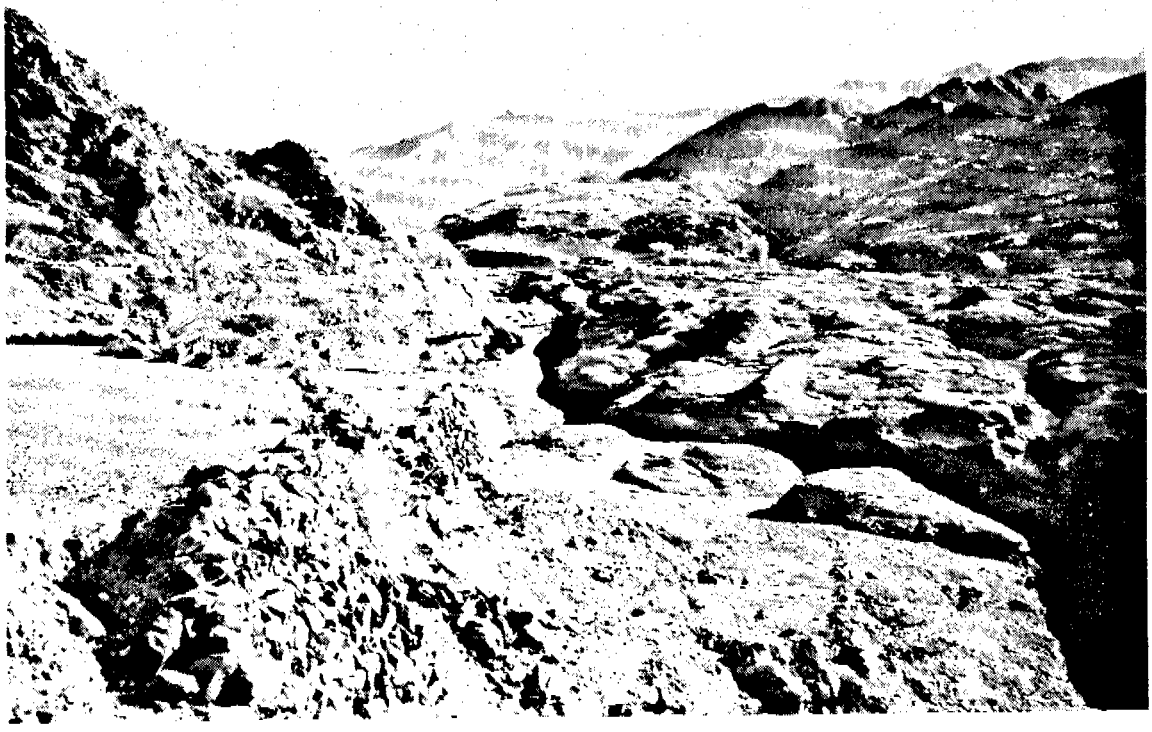


Typical Falaj in the small basin

Village sheik explains behavior of wells in Wadi Bani Khalid



Villager explains behavior of springs



Yuqul

Ministry of Water Resources worker discusses
water allocation methods with village youth

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Appendix

PERSONS MET

Omani-American Joint Commission

Dr. Duncan Miller	U.S Representative
Murl Baker	Deputy U.S. Representative
Mousa Al Masrooi	Project Officer
Anjab Sajwani	Project Officer
Mark Pickett	Training Officer

Ministry of Water Resources

Sayid Bargash al Said	D.G. of Water Resources Assessment
Saleh Issah al Mazrooi	D.G. of Water Resources Management
Alan Rendell	Planning Unit
Seif Rashid Seif Al Shaqsi	Drainage Basin Management Dept.
Abdullah al Arimy	Public Awareness Dept.
Harley Young	Dir. Research Department
Geoff Bonney	Regional Assessment Section, Research Dept.
Majid Bagheri	Drainage Basin Evaluation, Research Dept.
John Kay	Dir. Projects Department
Ian Hogg	Technical Library Section, Technical Services Dept.
Brian Eccolson	Dir. Groundwater Dept.
Simon McNielage	Groundwater Modelling, Groundwater Department
Suleum Salim Khalfan Al-Hamzy	Technician, Groundwater Dept.
Hamoud Abdulla Al-Jabry	Technician, Groundwater Dept.
Hashim Khamis Al-Bahishi	Technician, Groundwater Dept.
Wayne Curry	Act. Dir. Surface Water Dept.
Mel Johnson	Flood Studies Section, Surface Water Dept.
Dr. Mohammed Chebanne	Data Analysis Section, Surface Water Dept.
Seif Al Sinawi	Sr.Technician, Aflaj Monitoring Surface Water Dept.
Geoff Wright	Depty. D.G. of Regional Offices
Steve Poulter	Dir. Nizwa Regional Office
Zahir Al Adawi	Monitoring Section, Nizwa
Izzeldin Mohammed Ahmed	Well Permits Section, Nizwa
Eduardo Tabita	Geologist, Nizwa
Hamoud Al Busaidy	Technician, Niwa
Hamid Juma Al Sabary	Violations Section, Nizwa
James Laver	Dir. Sohar Regional Office

B. P. Verma	Dir. Rustaq Regional Office
Musalam Nasser Al Musalm	Monitoring Section, Seeb
Alexander Van der Meer	Dir. Mudayrib Regional Office
Yassir Salim Al-Harthy	Monitoring Section, Mudayrib
Michael Kaczmerak	Dir. Buraimi Regional Office
Izzis Abbas	Dir. Ibri Regional Office

Ministry of Interior

Abdulah bin Sabaa Al-Saad	Wali of Bahla
Abdulazziz bin Salim Al-Abdulsalam	Wali of Wadi Bani Khalid

Sheikhs and villagers in a number of villages visited

Ministry of Agriculture and Fisheries

Paul Barriere	Hydrologist

Consulting Firms

Keith Warne	Project Mgr. Yonkul-Dank Project
Peter Easton	Asst. Project Mgr. Yonkul-Dank Project
Keith Smiles	Res. Dir. Travers Morgan
Neil	Mott McDonald and Partners, Ltd.
Sri Lankan Guy	Mott McDonald and Partners, Ltd.
Carsten Kaergaard	Cowiconsult
	W.S. Atkins