FIELD REPORT

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

TASK 5: WATER MANAGEMENT
TASK 6: TECHNOLOGY DEVELOPMENT

GEOPHYSICS
Part 7

WASH Field Report No. 353
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WATER AND SANITATION for HEALTH PROJECT

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Part 7

GEOPHYSICS

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

Geophysical methods use the interaction of electromagnetic and seismic waves with the earth to determine properties of subsurface materials. Measurements of gravitational and magnetic fields and naturally occurring radioactivity are also used to determine the properties of subsurface materials. The measurements may be conducted in a borehole, on the earth's surface, or from an aircraft. Measurements of the surface properties of the earth are not considered to be geophysics and are usually classified as remote sensing. This report identifies programs of the Ministry of Water Resources (MWR) where geophysical methods may be beneficial and presents a plan to develop MWR's capabilities to use them.

Geophysical methods can provide quantitative information that cannot be obtained in any other manner or can increase the effectiveness of programs by providing information which would otherwise be obtained through more resource intensive methods such as drilling. Geophysics is best used in conjunction with other methods and is usually accompanied by some drilling to validate the interpretations. A properly executed geophysics program can save much time and money.

Chapter 2

SCOPE

This report identifies several MWR programs where geophysics should be considered and makes recommendations for the development of the suggested capabilities. Extensive discussions were held with MWR personnel and numerous field sites were visited. Many of the ideas presented here are not new to MWR but are offered as a unified approach for the use of geophysics. First, the projects themselves are considered individually, then the proposed geophysical methods are discussed as they apply to individual projects. Training and equipment recommendations are included.

Chapter 3

SUMMARY

The following programs can benefit from the application of geophysics:

- Saline intrusion investigations
- Wadi throughflow studies
- Regional assessment studies

Considering the range of desired capabilities and anticipated workloads, the best approach for MWR in the short term is to develop an in-house ability to design surveys, manage contracts, and interpret data. At this time actual field operations should mostly be conducted by contractors.

When MWR has gained sufficient expertise, it will be clearer which methods merit the resources required for development of in-house data acquisition capabilities. Premature development will divert attention from more pressing hydrologic issues confronting MWR, and may actually retard the development of geophysical capabilities that may be more useful.

Contractors should be brought in for four survey methods: transient electromagnetics, seismic reflection, seismic refraction, and gravity. The contracts should focus on the applicability of the methods to the hydrologic issues discussed in this report. Future work should use selected methods to address specific aspects of these hydrologic issues. An additional staff person with experience in seismic reflection and contract management is required. Postgraduate foreign training will be required for MWR to develop its Omani geophysics staff.

Chapter 4

INTRODUCTION TO GEOPHYSICAL METHODS

4.1 Transient Electromagnetics (TEM)

Transient electromagnetics has been used for deep geothermal investigations for several decades. It has been recently refined to allow investigations at depths ranging from 10 m to 300 m. The method involves measurements at individual stations along survey lines. At each station a wire is laid on the ground in a square loop. The length of one side of the loop is in the range of 10 m to 200 m, with 50 m being a likely size for the depths of investigations and equipment required for coastal studies in Oman. A pulse of current is applied to the loop and is abruptly turned off, inducing a transient electromagnetic field in the subsurface. A second round loop, typically only 1 m across, is used to detect the transient electromagnetic field. The rate of decay of the transient field determines how the electrical conductivity of the ground varies with depth below the station. The depth of investigation is controlled by how long the transient field can be detected, with longer times after the turn off corresponding to greater depths. The process is repeated at stations along the survey line. If the distance between the stations is comparable to the size of the transmitter loop, a continuous profile of formation electrical conductivity versus depth can be developed. There are limitations on the depth of investigation and the ability to resolve complex layering.

4.2 Airborne Electromagnetics

Airborne electromagnetics uses an instrumented helicopter or fixed-wing aircraft to rapidly survey a large area. Depending on the instrumentation, the electrical conductivity of the upper 50 m-300 m is measured with limited vertical resolution (one or two layer model). Features with a horizontal extent of a few hundred meters can be detected and surveys of hundreds of square kilometers are common. Although airborne methods do not have the spatial or vertical resolution of ground methods, they do offer a rapid assessment technique for large unexplored regions.

4.3 Frequency Domain Electromagnetics

Frequency domain electromagnetics uses a continuous electromagnetic field at several discrete frequencies to induce electromagnetic fields in the subsurface. The transmitter and receiver loops are typically 1 m across and 10 m to 60 m apart. The depth of investigation is controlled by the frequency and spacing of the coils. Depths of investigation are shallower than for TEM, typically a maximum of 30 m-40 m, and vertical resolution is not as great.

4.4 Induction Logging

Induction methods similar to electromagnetic techniques are sometimes applied to boreholes by lowering an electromagnetic device into a borehole and charting the variation in response at different levels (borehole logging). Induction logging induces an electrical current in the materials surrounding the borehole and measure the response (inductance) of the formation. Induction logging can be used to observe changes in the pore fluid conductivity by repeated measurements over several years.

The induction tool measures the electrical conductivity of the material around it. The radius of investigation is typically about 1 m. If a metallic casing is used the induction tool will be influenced by it. Since the conductivity of steel is roughly one hundred million times greater than that of typical earth materials, the measurement will be tremendously impacted by the casing. Because of this, a small diameter (preferably 10 cm or less) nonmetallic casing is required for use of the induction tool. By comparison, a 15 cm annulus of grout, which has an electrical conductivity comparable with that of typical earth materials, has relatively little effect on the induction tool, which measures a much larger volume. The grout does not adversely impact the tool's use for monitoring changes in pore fluid conductivity over time.

4.5 Gravity Methods

Gravity methods measure variations in the earth's gravitational field due to changes in the density of the subsurface materials and can cover large areas rapidly to serve as a useful reconnaissance tool. Difficulties occur when the density of the underlying formation changes unexpectedly or the density contrast between the unconsolidated material and bedrock is not large enough. Because of this, drilling is often needed to confirm the interpretation.

4.6 Seismic Refraction

Seismic refraction utilizes a surface source of seismic energy to produce a seismic wave in the subsurface. In areas where the velocity of the seismic wave increases with depth, a refracted wave is generated and can be detected with surface geophones. The depth to the high-velocity layer can then be estimated. For this method to be effective seismic velocity must increase with depth. Seismic refraction does not work if cemented material or other high velocity material masks the layers beneath. The method cannot effectively differentiate between cemented materials and bedrock.

4.7 Seismic Reflection

Seismic reflection utilizes a surface source of seismic energy to produce a seismic wave in the subsurface. Surface geophones are configured to detect reflected waves (echoes) from the subsurface. The seismic velocity does not have to increase as depth increases. Unconsolidated material (low velocity) can thus be recognized beneath cemented material (high velocity). With special instrumentation and field methods, the depth of investigation can be as shallow as 10 m, although the first meaningful information is usually from a depth of about 30 m. Seismic reflection is the best method for delineating complex stratigraphy and identifying small buried channels.

4.8 Resistivity

Resistivity surveys measure the resistance to the current flow between two electrodes in the soil surface. A decrease in resistivity may indicate the presence of water in a formation. Water quality can also be determined since dissolved salts reduce the resistivity of the water. The utility of the method is limited at sites that are rocky, dry, or not uniformly horizontal.

Chapter 5

APPLICATIONS OF GEOPHYSICS TO SALT WATER INTRUSION STUDIES IN OMAN

5.1 Background

The intrusion of sea water into coastal aquifers is a pressing problem that has adversely affected the Batinah and possibly the Salalah plains and has led to the abandonment of some agricultural areas. MWR programs are being developed to identify current conditions, monitor changes, and prepare for action. Without an effective monitoring program, the effectiveness of management actions cannot be assessed. The salinity monitoring program, discussed in Part 4 of this report, proposes a series of salt water intrusion monitoring transects. Each transect may consist of a series of clustered wells that will provide information on vertical variation in salinity and hydraulic head. The positioning of the clusters along a transect perpendicular to the coast will provide a cross section of the intrusion.

One limitation of the salinity monitoring transects is that they can provide only a two-dimensional view of the coast (depth versus distance inland) and will miss any variation that occurs along the coast between transects. An inspection of the electrical conductivity of shallow groundwater in the Sohar and Seeb areas indicates that there is considerable variation parallel to the coast attributable to the distribution of pumping centers and to geologic features. The transects can indicate conditions along the line but not what length along the coastline they represent. This could be solved by more closely spaced transects but would be expensive. Several geophysical methods could improve the saline intrusion investigations.

The replacement of fresh water by saline water in the pore spaces of subsurface materials greatly alters the electrical properties of the materials. Electrical geophysical methods, which measure the electrical conductivity of the subsurface materials as a function of depth, have been used extensively for delineating the extent of salt water intrusion. When used with appropriate well control, these methods can rapidly identify areas where intrusion has occurred. Commonly this information is used to optimize the location of monitoring wells and to determine how large an area is affected. In the context of the proposed salt water intrusion monitoring programs, electrical geophysical methods could markedly improve the interpretations between wells along the transects.

Induction logging can also be used in salt water monitoring programs to observe changes in pore fluid conductivity that change the formation conductivity. Vertical movement of salinity contours of one quarter of the thickness of the interval between 10 percent to 90 percent invasion can be detected.

5.2 Methods for Salt Water Intrusion Investigations

5.2.1 Transient Electromagnetics

The best geophysical method for salt water intrusion investigations is transient electromagnetics (TEM) because it is particularly sensitive to conductive layers and has good horizontal resolution. Several parallel TEM profiles centered along the proposed salinity monitoring transects would allow observation of the nature of variations between clusters of wells along each transect. The location of saline interfaces could be more accurately determined than from a few clusters. TEM profiles conducted parallel to the transect would determine how much lateral variation exists along the coast. Repeated measurements, separated by several years, could indicate changes in the extent of intrusion. Horizontal movement of the salinity contours of several hundred meters is required before the change can be detected with confidence. Borehole information is necessary along a portion of the transect to ensure that the TEM data are being correctly interpreted. Well logs, particularly induction logs, are essential if the TEM method is to be used most effectively. An example of the use TEM in a salt water intrusion investigation is presented by Mills et al. (1988) and Fitterman and Stewart (1986).

5.2.2 Frequency Domain Electromagnetics

Because its field operations are faster than those for TEM, the frequency domain method could be useful in identifying areas that have been invaded by saline fluids if the depth of the invasion is not greater than 30 m-40 m. Since for most of the transects the depth will be greater than this, this method would not be suitable. An example of this method is presented by Stewart (1982).

5.2.3 Borehole Methods

In areas where only information regarding relative changes in salinity over time is required, induction logging will be useful. A drawback is that only relative changes can be accurately determined. Because the induction log measures the formation conductivity, not the pore fluid conductivity, the actual salinity of the pore fluid can only be estimated. Also the only hydraulic head information that is obtained is from the one interval that is screened. The cluster well approach monitors the hydraulic head at several intervals.

Current MWR procedure is to determine the change in pore fluid salinity by measuring the electrical conductivity of the fluid in a fully perforated borehole as a function of depth. This practice should be discouraged because vertical flow within the borehole is likely and would adversely affect the results. A preferred method is the installation of a cluster of wells with each well sampling a discrete depth. This is discussed in detail in Part 4. A drawback of this approach is that drilling expenses are increased by the need for several wells at each monitoring location.

Monitoring salinity changes with induction logging requires the construction of a nonmetallic cased well that is perforated only over a short interval. As in the cluster well approach, the annulus around the well must be filled with low-permeability material to prevent vertical fluid flow in the borehole outside the casing.

A critical aspect of repeated logging for monitoring purposes is the establishment of a proper calibration program that is tied to absolute standards. If the logging is repeated after several years and the tools used in the two surveys are not properly calibrated, the results would be suspect. Typically, a calibration program involves two methods: absolute calibration and field calibration. Absolute calibration ensures that the tool is measuring the intended property correctly. In the case of the induction tool this is done by suspending the tool in water of known electrical conductivity. Several fluids with values of electrical conductivity within the range anticipated in the field are used. The tank must be sufficiently large that edge effects are negligible. The exact size is a function of the design of the tool but typically is at least 2 m in radius. There should be no metal (or reinforced concrete) in the tank construction unless the tank is exceptionally large. To demonstrate that the tank is sufficiently large, the tool should be moved by at least 1 m in all directions from the center and the instrument response should be the same. Absolute calibration is a cumbersome but essential requirement that should be conducted prior to a major logging program.

Field calibration is a simpler procedure which ensures that the tool response has not changed significantly since the absolute calibration. It is conducted at the well site prior to each logging operation. In the case of the induction tool this is done with a calibration coil that is held in a prescribed geometry with respect to the tool. The calibration coil has a constant effect on the tool and can only be used to ensure that calibration has not changed from one time to another. In particular, the field calibration is also performed during the absolute calibration and at the well site to ensure that tool response has not changed since the absolute calibration. Calibration coils are supplied by the tool manufacturer. A quality assurance program is an important part of any logging contract and is critical for a monitoring program.

5.3 Proposed Program for Salt Water Intrusion Monitoring

5.3.1 Surface Methods for Salt Water Intrusion Monitoring

TEM is the preferred method for salt water intrusion monitoring because many of the areas of interest to MWR will require a depth of investigation greater than 40 m. Before MWR invests in an in-house capability for TEM field operations, it should test the utility of the method in contract field operations and instead develop an in-house capability to interpret the data by providing its present geophysics staff with a geophysical work station and appropriate interpretation software (Table 7-1).

Table 7-1

Recommended Computer Software for Geophysics

Name	Description	Vendor	Approximate Cost
Grapher	2 dimensional plotting program	Rockware	R.O. 120
Surfer	3 dimensional plotting program	Rockware	R.O. 200
Quick Basic	development of data handling programs	Microsoft	R.O.40
Resix	resistivity interpretation	Interplex	R.O. 150
Emrix	frequency domain electromagnetic interpretation	Interplex	R.O. 150
Temix	time domain electromagnetic interpretation	Interplex	R.O. 2,000
Llogger	well logging interpretation	Rockware	R.O. 250
Reflex	refraction interpretation	Interplex	R.O. 800

Rockware Inc.
4251 Kipling St., Suite 595
Wheat Ridge, CO 80033
USA

Interplex
Box 839
Golden, CO 80402
USA

The following approach is suggested for the TEM field test.

- The geophysics staff should develop the ability to interpret TEM surveys after acquisition of the software and enough time to become familiar with it.

- Well logs should be used to model the response of the TEM method to actual conditions in the Batinah and Salalah areas. The model can be used to determine optimal field parameters and the sensitivity of TEM to changes in salinity for the expected range of conditions by having the project hydrogeologist present the geophysics staff with several possible scenarios (Figure 7-1). These scenarios would represent the subsurface as a series of layers, with each layer having a unique thickness and electrical conductivity. One scenario is a low-conductivity unsaturated zone above an aquifer that has either saline or fresh water. The geophysics staff can model the TEM response (Figure 7-2) to determine what parameters are required to detect the differences between the scenarios. It may be necessary to conduct a limited induction logging program to obtain a sufficiently representative set of well logs to construct a model based on actual conditions.

- A contract crew should be brought in to evaluate the utility of the TEM method in the study areas and to acquaint MWR staff with the method. The contract should be for a specified period rather than a fixed number of stations to give the contractor flexibility while working in a new area and enhance the training value of the work. The contract should clearly state that familiarizing the geophysics staff with TEM will be an important component of the project. MWR can reduce the cost of the contract and generate greater interest in the tender if it offers to provide in-country logistics such as vehicles and field staff. Such an offer would open the tender to many smaller geophysical firms that specialize in TEM.

  Survey lines should be established along and near the proposed salt water intrusion monitoring transects. The exact length and spacing of the lines should be developed by MWR staff after carefully considering the expected lateral variation around the transects. A contract crew should be able to do 30 km of line in one month.

- Interpretation of the field data should be a joint effort between the contractor and MWR staff.

After the utility of the TEM method has been determined by initial survey, it may be desirable to conduct additional surveys in surrounding areas under contract. Eventually it may be desirable to develop an in-house capability to conduct the surveys. This would require an investment of approximately R.O. 25,000 in equipment and several man-months to develop an efficient 3-4 man field operation after MWR staff have become acquainted with the method by participating in contract field programs.

5.3.2 Borehole Methods for Salt Water Intrusion Monitoring

Induction logging can be used to enhance the salt water intrusion monitoring program proposed in Part 4.

Figure 7-1

Possible Scenarios for TEM Response Model

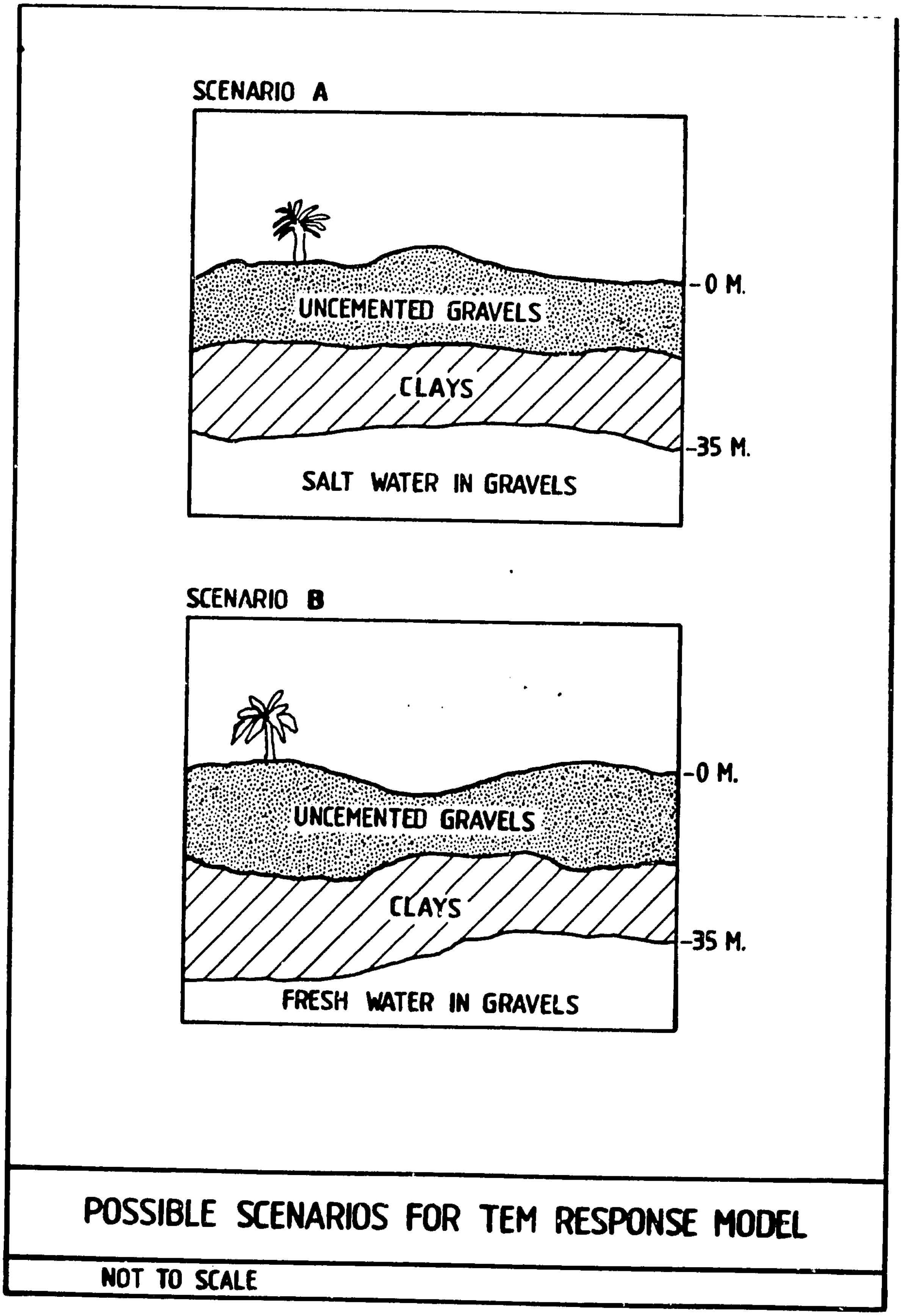
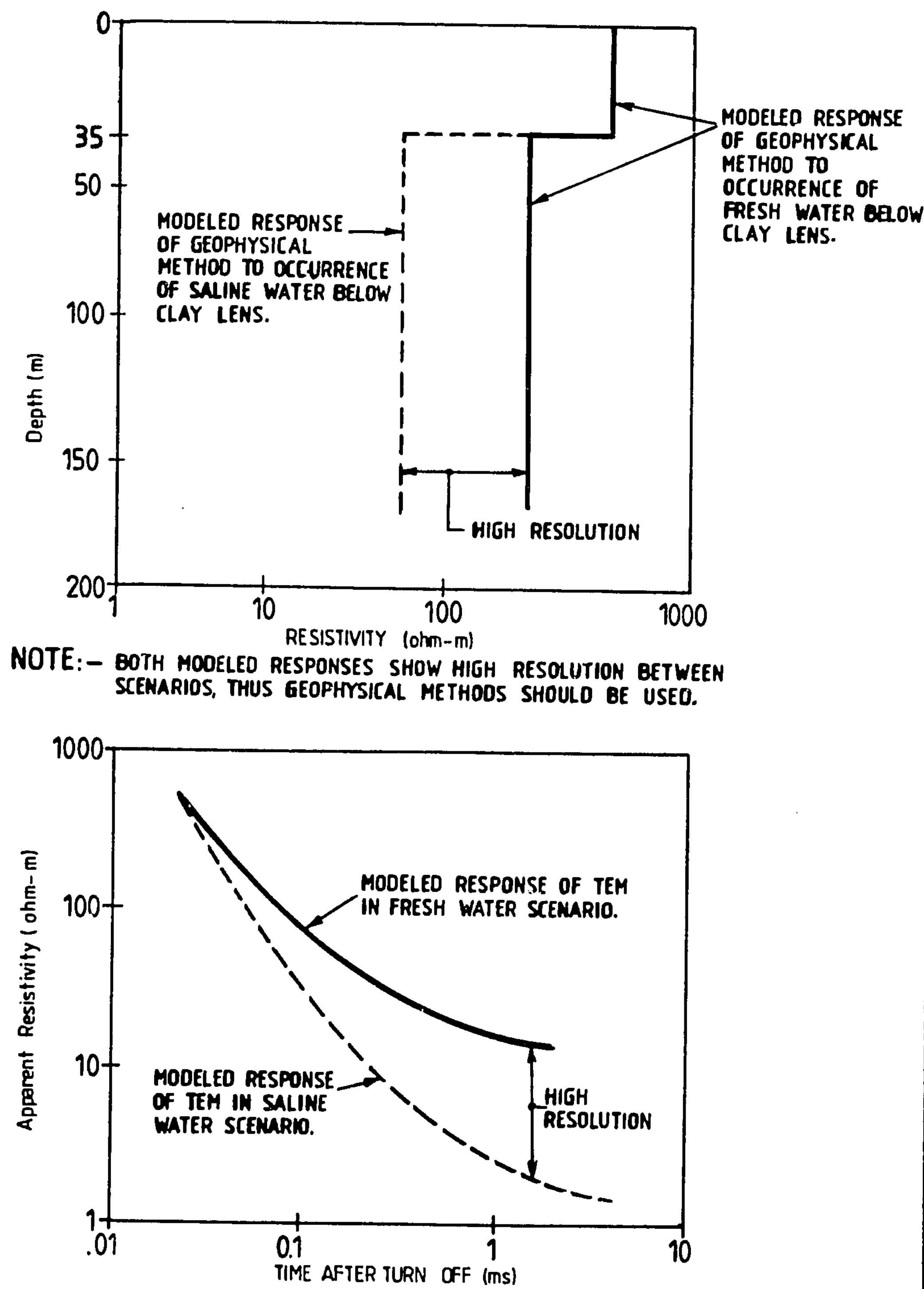


Figure 7-2

Examples of Modeled Responses



EXAMPLES OF MODELED GEOPHYSICAL SYSTEM RESPONSES TO DIFFERENT SITUATIONS (REF. FIG. 8-1 / SCENARIO A & B).

NOT TO SCALE

- The salinity monitoring network should be expanded into areas between the transects via boreholes that are used for induction logging. Optimal locations for the intervening induction logging holes can be selected by TEM work. Since the design of the induction logging holes is the same as for the cluster monitoring wells, they can be turned into cluster well sites if there is evidence that additional head and actual salinity values are required. The deepest hole of the cluster well installations should also be logged with induction tools to assess the utility of the method.

- It will be most cost effective to entrust initial field operations to a contractor because these will be done intermittently. Special attention must be given to data quality.

- If induction logging develops into a large program, consideration should be given to purchasing equipment. A logging system that is solely dedicated to induction logging for depths to 200 m can be obtained for approximately R.O. 11,000, including the winch, cable, electronics, and tripod. The system can be transported by light truck. A dedicated vehicle is not necessary.

- A quality assurance program must be implemented. In order to assist in the interpretation of the induction logging, software should be obtained to facilitate the presentation of well logs. The proposed software is listed in Table 7-1.

Chapter 6

APPLICATIONS OF GEOPHYSICS TO THE WADI AL BATHA REGIONAL ASSESSMENT

6.1 Background

MWR's regional assessment program seeks to produce a pre-regulatory understanding of the various basins of Oman. The assessment involves reviewing and integrating all the existing data on a region and defining programs to broaden understanding of the technical, economic, and cultural parameters relating to its water resources. In this way MWR hopes to prepare itself for its role of managing the country's water resources.

One of the areas for regional assessment is the 9,000 sq km watershed in Sharqiyah known as Wadi al Batha, which was one of the first areas selected for review because little is known about it. The area has several subdrainages with surface flows to Wadi al Batha and groundwater may extend under the Wahibah sands. A meaningful assessment will require a determination of the depth of unconsolidated material forming the uppermost aquifers of the region. Drilling indicates that the thickness of the uppermost alluvial deposits varies from zero to more than 300 m. The bedrock topography appears to be very rugged and can have a significant impact on groundwater quantity and quality. Therefore, it is desirable to determine the characteristics of the unconsolidated material and to define them in greater detail.

The size of Wadi al Batha makes it impractical to determine the bedrock topography by drilling boreholes. Geophysical methods will be more economical and will achieve results not possible otherwise. The size and geological diversity of the area also suggest that no single geophysical method will be applicable to the entire area.

6.2 Geophysical Methods for Delineation of Unconsolidated Aquifers

6.2.1 Introduction

Several geophysical methods can help delineate the thickness of unconsolidated material: gravity, seismic refraction, seismic reflection, and electrical surveys. Each of these methods will be effective in different parts of the study area. Initial efforts need to focus on developing an effective strategy to utilize these tools.

6.2.2 Gravity Methods

Cravity methods can be used to determine the general trends in the depth of unconsolidated material where this is less dense than the more competent bedrock. Even though it may not be possible to determine exact depths in areas where the density contrast between the unconsolidated materials and bedrock is not great, gravity methods may be useful for identifying regions with similar depths. Drill holes can then be efficiently located. Gravity surveys are commonly conducted along several parallel lines or along a grid. A typical two-man crew can cover 10 km-30 km per day, depending on survey design and instrumentation. Two additional man days per week of field work are required to interpret and analyze the data.

6.2.3 Seismic Refraction

Seismic refraction can be used to delineate the characteristics of unconsolidated aquifers in areas where the velocity of the seismic wave increases with depth. The method will not be effective in areas where high-velocity materials, such as cemented alluvium, occur at shallow depths, because they may be misinterpreted as bedrock. Explosives are the preferred source for seismic energy. Ballistic sources (modified guns) have been used successfully in environments similar to the study area, although depths of investigation would be more limited, particularly in unsaturated gravels. Seismic refraction investigations of 200 m depth can be conducted by a two- to four-man crew. Typically one to five sites per day can be surveyed.

6.2.4 Seismic Reflection

Seismic reflection has the greatest spatial resolution of methods presented here. Field operations can range in crew size from four to 40 people. Small crews can work on smaller, shallow problems (2 km profile 100 m deep). Large crews are required for larger surveys that involve hundreds of kilometers of profile at depths of thousands of meters. Examples of small-scale operations are presented by Miller et al. (1988) and Geissler (1989).

6.2.5 Transient Electromagnetics

Transient electromagnetics may have some use for delineating aquifer geometry but will be adversely influenced by salinity and clay variations in the subsurface. Although the exact depth of the unconsolidated material will be difficult to determine, it may be possible to identify areas with common characteristics. These areas can then be investigated with other, more resource-intensive methods, such as seismic reflection and drilling. Transient electromagnetics were used for this type of investigation in the United Arab Emirates (Fitterman et al., 1991).

6.3 Proposed Geophysics Program for Wadi al Batha

The four methods complement each other. If cost were not a factor, it would make sense to begin immediately with seismic reflection. However, to do so may be premature because much of the study area is overlain by shallow deposits (less than 30 m) and is ill-suited for investigation by a large seismic program. Regional gravity work can be used to identify areas where the more involved seismic reflection method can be effectively used. Seismic refraction can be used to help confirm the gravity work along selected profiles, and to obtain information where the unconsolidated material is too thin to justify seismic reflection. Careful consideration of the geology and occasional drilling will ensure that the gravity and seismic refraction data are being accurately interpreted. Transient methods may also provide sufficient information in much of the study area and can be followed up with seismic reflection in areas of special interest.

The proposed program will be in three phases over four years. Phase 1, lasting one year, will evaluate specific geophysical methods in a few representative areas. Phase 2 will apply the methods identified in Phase 1 as the most useful for most of the study area and will last two years. Phase 3 will allow follow-up in areas that merit greater study and will cover the fourth year.

In Phase 1, the following areas should be selected to represent common characteristics found in the basin: upper drainage sedimentary basin, upper drainage erosional basin, and lower drainage cross-section extending into the Wahibah sands. Each of these is likely to have different subsurface conditions that will influence the effectiveness of the proposed geophysical methods. In each area, a line should be selected that spans shallow and deep unconsolidated material.

Several parallel gravity profiles should be obtained in each of the areas. Modeling will be required to determine what the characteristics of the survey should be and the level of precision that is needed. An effort should be made to determine if gravity data are available that can reduce the field work. If appropriate information is not available, contractors will need to conduct the surveys. Seismic refraction should be conducted at selected locations to confirm the general trends of the gravity work and quantify the interpretations. A seismic reflection and transient electromagnetics program should be developed along the profiles. The emphasis should be on determining which methods will be most efficient and how they will be employed.

An important task in Phase 1 will be to assess the utility of TEM. If surface electrical methods prove to be a useful source of information, the use of airborne electromagnetics should be considered. Once representative surface TEM data are available, it will be possible for contractors to assess the utility of different instrumentation configurations. This is done by having the contractor prove that the proposed instrumentation and survey design can discriminate among the scenarios presented. If airborne methods are effective, large areas could be covered rapidly. This issue merits careful consideration. The use of airborne electrical surveys is presented by Paterson and Bosschart (1987).

Phase 2 will identify specific transects of the study area that address pertinent hydrologic issues. These transects (on the order of 150 km) will be investigated with the approach developed from activities in Phase 1.

In Phase 3, follow-up work would continue in areas where the above approach identifies significant unresolved issues.

In all of these phases, MWR should concentrate on developing contract management and interpretation skills. The field work is best handled by a contractor initially, because the volume of work will be high for a short period and some methods may not prove their worth. Current staff have experience in gravity and seismic refraction and can perform the contract oversight and interpretation roles. The project hydrogeologists will have to work closely with the geophysics staff to define what level of resolution is required and to ensure that it is obtainable. Each geophysical method should be clearly assigned to an individual staff member who will be responsible for preparing the contract, overseeing field operations, and assisting the contractor in data interpretation. Seismic reflection will require an additional person with experience. If gravity and seismic refraction prove to be useful methods, consideration should be given to developing an in-house capacity to conduct the field programs. MWR should get a clear idea of the expected level of utilization of the methods before investing sizeable resources in developing an in-house data acquisition capability.

Appropriate software will be required to plan and interpret the proposed gravity and seismic refraction surveys (Table 7-1), which may cost several hundred thousand rials. The geophysics staff should begin discussions with likely contractors to determine the exact costs of the proposed work.

In addition to the methods described, the location and types of surveys that have been performed for petroleum exploration should be examined. Although these surveys are usually conducted in such a way that information about the near surface is not developed, unconventional approaches can sometimes be applied to reprocess the data. A good example of this is in the Al Ain area of the United Arab Emirates, where weathering correction data collected for a petroleum seismic survey were reprocessed to construct a map of the depth of surface unconsolidated material (Woodward and Menges, 1990). This resulted in an excellent regional study at reduced cost. Once the location and data collection methods of petroleum exploration in the area are determined, the geophysics staff can decide if the information can be reprocessed to yield beneficial information.

6.4 Application of Geophysics to Regional Assessments in Other Areas

MWR is planning a number of other regional assessment programs for which the general approach proposed for Wadi al Batha can serve as an example. In general, regional assessments using geophysics should be carried out in the following manner:

- Identify a few characteristic areas.

Ideally, the region under review would be analyzed by rapid field survey to determine areas that might be representative of larger tracts of the region. Preference would be given to situations where there are known calibrations or anomalies. If a source of fresh water is known in an otherwise brackish zone, the survey may begin in that area.

- Apply an appropriate range of geophysical methods to the characteristic areas.

Once areas of interest have been selected, an array of geophysical methods should be reviewed and their responses modeled on the assumed conditions at the site. Several methods should be tried to determine the best for later full-scale work.

- Review the success of the methods used.

Once preliminary surveys and trials have been carried out, it is possible to design a program using the initial surveys as a guide. The resolution of surface methods, especially surface electrical surveys, can also provide important information on the applicability of more rapid airborne surveys. Such work should precede any airborne work.

- Use the most applicable methods on a regional scale.

Once the facts regarding the preliminary surveys are known, larger scale surveys that are appropriately phased and balanced can be successfully undertaken.

There are few short cuts to successful application of geophysics in large areas of unknown conditions. The key to conducting effective and cost efficient work will lie principally in MWR's ability to devise, contract, and evaluate a variety of geophysical services. In this manner the program can be both adaptive and responsive to the needs of the regional assessment study groups.

Chapter 7

APPLICATIONS OF GEOPHYSICS TO WADI THROUGHFLOW STUDIES

7.1 Background

A common hydrologic feature in Oman is the funneling of surface and possible groundwater flows from one basin through mountain gaps of unconsolidated material. To quantify the flow through these gaps requires the determination of the cross-sectional area of the gap and the groundwater velocity through the cross-section. The gaps are 500 m-3000 m wide and 0 m-100 m deep. MWR's approach for finding groundwater velocity uses extensive drilling to determine cross-sectional area and aquifer tests to identify hydraulic properties. While this approach is valid, difficulties in drilling have been encountered due to the coarse resolution of sampling (approximately one hole every 50 m), and in interpretation of the aquifer tests due to vertical anisotropy and boundary conditions. Work should continue in this area, as advanced interpretation methods being tried by the staff may prove fruitful.

An attempt has been made to use frequency domain electromagnetics to determine wadi cross-section geometry but only a cursory effort has gone into interpreting the frequency domain data. Other methods—transient electromagnetics, seismic refraction, and seismic reflection—may also help. Surface geophysical methods can also monitor the movement of a tracer used to calculate groundwater velocity.

7.2 Determination of Wadi Cross-Section Geometry

7.2.1 Frequency Domain Methods

Frequency domain electromagnetics may yield information about wadi cross-section geometry. The success of the interpretation will depend on a large difference in the electrical conductivity between the unconsolidated material and the bedrock formations. This difference may be due to differences in porosity between the two units. A complicating issue will be the presence of clays which also have a high electrical conductivity. An effort to use frequency domain electromagnetics has been made, but because the data have not been sufficiently interpreted, the utility of the method has not been adequately tested. Even if actual depths to bedrock cannot be determined, there would be considerable benefit if regions with similar characteristics along the cross-section could be identified. Future drilling could then proceed with some advance knowledge, and the placement of holes could be optimized.

7.2.2 Transient Electromagnetics

Transient electromagnetics has better vertical resolution than frequency domain methods and is likely to have an advantage in determining wadi cross-section geometry. If a contract transient crew becomes available, consideration should be given to a field effort to determine how much additional benefit is obtained with the transient method than the frequency domain method.

7.2.3 Seismic Refraction

Seismic refraction is a promising method to investigate wadi cross-section geometry. A complicating factor will be the presence of cemented gravels above uncemented material, a condition that is likely to be misinterpreted as shallow bedrock. The refraction method will be able to identify sections of the cross-section where similar conditions exist. Follow-up drilling could verify the interpretation at selected locations. This would reduce the total number of holes required because they could be optimally located. There are advanced interpretation methods to determine the depth of subsurface layers under each geophone that should be utilized. The geophysics staff is well acquainted with these methods. Field tests could be conducted in conjunction with the proposed refraction work for Wadi al Batha.

7.2.4 Seismic Reflection

Seismic reflection will provide the greatest level of detail of cross-section geometry. A project on the scale of the throughflow studies may be too small to be handled by a large seismic contractor and a smaller operation may be required. This may mean that separate seismic reflection contracts will be required for the throughflow investigations and the regional assessment work.

7.2.5 Tracer Tests

Tracer tests can be used to determine groundwater velocity. A tracer is injected into the flow system above down-gradient monitoring locations and the velocity is established from the travel time of the tracer. Two types of tracer tests can be considered: direct monitoring of the subsurface fluid via monitoring wells, and indirect monitoring of fluid via surface geophysics. Once the groundwater velocity is established for a given gradient (the gradient can be determined by piezometer), groundwater velocities at different gradients can be calculated using Darcy's law.

Direct monitoring of the groundwater chemistry requires that several wells be located in a fan pattern down-gradient from the injection well. Several wells are required because of uncertainties of the gradient and the likelihood of preferred flow along high-permeability paths. There is a wide choice of tracers. Commonly, several tracers with radically different properties are employed (e.g., an organic dye and an inorganic ion) to ensure that chemical transformations along the flow path can be detected. The amount of tracer to be injected is a function of the detection threshold, background concentration of the tracers, and the expected degree of dilution, which in turn is a function of the flow system and well geometry. Small concentrations can be used safely without affecting downstream water quality. Tracer tests need to be carefully planned. Frequently, several attempts are required before the procedure is properly tuned for the specific site. The book, "Tracers in Groundwater Investigations," (National Water Well Association, Dublin, Ohio, USA) is recommended for reference purposes. Current project staff will need to conduct only minor background research to properly plan tracer tests.

A second way to conduct the tracer tests is to use surface geophysical methods to monitor the movement of the tracer. This requires that the tracer affect a property such as electrical conductivity that can be detected from the surface, and be present in sufficient concentration to be detectable above the ground. In practice, an initial electrical survey is made along a grid over the suspected flow path. A large quantity of salt is then injected into the flow system. The movement of the saline water is monitored by comparing repeated measurements of the electrical survey with the original survey to determine differences due to the location of the saline water. The advantage of this technique is that additional drilling is not required and the existence of preferential flow paths can be identified. The disadvantage is that large quantities of salt must be used. Preliminary calculations suggest that 100 kg of salt would have to be injected to be detectable with surface methods. Usually this injection is done with a saturated brine solution. Alternatively, fluid can be withdrawn from a well, circulated through a tank with salt, and then reinjected into the same well. Before salt is injected into the flow system, careful consideration must be given to potential effects on downstream use. The preferred geophysical method for this type of tracer test would be TEM with a small transmitter loop (5x5 m) and close station spacing (7.5 m).

7.3 Proposed Geophysics Program for Determining Wadi Throughflow

7.3.1 Determining Cross-Section Geometry

- The frequency domain electromagnetic data collected by Hydrotechnica in 1991 should be properly interpreted. This will require the acquisition of appropriate software (Table 7-1) and a modest effort by the geophysics staff. The staff should then work closely with the project hydrologists to determine the pertinent hydrologic issues and whether the frequency domain method is capable of addressing these issues with sufficient resolution.

- If a contract TEM crew is available, the crew should repeat the profiles that have been done to determine the advantage of using the transient method instead of the frequency domain method.

- In situations where there is established uncemented alluvium underlain by bedrock, seismic refraction is cheaper and quicker than seismic reflection. Because refraction methods may not be useful on account of the persistent presence of cemented material over uncemented material, it would be wise to contract out initial work. MWR should develop an oversight and interpretation capacity and avoid committing resources to data acquisition until the effectiveness and level of use of the refraction method are demonstrated.

- When future throughflow studies are conducted, or if there is sufficient interest in the existing sites, or conditions prevent seismic refraction from being effective, seismic reflection should be employed.

7.3.2 Determining Groundwater Velocity

- Advanced hydraulic testing being conducted by MWR staff should continue.

- A tracer test should be conducted at one of the throughflow sites to evaluate the utility of the method and for comparison with the hydraulic testing approach. The tracer test can be either of the two types discussed. Although the current staff has not conducted a tracer test, they should be able to do so.

Chapter 8

DEVELOPMENT OF GEOPHYSICAL CAPABILITIES IN THE MINISTRY OF WATER RESOURCES

8.1 Introduction

The development of geophysical abilities in MWR requires a variety of resources, including staff, interpretation software, and equipment. At this early stage, MWR should focus on staff development and identification of useful methods. Staff should concentrate on the improvement of interpretation skills and contract oversight. After the staff gains more experience with the methods, it will be possible to determine which ones merit the development of in-house data acquisition capabilities. Seismic refraction and electrical methods are likely candidates. Gravity and small-scale seismic reflection are less likely candidates, but may merit consideration in the long term.

8.2 Staff Development

The current geophysics staff needs to work closely with the project staff and be fully integrated into projects. They have considerable experience with gravity, seismic refraction, and electrical resistivity methods and should be given the opportunity to demonstrate them. Additional training is needed in the use of transient electromagnetics. It is expected that the staff can develop this capability by close involvement in the proposed contract survey for salt water intrusion monitoring. Because seismic reflection is likely to play a significant role in regional assessment and throughflow studies, consideration should be given to adding a staff person with suitable experience. Borehole geophysics is an important aspect of MWR's drilling programs, which are expected to increase considerably. For this reason, an individual with geophysical log interpretation experience is also desirable. The geophysics group needs a person who can manage contracts, promote geophysics within MWR, and explore new approaches and methods.

The geophysics staff has experienced expatriates and two Omanis who have not yet had much practical experience. The specialized nature of geophysics makes adeauate learning difficult without a formal course of study. Promising Omanis should be sent to study abroad. In the near term the Omanis should be given the opportunity to participate in field operations and data processing. This experience will provide an excellent basis for future learning. Specific recommendations regarding the advanced training of Omanis in geophysics and hydrology are discussed in Chapter 11.

8.3 Interpretation Software

Interpretation software is essential to properly planning and interpreting a geophysical program. MWR should not be totally dependent on a contractor to provide data analysis. An exception to this is large seismic surveys where specialized computing systems are required. Specific software recommendations are given in Table 7-1.

8.4 Instrumentation

The establishment of a data acquisition capability for any geophysical method involves some risks. The proper instrumentation must be obtained but may not perform as desired in the particular setting that is of interest. Considerable time may be required to become familiar with the equipment and more time will be required to develop and maintain an efficient field operation. Equipment maintenance can become a significant resource commitment. Previous MWR experience with borehole instrumentation has demonstrated the difficulties of keeping complex equipment in proper repair. The equipment discussed here can only be repaired at the original manufacturing facility. There is also a tendency to overuse in-house equipment because of its ready availability on projects for which it is ill suited, This can divert a project from the real issues. On the other hand, in-house instrumentation permits smaller jobs to be implemented and makes it easier to explore new ideas. In general, the commitment of resources should be postponed until the utility of a method and a persistent need for it have been demonstrated. Even at that time, consideration should be given to renting the required instrumentation.

Because of the uncertainties regarding the applicability of some geophysical methods in Oman, MWR should not establish geophysical data acquisition capabilities at this time. A more prudent approach will be to contract out the initial data acquisition programs. This will yield quicker results in the short term and will not bias the development of geophysical operations in the long run.

8.5 Specific Geophysical Methods

8.5.1 Transient Electromagnetics

Transient electromagnetics promises to be exceptionally useful. It is suggested that a contractor be brought in to demonstrate the method and assess its applicability in Oman. Initial studies to which TEM should be applied are the detection of salt water intrusion, throughflow cross-section analysis, and selected areas of Wadi al Batha. The staff should develop an interpretation capacity prior to the arrival of the contract crew by working with the appropriate interpretation software (Table 7-1). Some induction logging will be required to make the most of the TEM studies and can precede the TEM work in specific areas of interest, helping to define the parameters of the field survey. TEM may prove to be of sufficient use to justify an in-house data acquisition capability at a later date.

8.5.2 Frequency Domain Electromagnetics

Frequency domain electromagnetic data have already been collected by Hydrotechnica at two throughflow sites but have not been interpreted. It is recommended that the geophysics staff be given the opportunity and the resources to complete this test of the method which will require the acquisition of advanced interpretation software (Table 7-1). It should be recalled that the method is unlikely to give accurate depths to bedrock but will hopefully identify sections with similar characteristics so that drilling can be done more efficiently.

8.5.3 Resistivity

Resistivity can be an effective way to determine subsurface electrical properties. The current expatriate staff has considerable experience with the method. Resistivity is not effective at sites that are rocky, dry, or have limited horizontal uniformity. TEM does not have these restrictions and is preferred in most cases. In some situations there is a benefit to conducting both resistivity and TEM soundings at the same site in order to reduce interpretation ambiguities. Advanced interpretation software for the resistivity method should be obtained at this time (Table 7-1). However, MWR should not commit too many resources to resistivity methods until the staff becomes more familiar with transient methods.

8.5.4 Gravity

Gravity methods can identify general basin characteristics such as thickness of unconsolidated material. The complexity of the host rocks in Oman will make interpretation difficult in many areas. It is also likely that extensive gravity data exist for parts of the country as a byproduct of petroleum exploration. This could be a valuable resource and should be investigated. A gravity survey should be conducted by a contractor in selected parts of Wadi al Batha to determine the utility of the method in that area. It is unlikely that the gravity method will give precise depths to bedrock but it may serve to rapidly identify areas where the bedrock depths or complexity require seismic reflections methods. If any in-house data acquisition is contemplated, the use of differential mode Ground Positioning System (GPS) should be considered for survey operations. The geophysics staff needs advanced gravity interpretation software (Table 7-1) so that an interpretation capability can be developed.

8.5.5 Seismic Refraction

Seismic refraction may help determine depths to bedrock in wadi throughflow studies and in shallow basins such as those in the Wadi al Batha drainage. Difficulties are likely to occur in some areas because of cemented gravels, but this should not disqualify the method from use in all situations. The expatriate geophysics staff is well acquainted with the method and should be given the opportunity to evaluate it in Oman's field conditions. This could be accomplished by having an experienced contractor perform several surveys in selected areas of Wadi al Batha and one of the throughflow sites to determine the utility of the method. It will be important to test the utility of ballistic seismic sources because they may provide an attractive alternative to the more restricted use of explosives. It may be desirable to develop an in-house data acquisition capability after the utility of the method has been demonstrated.

8.5.6 Seismic Reflection

Seismic reflection is an advanced method that requires a large crew and considerable planning. It will be particularly critical for studies of basin structure in the Wadi al Batha and throughflow geometry. Seismic reflection on the proposed scale can only be performed by an experienced contractor and careful oversight is required. The current staff lacks sufficient experience to oversee a reflection program.

8.5.7 Borehole Geophysics

MWR is using borehole geophysics as an effective part of its drilling programs. Previous experience highlighted the difficulty of maintaining complex instrumentation in the rugged environments of Oman. Logging operations can be separated into two classes: measurements made in an open hole as part of a drilling program, and measurements made to monitor changes in a hole as part of a repetitive program. In the first case, a wide variety of tools are used only occasionally. This type of work is best handled by a contractor. In the second case, fewer tools are used but more often.

Consideration was given to purchasing instrumentation for the second class of measurements, in particular for the fluid conductivity logs currently used for salinity monitoring. Because of serious concerns regarding the adverse impact of fluid flow in the well on fluid conductivity logs, this method is not considered to be particularly useful for monitoring saline intrusion as it can give very misleading results. Induction logging in properly constructed boreholes where interformation fluid flow is eliminated is preferable. Because it is not clear how much induction logging MWR will be conducting, it is premature to purchase an induction logger. Instead, a local contractor should be encouraged to develop the capability. In any case, the lessons learned from the difficulty of maintaining previous borehole instrumentation should not be forgotten. Attracting a competitive logging contractor to the market is also desirable. This is best done by providing more contract work, not by doing more work in house. The geophysics staff needs to develop the capacity for more logging interpretation and oversight of contracts. Quality control of logging contracts is important and should be given more attention. This task should be assigned to one individual who would observe all logging programs, develop and monitor a quality assurance plan, and develop a repository for the information. Because drilling (and hence geophysical logging) is likely to increase considerably, MWR should consider hiring an individual experienced in geophysical log interpretation. The project hydrogeology staff should bring the geophysics staff in early on logging programs. Appropriate interpretation software should be obtained (Table 7-1).

8.5.8 Airborne Electromagnetics

Airborne electromagnetics has promise of becoming a valuable tool for regional assessment. It may be able to tackle such difficult problems as the regional extent of shallow aquifers and the extent of shallow fresh water resources in otherwise saline areas. Before a contractor is brought in, ground electrical surveys should be done to determine if the particular hydrogeologic issue can be approached with electrical methods in general and used to model if airborne methods are appropriate. Because of the regional utility of this method, careful consideration should be given to this issue.

Chapter 9

PURCHASING RECOMMENDATIONS

No data acquisition equipment should be acquired until the utility of the instrumentation and a continuing need have been proved. The geophysics group should concentrate on developing interpretative abilities in all of the methods discussed. This will require the acquisition of appropriate computer hardware, software, and reference materials. Table 7-2 lists the required computer hardware and justification for the specifications. It is critical that the specifications be followed; if a less capable machine is substituted the software will not function and the system will have no value. Table 7-1 lists the software that is required to make the system useful.

A significant amount of general field equipment will be required. This will include a GPS, survey instruments, fluid conductivity and water level indicators, calculators, and possibly camping equipment. The exact details of most of these needs cannot be determined until the field operations are planned.

It is important that the geophysics staff be given the opportunity to develop a small library of geophysical references. A necessary start is a subscription to Geophysics (Society of Exploration Geophysics, Tulsa, Oklahoma) and Geoexploration (Elsevier Scientific Publishing Company, Amsterdam).

Table 7-2

Recommended Computer Hardware for Geophysics

Office Machines (2 required)

Specification	Rationale
IBM compatible, 386 25 mhz or faster	many geophysical interpretation packages only run on IBM machines and are computationally intensive; slower machines greatly reduce productivity
Math co-processor	many geophysical interpretation programs require this
150 megabyte hard disk or greater	large volumes of information must be stored
VGA graphics	many geophysical interpretation programs require this
Tape back-up	to preserve data
3.5 inch floppy drive	for loading software
connection to local area network	to share information
power conditioner	to protect against power fluctuations

Field Machine (1 required)

Specification	Rationale
IBM compatible, 386 processor	for in field data processing and quality control
Math co-processor	many geophysical interpretation programs require this
battery powered digitizer	for digitizing maps
printer	for hard copy output
plotter	for hard copy output

Chapter 10

CONTRACT MANAGEMENT

Successful use of a geophysical contractor requires close cooperation among the project hydrogeology staff, geophysics staff, and the contractor. The hydrogeology staff must clearly state the hydrologic objectives. The geophysics staff must understand the issue and analyze it in a geophysical sense and must also prepare the contract specifications, closely monitor contract performance, and play an active role in data interpretation. If the staff does not write the contract, it will be less able to perform the critical roles of contract oversight and to relate the geophysical results to the hydrogeology. The writing of the contract can serve as a check early in the process. For this reason external help should not be obtained for the sole purpose of writing the contract. If external help is obtained it must include assistance in contract oversight (in the field) and data interpretation. An international guide to geophysical contractors, "The Geophysics Directory," is published by the Society for Exploration Geophysics in Tulsa, Oklahoma, USA.

Chapter 11

TRAINING OF OMANI MWR STAFF FOR GEOPHYSICS WORK

Geophysics and hydrogeology are technically demanding disciplines. A qualified individual who can work independently must follow a formal course of study and obtain considerable practical training in field work and crew management. While practical training can be obtained in Oman, a formal course of study requires a sizeable student and faculty population in the given specialty and is best accomplished through enrollment in a foreign university.

There is an unfortunate tendency to select the best students, grant them a stipend, and send them away for a few years to earn an advanced degree. This is a poor approach. The first obstacle is getting the student accepted to a suitable program. It is difficult for universities to evaluate a student based on standardized exams, and there is a reluctance to accept students without direct communication. When a foreign student enrolls in the university, the faculty is not sure of the student's needs and will frequently direct him to an inappropriate program. The student returns home confused and without taking full advantage of the opportunity.

MWR can improve the situation by developing relationships with a few universities that are likely candidates for students' enrollment. The universities should be encouraged to send one or two of their faculty members to Oman for an informal lecture series. This will provide them with an opportunity to acquaint themselves with potential joint projects with MWR and to meet prospective students. The university faculty should be encouraged to submit a proposal to conduct a research program involving training for Omani students at the foreign university and field work in Oman. If MWR feels the proposal is of sufficient interest and that the foreign university is truly dedicated to the project, funding for the proposal should be developed.

This approach has many advantages. First, MWR has the assurance that its best candidates will be educated appropriately. When the students finish, they will be familiar with issues of interest to MWR. The active involvement of the student's advisor in a funded research project assures that the advisor will have increased interest in the project and the student. The lecture series will be a vehicle to introduce new ideas to MWR. This method of education, where students are effectively granted research projects along with educational expenses, will be more costly per student. However, the quality of the education will be higher because of the increased involvement of the student's advisor and the relevance of the topic.

Candidates for foreign training need to be exposed to the practical realities of work in Oman so that they have a frame of reference for discussing their education. They should also be exposed to foreign travel prior to the several years that are required for an advanced degree. Language skills and self-motivation are critical and need to be stressed. There should be a clear incentive for advanced education so that the student knows his successful work will be rewarded when he returns. In order to retain Omanis with advanced training MWR must provide opportunities as attractive as those available elsewhere to the foreign-trained Omani upon his return. MWR should consider allowing promising staff to take university courses in Oman during the first year or two of employment, prior to foreign training. This will correct deficiencies that may prevent acceptance into advanced programs and to identify the best candidates for foreign study.

Currently there is a required waiting period of two years between employment and the prospect of advanced foreign training. In some specialties where the number of potential candidates is small and all are new hires, this means that no advanced training will take place for two years. Consideration should be given to accelerating this process. The training may even be more effective because students could maintain the momentum of their undergraduate education. Specialties within the hydrological sciences important to MWR should be identified. A training program for each specialty should be developed to ensure that a critical component is not ignored or excessively delayed. Specialties may include aqueous chemistry, aquifer analysis, ground and surface water modeling, and geophysics.

Chapter 12

SUMMARY OF RECOMMENDED STEPS

The program outlined in this report can be implemented by carrying out the following steps promptly. Failure to act decisively will hamper progress on many fronts within the Ministry. On the other hand, the successful development of a functional geophysics department can add substantially to progress and reduce markedly the amount of funds spent to define subsurface conditions in Oman.

- A reflection seismologist who can also act as a dynamic leader for the geophysics group should be hired immediately. This person must be able to promote geophysics within MWR and integrate geophysics and hydrogeology.

- Interpretation software and hardware (Tables 7-1 and 7-2) should be acquired and its use mastered by the department.

- An Omani who has a suitable background for advanced training in the application of geophysics to hydrogeologic issues should be identified.

- The geophysics and saline intrusion monitoring staffs should conduct field trips to plan lines for a TEM survey to support the salt water monitoring transects.

- The geophysics staff should conduct field trips with key people from the Research Department to plan profile lines for Phase 1 of the Wadi al Batha assessment and other assessment areas that may be nominated.

- The geophysics staff should prepare requests for proposals for TEM profiles in Wadi al Batha and in support of the salt water intrusion monitoring project. The requests should be advertised internationally.

- The geophysics staff should prepare requests for proposals for gravity and seismic reflection profiles in Wadi al Batha. The requests should be advertised internationally.

- The geophysics staff should prepare a proposal for conducting the gravity and seismic reflection profiles with MWR personnel and rented instrumentation.

- The contractor's bids and the geophysics staff's proposals should be considered and one of the two approaches chosen.
- All field operations should closely involve the geophysics staff.
- The results should be interpreted with respect to the relevant hydrologic issues.
- The geophysics group should strive to eventually develop expertise in all the methods discussed in this report.

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