FIELD REPORT

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

TASK 5: WATER MANAGEMENT
TASK 6: TECHNOLOGY DEVELOPMENT

APPLICATIONS FOR REMOTE SENSING
Part 8

WASH Field Report No. 353
December 1991

WATER AND SANITATION for HEALTH PROJECT

Sponsored by the U.S. Agency for International Development
Operated by CDM and Associates

WASH Field Report No. 353

Part 8

APPLICATIONS OF REMOTE SENSING

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

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December 1991

Water and Sanitation for Health Project
Contract No. DPE-5973-Z-00-8081-00, Project No. 936-5973
is sponsored by the Office of Health, Bureau for Research and Development
U.S. Agency for International Development
Washington, DC 20523

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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

Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through analysis of data acquired by a device that is not in contact with the subject under investigation (Lillesand and Kiefer, 1979). It encompasses a spectrum of activities and is frequently used in investigations of water resources. This section discusses the application of Landsat, SPOT satellite imagery of the earth's surface, and other remote sensing technologies including radar, meteorological satellites, and aerial photography and imagery.

The scope of work outlined the following activities:

- Review the key data acquisition needs, including monitoring of changes in the extent of saline intrusion by detection of crop stress

- Evaluate remote sensing in relation to the water resources data needs of Oman

- Develop a program for data acquisition by appropriate modern technological methods, and identify the equipment, personnel, and logistical support needed for this program and for pilot projects as appropriate

- Identify the most suitable imagery and assist MWR to prepare specifications for the procurement of new equipment

Chapter 2

SUMMARY

2.1 Findings and Conclusions

- Satellite imagery is a cost-effective method for data acquisition and a primary data source for water resources investigations. Remote sensing can be of value in fulfilling the ongoing mission of MWR.

- The most important application of remote sensing is in determining agricultural water use in Oman, especially in the critical areas of the Batinah and Salalah plains. Such data can help MWR formulate sensible water use management policies.

- The United Nations Food and Agriculture Organization (FAO) is currently using large-scale aerial photography to map agricultural land use at Salalah and on the eastern Batinah, and estimating water use for selected farms in these areas. This information can be used to determine the accuracy of satellite imagery for national and historical water use studies.

- Satellite imagery can be used for investigations in groundwater and surface water hydrology, development of geographic information systems (GIS), and as a management tool.

2.2 Recommendations

- Every effort should be made to obtain the results of the FAO study, the first phase of which will be completed in December 1991.

- MWR should engage a qualified contractor to conduct a land and water use pilot study for the eastern Batinah plain, using Landsat TM and SPOT remote sensing imagery. The FAO maps should be used in place of ground surveys to check the accuracy of the results, which will determine the feasibility of satellite imagery for nationwide and historical water use studies. Estimated cost of the pilot study is R.O. 55,000.

- Subsequent uses of remote sensing for agricultural water use assessment and acquisition of in-house capabilities should be based upon the outcome of this study.

- A comprehensive land and water use study for other developed areas in the country should follow the pilot study. Estimated cost is R.O. 70,000.

- An analysis of historical land and water use in the eastern Batinah should be conducted as part of the regional assessment program to provide information for a comprehensive water use and management plan for that area. This project could run concurrently with the national land and water use study. Estimated cost is R.O. 40,000.

- MWR should obtain image interpretation training for its personnel.

- If the pilot study for the eastern Batinah is successful, MWR should retain a remote sensing specialist and acquire appropriate computer hardware and software for image processing. All work done in-house should be supervised and coordinated by a specialist based in a computing services support department. This will ensure that the work is accurate and that all parts of MWR are served. Equipment costs will be approximately R.O. 60,000.

Chapter 3

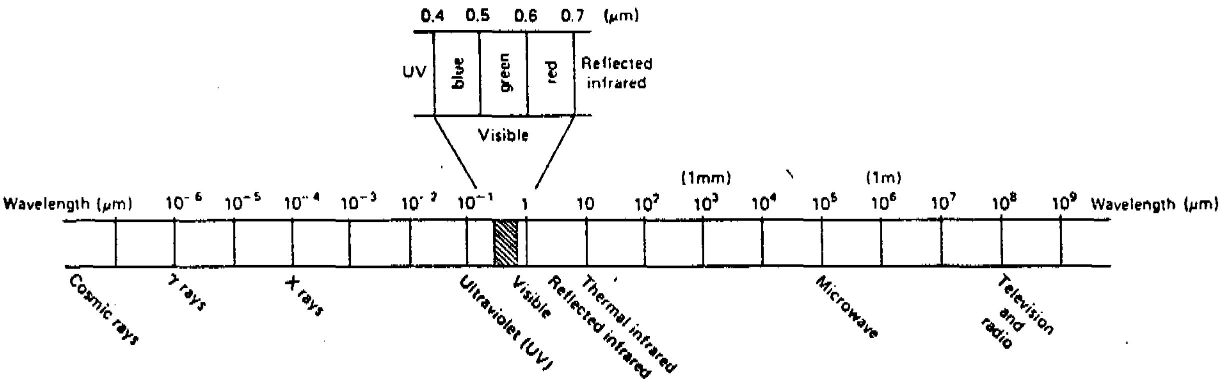
METHODS

3.1 Introduction

Visible light is one form of electromagnetic energy (Figure 8-1), which includes radio waves, X-rays, microwaves, and ultraviolet rays. Each type of electromagnetic radiation has a characteristic wavelength. The wavelengths of visible light vary across the familiar rainbow spectrum, from blue light at 0.4 micrometers (μm) to red light at 0.7 μm. Ultraviolet radiation has wavelengths slightly shorter than blue light, while infrared radiation, microwaves, and radio waves all have wavelengths longer than visible light.

Figure 8-1

The Electromagnetic Spectrum
(from Lillesand and Kiefer, 1979)



Satellite imagery can record reflected and emitted electromagnetic radiation across the electromagnetic spectrum, including visible light, ultraviolet and infrared radiation, and microwave energy. Reflected and emitted electromagnetic radiation detected by satellites, like visible light detected by the human eye, can enhance our understanding of nature.

Satellite imagery differs fundamentally from photography (Figure 8-2). Photography uses a lens to record visible light (as well as ultraviolet and near-infrared wavelengths) on light-sensitive film. Satellite imagery uses electronic sensors to detect the intensity of certain wavelengths of electromagnetic radiation emitted from a scene. Each scene "viewed" by a sensor is recorded as a single number indicating the intensity of radiation within a specific frequency range. The image of an object comprises many discrete measurements of the radiation from small parts of the object. Each of these measurements is termed a pixel (picture element). To record the natural color of an object, three sensors are required to register the intensity of blue, green, and red light respectively.

A satellite image can be reproduced as a raster image (a grouping of pixels) on a video display or on photographic film. The colors used to reproduce a satellite image must be arbitrarily designated in the case of invisible wavelengths, since we can only distinguish red, green, and blue light. The most familiar types of false-color images are those made with green light depicted as blue, red light depicted as green, and infrared depicted as red. Since vegetation is highly reflective in infrared wavelengths, these images depict vegetation as bright red.

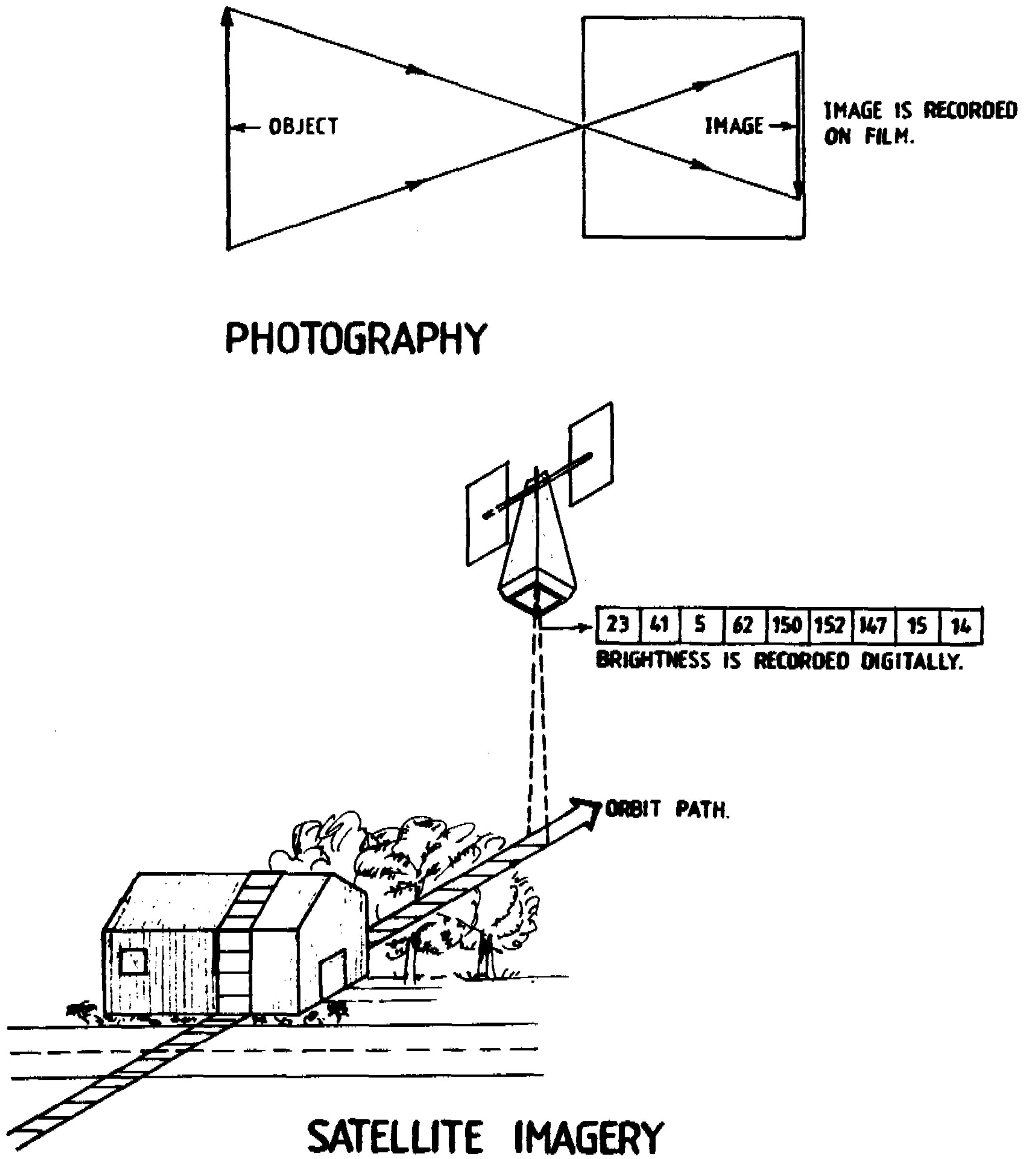
3.2 Landsat and SPOT

The imagery obtained from a satellite may be described in terms of its spatial, temporal, spectral, and radiometric characteristics. Both Landsat and SPOT obtain scanned imagery of almost the entire earth's surface. Table 8-1 summarizes the characteristics of the sensors on Landsat and SPOT satellites. The satellites circle the earth every few hours in near-polar orbits (from pole to pole—Landsat at an altitude of 705 km, SPOT at 832 km). They scan a small swath of land (e.g., spatial resolution of 79 m for the Multispectral Scanner [MSS]) every few seconds, returning to the same location every few weeks (e.g., temporal resolution of 18 days for Landsat 1, 2, and 3).

The satellites record the reflected and emitted electromagnetic radiation from the earth within selected frequency ranges (e.g., MSS has four-channel spectral resolution) as numeric brightness values (e.g., MSS indicates an integer reflectance level between 0 and 63 for each channel, so it has 64 levels of radiometric resolution per channel). The frequencies recorded by the sensors range through the visible spectrum and the photographic infrared, and, for the Thematic Mapper Sensor (TM), into the thermal infrared (up to 12.5 μm).

Landsat (originally known as ERTS), owned by the U.S. National Aeronautics and Space Administration (NASA), has provided imagery of the earth's surface on a regular basis since 1972 (although no imagery of Oman was obtained from 1973 to 1977 and from early 1979 to late 1983). The quality of Landsat imagery was advanced greatly in 1982, when TM was deployed on Landsat 4, supplementing the MSS used on all Landsat satellites to date. TM provides much greater spatial, spectral, and radiometric resolution than MSS. Landsat 4 and Landsat 5 (launched in March 1984) remain in operation to this date. (Landsat 1, 2, and 3 have been decommissioned.) Landsat 6, scheduled for launch in 1992, will supplement its TM sensor with a high spatial resolution panchromatic sensor (15 m resolution versus 30 m on existing TM channels). Landsat operations and image distribution are managed by EOSAT (Earth Observation Satellite Company, Lanham, Maryland). Landsat receiving stations that can record imagery of Oman are located in Saudi Arabia and Pakistan.

Figure 8-2



PHOTOGRAPHY VERSUS SATELLITE IMAGERY

NOT TO SCALE

Table 8-1

Characteristics of Landsat and SPOT satellites

Sensor	In Operation Since	Return Time (days)	# of Bands	Radio-metric Reso-lution	Scene Size (km)
MSS (on Landsat 1 - 5)	July 1972	16-18[a]	4	64	170x185
TM (on Landsat 4 & 5)	July 1982	16	7	256	170x185
HRV (on SPOT 1 & 2)	Feb. 1986	26[b]	4	256	60x60

Sensor	Band #	Wavelength (μm)	Description	Spatial Resolution (m)
MSS	4[c]	.5 - .6	green	79
	5	.6 - .7	red	79
	6	.7 - .8	reflected infrared	79
	7	.8 -1.1	reflected infrared	79
TM	1	.45 - .52	blue-green	30
	2	.52 - .60	green	30
	3	.63 - .69	red	30
	4	.76 - .90	reflected infrared	30
	5	1.55 -1.75	reflected infrared	30
	6	10.4 -12.5	thermal infrared	120
	7	2.08 -2.35	reflected infrared	30
HRV	P	.50 - .73	panchromatic	10
	XS	.50 - .59	green	20
	XS	.61 - .68	red	20
	XS	.79 - .89	reflected infrared	20

Notes
a— 18 days on Landsat 1-3; 16 days on Landsat 4-5
b— SPOT can image areas more frequently using its adjustable viewing angle
c— Channels 1, 2, and 3 were for the relatively unsuccessful Return-beam vidicon (RBV) sensor on the early Landsats. On Landsat 4 and 5, which have MSS and TM sensors but not RBV, the MSS bands were renumbered 1-4.

Sources
Landsat: Sabins, 1986
SPOT: SPOT IMAGE Corporation.

SPOT 1 (Systeme Probatoire pour l'Observation de la Terre), operated commercially in France (with co-ownership by Belgium and Sweden), was launched in 1986. The two HRV sensors (Haute Resolution Visible) on SPOT provide greater spatial resolution than Landsat but offer less spectral resolution than TM. SPOT can also provide customized satellite coverage to produce greater temporal resolution of a scene, create stereo imagery and digital terrain maps, and offer rapid response to specific requests. SPOT receiving stations are located worldwide and include a station in Saudi Arabia operated by the Saudi Center for Remote Sensing at the King Abdul Aziz City for Science and Technology, and a station in Pakistan near Islamabad. SPOT 2, launched in January 1990, and the planned SPOT 3 have specifications identical with SPOT 1, which is still in use. SPOT 4, planned for launch in 1995, will replace the HRV sensor with the HRVIR sensor. HRVIR will have an additional near-infrared channel (1.58 to 1.75 μm) and different spectral characteristics for the 10 m resolution band (Brachet, 1990).

3.3 Weather Satellites

Weather satellites, which have been in use for over 30 years, detect the temperature of cloud cover and provide continuous coverage of a selected area, rather than periodic imagery of the entire globe. They generally have much lower spatial resolution (e.g., NOAA AVHRR satellites have 1 km resolution) than Landsat and SPOT, but provide better temporal and spectral resolution of information relevant to meteorological forecasting (e.g., better resolution of thermal infrared frequencies). While Landsat, SPOT, and some weather satellites are in near-polar orbits, many weather satellites, such as the European Space Agency's Meteosat, are in geostationary (fixed position) orbits above the equator. MWR has commissioned a number of studies that used weather satellite data to investigate the weather patterns that produce rain in Oman (e.g., Barrett, 1990). Tasks 3 and 4 of the WASH report (1991) discussed future uses of such information at MWR. The only activity of the present task pertaining to these satellites was to help MWR acquire the telecommunications equipment and computer software to receive weather satellite imagery.

3.4 Radar

While satellite imagery is a passive system that measures reflected and emitted electromagnetic radiation, radar (Radio Detection And Ranging) is an active system. Radar transmits a microwave signal (within wavelengths of 1 mm and 1 m) and measures the response of the targeted surface. Radar can penetrate clouds and is thus especially useful in detecting precipitation and imaging the earth's surface in areas where cloud cover prevents the use of satellite and conventional aerial imagery. Radar systems can be operated from the ground (e.g., to observe clouds) or from airborne equipment (e.g., to map the earth's surface). Side-looking airborne radar (SLAR) is the most common use of airborne radar for detecting earth features. Radar images of much of the earth's surface (including Oman) were obtained by the NASA Columbia space shuttle (see Section 4.3).

3.5 Aerial Photography and Imagery

Aerial photography was the first "modern" technique for remote sensing of water resources. Photography uses light-sensitive film as its recording medium, as opposed to the digital signal obtained by optical scanners, and is a means of obtaining detailed maps of the earth's surface. Photography can detect some ultraviolet (0.3 to 0.4 μm) and near-infrared frequencies (0.7 to 0.9 μm) invisible to the eye, but cannot detect far-infrared radiation, which can be measured by scanners.

Aerial imagery applies the principles of satellite imagery at much greater resolution. While satellite imagery has at most 10 m spatial resolution and 7 bands of information, aerial scanners can obtain much greater spatial and spectral resolution (as many as 128 channels) and are used where high-resolution data are needed.

Chapter 4

POTENTIAL APPLICATIONS

4.1 Land Use Assessment

Assessment of agricultural lands is one of the most common uses of remote sensing technology. Cropped area can be readily determined from reflected infrared light because vegetation is highly reflective in this range and from its strong absorption of red and blue wavelengths in the visible spectrum (which leads to the green color of most vegetation). It is also possible to quantify irrigated acreage. Crop types and their vigor can be determined by spectral response patterns. Agricultural change mapping is helpful for understanding trends in land use. Remote sensing can also be used to assess land and water use in pasture and rangeland, although there are difficulties in employing it in arid environments (see Section 4.3).

The vigor of vegetation can be determined from the intensity of reflection of infrared light; stressed vegetation produces less chlorophyll and thus absorbs less blue and red energy. Changes in leaf structure due to stress also affect reflectance of infrared energy between 0.7 and 1.3 μm. Stress detection can provide clues to moisture deficiencies, saline conditions, mineral deficiencies, disease, and infestation, but is generally more difficult than type classification. It is most successfully applied to vegetation in a small area, where slight changes in spectral reflectance patterns are likely to be due to stress rather than a result of lighting and crop conditions. No studies for detecting stress in date palms were identified in research for this report.

Crop types can be distinguished by color and reflectance patterns, often by examining imagery obtained at different stages of the growing cycle.

Agricultural water use can be estimated from remote sensing imagery if the water requirements of each crop type and local practices are known and imagery obtained on several dates. Thermal infrared imagery is best, as moisture is most easily detected at these frequencies. Latham et al. (1983) used the results of an irrigated lands survey in Libya as input to a hydrological model of the area, which was suffering from sea water intrusion.

Remote sensing can be used to detect the changes in an area over time by comparing images from different periods. Change mapping can be used to show development patterns, such as the expansion of agriculture in one area and its abandonment in another.

4.2 Surface Water Hydrology

The most common uses of remote sensing in water resources work are for surface water investigations, especially flood studies, water pollution detection, water quality measurements, and watershed physiography analysis. Weather satellite data interpretation may also be considered within this category.

The most relevant of these applications for MWR are flood studies and watershed physiography. Flood studies typically use aerial photography shortly after a flood to determine the wetted area. This application may be of limited use in Oman, where flood conditions are extremely short-lived and frequently occur at night (Wayne Curry, personal communication). Consideration should be given to the rapid post-storm deployment of helicopters to photograph flooding along the length of wadi channels. Infrared photography is frequently used in these investigations because of the high absorption of infrared energy by water and moist surfaces. Satellite imagery can also be used where imagery is available for the period of interest.

Studies of watershed physiography can be greatly enhanced by remotely sensed imagery. Watershed delineations can often be distinguished much more readily from aerial photograph or satellite images than in the field. Change maps of physiography can be used to determine erosion and sedimentation trends occurring over seasons or years. Imagery can also be used to track the temporal and spatial extent of intermittent streams that occur in the upper parts of many watersheds in Oman.

As discussed in Tasks 3 and 4 of the WASH report, weather satellite imagery could track the origin and history of storms that produce significant precipitation in Oman and would be of use in rainfall distribution studies.

4.3 Groundwater Hydrology

Satellite imagery can be used to identify sites of groundwater recharge and discharge and groundwater pathways. It is also helpful in determining geology, providing valuable inputs to hydrological investigations. Although satellite imagery cannot indicate the depth of the water table, such indicators as soil moisture, vegetation types and distribution, surface sediment types, and locations of springs and seeps can identify groundwater flowpaths. Jones et al. (1988) used Landsat TM imagery for terrain classification in the Wahibah Sands, while McBean (1988) used TM, synthetic aperture radar obtained by the Columbia space shuttle, and a field radiometer for land cover classification in the same area.

Soil moisture can be determined from thermal infrared imagery; springs and seeps show up visibly, or can sometimes be detected thermally. Thermal imagery is usually best at night and is also sensitive to the time of year; the investigator must obtain imagery at a time when the phenomenon is most apparent. For example, researchers mapping the location of groundwater springs off the coast of the United Arab Emirates (UAE) used aerial scanned thermal imagery in February and March, when the ocean was at its coldest, providing the best contrast with the warmer groundwater (Thomson and Nielson, 1980).

In many locations, vegetation types can be used as indicators of groundwater conditions. This has been more difficult in arid lands, as it has not been possible hitherto to quantify vegetation cover of less than 40 percent. Recent research using TM imagery has been successful in computing vegetation fractions at lower levels (Smith et al., 1990), so that use of satellite imagery for detecting desert vegetation may become more common in the near future.

4.4 Geographic Information Systems

Geographic information systems (GIS) are computerized databases that contain geographically referenced data and permit the integration of spatially referenced data, such as well water levels, with digital maps. Computer software developed for satellite image interpretation is one type of GIS. The raster images produced by such software may also be interfaced with vector-oriented GISs such as ARC/INFO (where geographic features are represented by connected points).

Raster imagery can be used in two ways in a GIS: as a background image for vector data overlays, and in vector database development. In the latter application, features such as roads and drainage divides may be digitized from the raster image into a less data-intensive vector form. Similarly, a land use map (or other image classification) can be converted to vector-GIS form, permitting the use of the interpreted results by users who do not have access to the original images. Kay (1988) used a TM image as a basemap in a comprehensive GIS developed for an 8 sq km area in the Minitrib area.

Although using remote sensing data in a GIS is not in itself a method of water resources assessment or management, the combination is extremely helpful. For instance, a land use map of cultivated area derived from remote sensing imagery could be combined with a GIS containing wilayat boundaries to produce a table of agricultural acreage by wilayat.

Chapter 5

PREVIOUS WORK

Several remote sensing studies of water resources have been undertaken in Oman in the past. These include five remote sensing projects conducted for the Regional Development Council and the Public Authority for Water Resources (PAWR), MWR's predecessor organization, between 1979 and 1986, work by the Japan International Cooperation Agency for MAF (JICA, 1990), and a 1988 study by World Exploration Consultants for the Royal Court. The earliest project was conducted for the Water Resources Council in 1978 (EscaTech, 1978).

Three studies were undertaken by Earth Satellite Corporation (EarthSat, Chevy Chase, Maryland, 1979, 1982, 1985), several pilot studies were conducted by JICA (1986), and the Omani-American Joint Commission sponsored a training and needs assessment program (Smigielski, 1985; Blanchard, 1985).

The 1978 EscaTech study used a November 1972 image of the Dhofar region to compile 1:250,000 land use and soil maps. The 1979 EarthSat study included a broad analysis of the hydrology of northern Oman using four MSS images from December 1978 and January 1979, and an investigation of the mineral resources of the region and a land use classification exercise. It assembled a 1:500,000 scale basemap from the four Landsat images used in the study, as well as overlay maps showing water, mineral, and land use evaluations. In 1982, it mapped vegetation distribution and density in northern Oman using seven MSS images obtained in October and November 1972. In 1985, it prepared a map showing changes in agricultural land use in the Buraimi area using MSS imagery from November 1972 and May 1984.

JICA conducted a number of studies using satellite imagery in 1986. They used six MSS images from October and November 1972, December 1978, January 1979, October 1981[1], and June 1984. Their primary objective was analysis of vegetation distribution and change mapping and geomorphological analysis using Landsat MSS imagery within wadis Ahin, Bani Ghafir, Fara, Bani Kharus, and Ma'awil. Investigations of rainfall distribution and soil moisture were conducted using weather satellite imagery. The JICA studies concluded that their analysis could be used to estimate annual regional rainfall distribution but not for more detailed determinations.

The JICA Master Plan for Agricultural Development (1990) estimated cropped area nationwide using Landsat images covering northern Oman (four scenes) and Dhofar (two

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[1] The October 2, 1981 image reportedly used by JICA does not show up in the list of available imagery in Table 8-2.

scenes). Acreage for 1984-1985 was estimated using MSS imagery from January and May 1984 and January and February 1985. Acreage for 1986-1987 was estimated using MSS and TM imagery from January and February 1986 and January 1987. Vegetation was classified as either dense or coarse. The results indicated that total vegetated area increased by 20 percent, from 59,000 ha to 71,000 ha, over the two-year study period, with densely vegetated areas increasing from 24,000 ha to 31,000 ha.

The Environmental Research Institute of Michigan (ERIM) conducted a series of remote sensing seminars and evaluation for PAWR and the Ministry of Communications Directorate of Meteorology under the sponsorship of the Omani-American Joint Commission in 1985. The final reports contained a number of recommendations for training and equipment to develop local remote sensing expertise.

World Exploration Consultants (1988) conducted a study of the mineral and water resources of the Sultanate using satellite imagery. The conclusions of that report are too general to be of use in MWR's work.

Chapter 6

INSTITUTIONAL SETTING

6.1 MWR Mission

The 1991-1995 Five-Year Plan for MWR (1990) includes a general discussion of activities, of which those listed below could benefit from the use of remote sensing data:

- Assessment of resources
- Water use monitoring
- Development of management criteria
- Enforcement of water use permits and control of extraction

6.2 MWR Sections Interested in Remote Sensing

During interviews conducted for this report, personnel in the Management Directorate, the Regional Affairs Directorate, and the Research, Groundwater, Surface Water, and GIS Departments of the Assessment Directorate expressed an interest in using remote sensing imagery.

The Management Directorate, which recently has been reduced in size, drew up a remote sensing study proposal between 1989 and 1991 to map crop types throughout the developed areas of Oman at approximately five-year intervals dating back to 1972. The final products were to include digital maps and change maps, raster images, and photographic images. The objective of the study was to establish a basis for land-use management and to determine the extent of changes in agricultural practices over the last 20 years. The proposal was rejected in part because it requested nearly 7,000 photographic images (Rendell, 1991).

The Regional Affairs Directorate, which now has many of the responsibilities previously delegated to the Management Directorate, is interested in using remote sensing imagery to determine current cropped areas and establish a basis for regulating future growth.

The Research Department of the Assessment Directorate is primarily interested in the use of remote sensing imagery for its regional assessment programs, including detecting areas of groundwater recharge and discharge, irrigated area change mapping, geological mapping, detailed hydrologic modeling, and determining physiography. The Wadi al Batha regional assessment project currently lacks any irrigated area inventories and geological mapping.

The Surface Water Department of the Assessment Directorate has commissioned a number of remote sensing studies of rainfall distribution in the past (Barrett, 1990). Future uses could be in the area of rainfall distribution as better methods are developed and in floodplain analysis.

The Groundwater Department of the Assessment Directorate is interested in the use of remote sensing data for water use assessment to establish groundwater usage within selected basins.

The GIS Department of the Assessment Directorate has recently begun to obtain digital maps of the Sultanate for plotting water resources data. It is considering a contract to obtain digital maps in ARC/INFO format that could be created from a basemap using remote sensing imagery.

6.3 Remote Sensing Elsewhere in Oman

Other agencies using remote sensing data are the FAO, the Directorate General of Meteorology at Seeb Airport, the Ministry of Petroleum and Minerals, and Sultan Qaboos University. Organizations contemplating the acquisition of such capabilities are the Ministry of Agriculture and Fisheries and the Planning Committee for Development and Environment in the Governorate of Dhofar (PCDEGD). Additionally, while the Supreme Committee for Town Planning does not conduct any remote sensing work, the head of its GIS department is trained in remote sensing techniques.

FAO is using aerial photography to map land use on the Batinah plain and has compiled a 1:20,000 map of land use between Bait al Barka and Wadi Abayadh which is being used by BRGM (Bureau de Recherches Geologiques et Minieres), under contract to the Ministry of Agriculture and Fisheries, to develop land use management plans for that area. By December 1991, FAO expects to complete 1:10,000 maps covering 46,000 ha of the eastern Batinah as far north as As Suwayq. The maps are being compiled from aerial photographs obtained in March 1989 and involve extensive ground surveys. The land use categories for these maps were not available for inclusion in this report. Land use classifications on the 1:20,000 map are presented below:

- Settlements
- Agricultural Land
    - date palms
    - other fruit trees
    - alfalfa
    - rhodes grass
    - vegetables
    - young plantations

other fodder
new farms

Nonagricultural Land

fallow
sparsely wooded
thickly wooded
scrub, bushes, and halophytes
wasteland
wadi channels

FAO is also conducting detailed inventories of wells and water use on farms within the study area that have been selected for the installation of modern irrigation technology. Another FAO team is conducting a soil survey of the entire Sultanate for MAF. The results of this project will be incorporated into an ARC/INFO database.

The Directorate General of Meteorology at Seeb Airport receives on-line cloud cover imagery from the Meteosat weather satellite.

The Ministry of Petroleum and Minerals is mapping the geology of Oman with the aid of remote sensing imagery. It has a PC-based system using ERDAS image processing software and a library of TM images of the country. BRGM, which is also undertaking field investigations for the study, is providing training support. Sultan Qaboos University has hardware, software, and imagery for remote sensing work. Its PC-based system uses ERDAS and ARC/INFO GIS software. Professor A.K. Bagchi of the civil engineering department has expressed an interest in cooperating with MWR in remote sensing investigations.

MAF and PCDEGD are considering the requisition of remote sensing imagery and in-house capabilities. At this writing, PCDEGD is evaluating tenders for a SUN work station with ARC/INFO software and is planning possible addition of remote sensing capabilities to the work station.

Chapter 7

AVAILABLE IMAGERY AND WARES

7.1 Imagery

Landsat and SPOT imagery are widely available both as digital data and through numerous vendors who can offer a broad range of interpretive services. Landsat imagery can be obtained directly through EOSAT, while SPOT imagery is offered by sales agents worldwide and by SPOT IMAGE. A single Landsat TM scene covering 170x185 km can be obtained in digital form for R.O. 1,525 (U.S. $3,960), while a single SPOT scene covering 60x60 km costs approximately R.O. 930 (U.S. $2,450). Current Landsat MSS data cost R.O. 385 (U.S. $1,000) per scene, while older MSS data cost R.O. 77 (U.S. $200) per scene. Complete processing costs for imagery (geocoding[2], annotating, filming, and creating mosaics) are approximately R.O. 1,155 (U.S. $3,000) per Landsat TM, R.O. 965 (U.S. $2,500) per SPOT scene, and R.O. 1,540 (U.S. $4,000) for combined Landsat and SPOT imagery. Geocoded imagery can be obtained from EOSAT for R.O. 1,890 (U.S. $4,900) per full scene, R.O. 965 (U.S. $2,500) per mini-scene (50 x 100 km), and R.O. 230 (U.S. $600) per floppy disk scene (15 x 15 km).

Northern Oman can be covered by 4 Landsat or 25 SPOT scenes, all of Oman can be contained by 22 Landsat or 110 SPOT scenes.

As mentioned earlier, no satellite imagery of Oman was recorded between 1973 (when the on-board recorder on Landsat 1 broke) and 1978 (when a receiving station was opened in Teheran), nor between 1979 and 1983. The EROS Data Center reports that an average of 12 cloud-free MSS scenes of each coverage area in Oman have been obtained since the start of the Landsat program. Since 1984, an average of 12 cloud-free TM scenes have been recorded for each coverage area in Oman, or about two images per year per location. Additional scenes with partial cloud cover are also available. Table 8-2 lists the available Landsat imagery for the Batinah coast. New Landsat data acquisition requests will cost R.O. 193 (U.S. $500) beginning October 1991.

The two principal SPOT receiving stations near Toulouse, France, and at Esrange, Sweden, which collect data worldwide, had recorded over 750,000 scenes by the end of 1989 (Brachet, 1990). The stations in Saudi Arabia and Pakistan collect data of local interest. SPOT imagery can be obtained to meet customer requests for imagery suitable for stereographic viewing and for the collection of data on specific dates. A search of the SPOT

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[2] Geocoding is the rectification of a satellite image from its initial form to a standard map projection (such as Universal Transverse Mercator, or UTM).

IMAGE catalog for scene K170 J303 (centered near Barka) showed only a single panchromatic image on file dated October 2, 1989.

Table 8-2

Landsat Data Availability for Batinah Coast

Year	Eastern MSS	Eastern TM	Western MSS	Western TM
1972	10/22 11/27		10/23 11/28	
1973 1974 1975 1976 1977				
1978	2/25 3/15 5/18 6/5 6/23 8/16 12/2		2/26 5/1 5/19 7/30 8/17 9/22 10/1 12/21 12/30	
1979	1/7		1/8	
1980 1981 1982				
1983	10/14			
1984	6/18 10/8 11/25	10/8	1/9	

Year	Eastern MSS	Eastern TM	Western MSS	Western TM
1985	1/12 1/28	1/12 1/28	2/4	2/4
1986	1/15	1/15	1/6 2/23	1/22 2/23
1987	5/10 5/26 6/27 7/29 8/30	1/2 1/18 2/3 5/10 5/26 6/11 6/27 12/12 12/28	7/20 9/22 10/8	1/9 1/25 9/22 10/8
1988		3/1 11/13 12/14	9/8 9/24	2/5 9/8 9/24 12/5
1989				
1990		8/30		

Satellites used for Batinah images	Row:path Eastern	Row:path Western
Landsat 1: 1972	170:44	171:43
Landsat 2: 1978	"	"
Landsat 3: 1978-1979	"	"
Landsat 4: 1983-1984 (MSS); 1987-1990 (TM)	158:44	159:43
Landsat 5: 1984-1988 (MSS and TM)	"	"

Note: Eastern Batinah image extends from Muscat to Al Khaburah.
Listed images have no more than 10 percent cloud cover.
Source: EROS Data Center, 1991.

Weather satellite imagery of Oman is obtained by Meteosat, the European Space Agency's weather satellite. WSI Corporation of Billerica, Massachusetts, can provide on-line computer updates of the Oman coverage by Meteosat every three hours. As of August 1991, WSI expects to be able to provide strip maps obtained from polar-orbiting satellites, which will provide better resolution images of Oman. These images will be updated every six hours.

Ground radar stations operate at Seeb Airport and Masirah Island to serve local air traffic. No other radar systems in Oman were identified during investigations for this report.

Aerial photography and scanning are usually contracted for specific projects. The National Survey Authority has the most extensive aerial maps of Oman, but access to this information is limited. NSA is producing digital versions of its basemaps for general use. MAPS in Sharjah, UAE, is the nearest company that has aircraft for aerial surveys. Survey costs (U.S. dollars converted to R.O.) for aerial photography, airborne scanning, and SPOT satellite imagery are shown in Table 8-3.

Table 8-3

Data Acquisition Costs

Method	Maximum Map Scale	R.O.[a] per 1,000 km^2
35 mm color photography	1:50,000	900
70 mm color photography	1:25,000	1,800
230 mm color photography	1:15,000	3,100
230 mm color photography	1:3,000	75,000
Scanning 10 m resolution	1:25,000	13,000
Scanning 5 m resolution	1:10,000	17,000
SPOT XS 20 m resolution	1:50,000	1,500[b]
SPOT Pan 10 m resolution	1:25,000	1,600[b]
Landsat TM 30 m resolution	1:75,000	2,100[c]
Landsat MSS 79 m resolution	1:200,000	800[c]

a— Converted from U.S. dollars for data collection and pre-processing. Does not include transportation to site, per diem, etc.

b— SPOT costs are for an entire 3,600 km^2 scene, including geocoding. Map scale based on 2.5 pixels per millimeter.

c— Landsat costs are for an entire 31,000 km2 scene. Map scale based on 2.5 pixels per millimeter.

Source: ERIM, 1991.

7.2 Support Services

A number of vendors in Oman provide remote sensing imagery acquisition and interpretation services. Numerous companies in the U.S. and Europe also have experience providing such services in the Middle East.

Local remote sensing vendors identified for this project are BRGM and Arabian Mapping Services. BRGM has a local staff of hydrologists and a remote sensing expert and provides a full range of image processing and interpretation services. Arabian Mapping Services produces many kinds of maps and is the local agent for SPOT and EASI/PACE, a remote sensing image processing software package developed by PCI Inc. (Richmond Hill, Ontario, Canada).

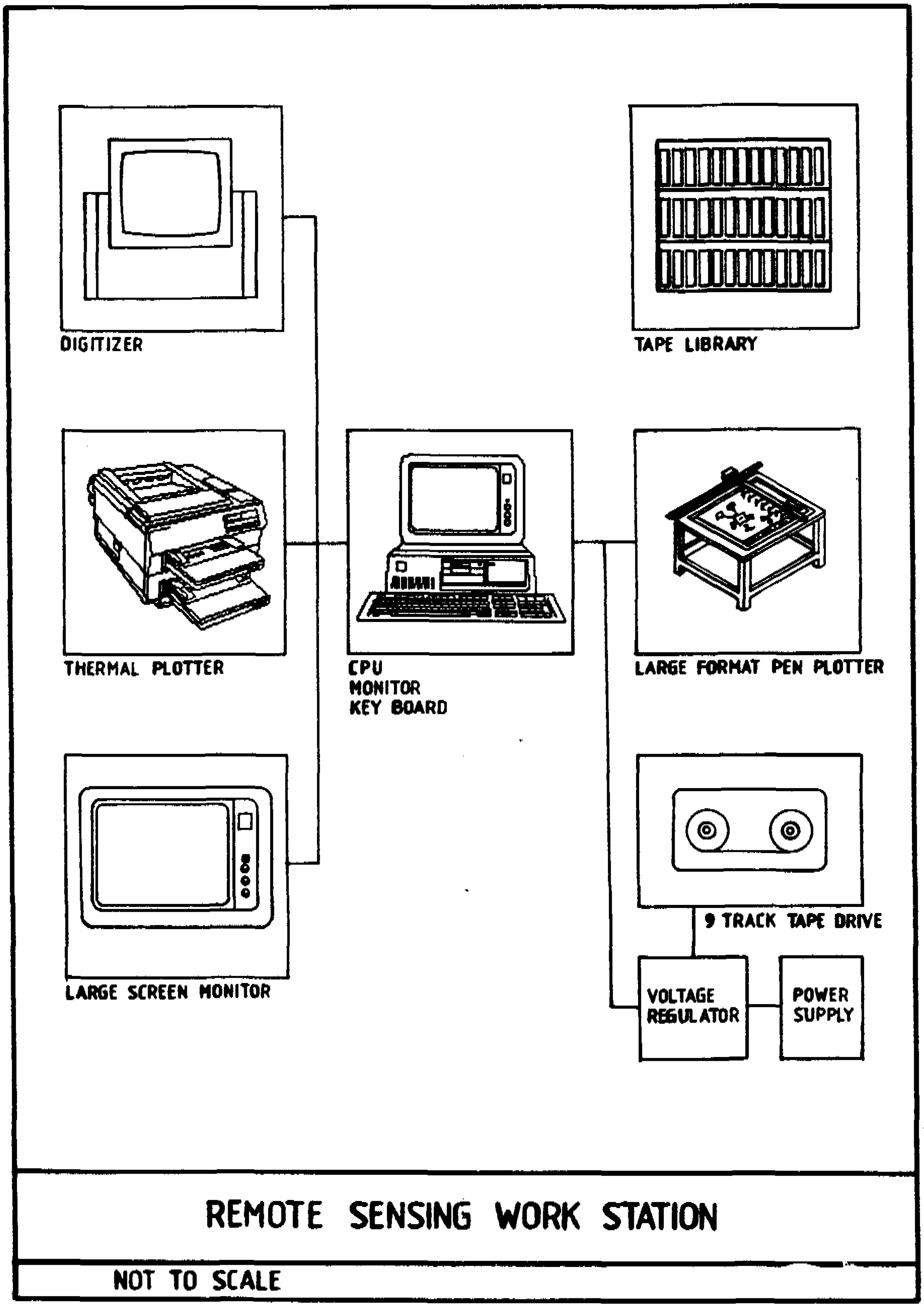
EOSAT publishes a directory of suppliers of Landsat-related products and services. U.S. vendors listed in the directory are: EarthSat, the largest value-added processor of Landsat data (which performed the studies mentioned in Chapter 5); ERIM, a non-profit corporation and one of the oldest organizations in the field; and ERDAS (Atlanta, Georgia), which markets a popular software package for remote sensing image processing. ERIM estimates that it would cost R.O. 77,000-96,000 (U.S. $200,000-$250,000) per individual, including per diem and travel, to provide in-house expertise for a year.

Photographic reproduction services in the U.S. (when the user has the digital data) cost from R.O. 100 (U.S. $250) for a monochrome print to R.O. 385 (U.S. $1,000) for color, with additional copies costing R.O. 20-39 (U.S. $50-$100). When the user does not have the digital data, EOSAT will produce a 1:50,000 TM subscene for R.O. 925 (U.S. $2,400), and SPOT IMAGE Corporation will sell a 1:60,000 SPOT scene for R.O. 810 (U.S. $2,100).

7.3 Requirements for In-House Development

In-house remote sensing capabilities will require investment in computer hardware, software, imagery, peripheral devices, storage facilities, support services, dedicated staff, and training for other users. The hardware and software for the system installed at the Ministry of Petroleum and Minerals cost approximately R.O. 50,000. The simplest PC-based systems cost as little as R.O. 10,000, while workstation systems cost upwards of R.O. 60,000 and large multiple-user systems can cost R.O. 400,000 to R.O. 1,000,000. A PC-based remote sensing workstation is shown in Figure 8-3. The actual cost of a system depends on the number and frequency of imagery updates and on the costs of personnel and services. A well-equipped remote sensing workstation is also a GIS workstation.

Figure 8-3


DIGITIZER
TAPE LIBRARY
THERMAL PLOTTER
CPU
MONITOR
KEY BOARD
LARGE FORMAT PEN PLOTTER
LARGE SCREEN MONITOR
9 TRACK TAPE DRIVE
VOLTAGE REGULATOR
POWER SUPPLY
REMOTE SENSING WORK STATION
NOT TO SCALE

Software. Software that can be run on PCs, workstations, and mainframe computers is available for remote sensing image interpretation. ERDAS software is available for DOS operating system PCs, SUN workstations, and VAX mini- and mainframe computers. ERDAS software offers raster-vector data integration through its "Live Link" connection to ARC/INFO.

Computing platform. Remote sensing software can be run on most computers. More powerful machines can process the data-intensive images more quickly. PC ERDAS requires 640 kilobytes of memory and 80 megabytes of hard-disk space.

Peripherals. In addition to large capacity storage devices, peripheral equipment for an image interpretation workstation includes a 9-track tape drive capable of reading 6,250 bits per inch (bpi) tapes, a 19-inch (48 cm) color graphics monitor, a secure power supply (e.g., a voltage regulator), a digitizing tablet, and an image scanner.

Output devices. Digital imagery can be printed with thermal graphics plotters, pen plotters, electrostatic plotters, and via photographic reproduction. Electrostatic plotters and photographic reproduction are the most costly options but offer the highest quality output.

Imagery and storage facilities. Remote sensing imagery is costly and voluminous. A remote sensing workstation must have a library of images of the areas of interest and must be updated periodically to meet ongoing needs. It must have adequate storage facilities to ensure the security and continued accessibility of the data.

Personnel. Although commercially available remote sensing software can be readily learned by most scientists, image processing is a highly complex field. Remote sensing images should be interpreted under the supervision of a person with extensive training and experience.

Training. Whether remote sensing work is done in-house or under contract, those who prepare scopes of work or use the results of analyses can benefit from supervised training in image interpretation. Graduate programs and short courses are available overseas. The American Society for Photogrammetry and Remote Sensing (1988) has compiled a list of over 100 U.S. and Canadian schools offering remote sensing courses. Some of the foremost programs are offered by Colorado State University, Ohio State University, Rutgers University, the University of Arizona, and the University of Wisconsin at Madison. The Boston University Center for Remote Sensing is headed by Farouk El-Baz, an authority on applications of remote sensing in arid lands (see El-Baz, 1984, in References). In Oman, BRGM can provide in-house training. In the U.S., the U.S. Geological Survey provides training at its EROS Data Center. Courses and conferences are also offered by institutions in Canada, Europe, Japan, and Australia.

Support. Any in-house remote sensing workstation requires support services. These range from materials and imagery supply, through reproduction services and equipment maintenance.

Chapter 8

RECOMMENDATIONS

8.1 Programs

Remote sensing imagery can be a valuable tool in the assessment and management of Oman's water resources if it is used in conjunction with appropriate field investigations. MWR must establish priorities for the different kinds of information its departments are seeking and move forward with a sensible plan that will ensure the maximum utility of work that is undertaken. Figure 8-4 presents the sequence of work for the recommended programs. Table 8-4 summarizes the costs of the three principal investigations. The paragraphs that follow discuss the importance, feasibility, and costs of the projects that should be considered and how they fit MWR's mission.

Table 8-4

Cost Summary (R.O.) for Proposed Remote Sensing Projects

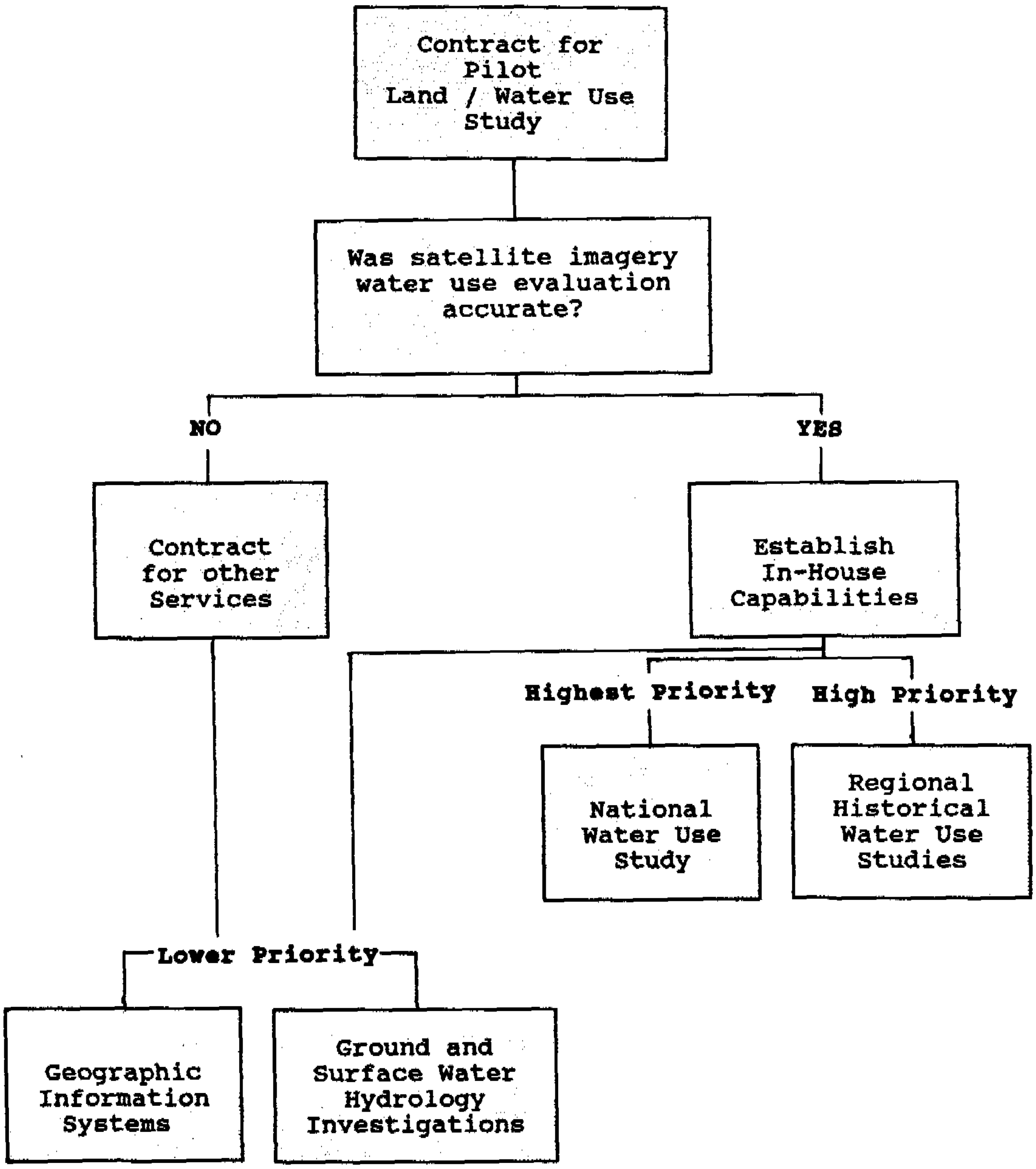
#[a]	Project	Imagery	Labor[b]	Total
1	Pilot Land/Water Use Assessment for Eastern Batinah	9,000 (2 TM subscenes, 1 SPOT, 1 MSS)	46,000 (230 days @ 200/day)	55,000
2A	National Land/Water Use Assessment	26,000 (10 TM)	44,000 (220 days @ 200/day)	70,000
2B	Historical Land/Water Use Assessment for Eastern Batinah	12,000 (7 TM miniscenes, 6 MSS)	28,000 (140 days @ 200/day)	40,000

Notes:

a— Projects 2A and 2B should only be implemented if the pilot project (#1) proves successful.

b— Labor costs averaged for support, junior, and senior staff. There could be cost savings for work performed in-house. The pilot project should be done by a contractor.

Figure 8-4



FLOW CHART FOR REMOTE SENSING PROGRAMS

NOT TO SCALE

8.1.1 Water Use Monitoring Programs

Land use assessment. This is one of the most common uses of remote sensing imagery and will meet one of MWR's most pressing needs. Information could be used to corroborate cropped land measurements made during the planned national well inventory. Since agriculture in Oman centers on small plots of field crops interspersed with palm groves, the accuracy of the information must be subjected to close scrutiny.

An initial study should be funded for an area of the Batinah previously mapped by FAO that fits within a single SPOT scene, using the most recent SPOT, TM, and MSS imagery available. The results could be compared with the FAO maps, which are being produced at 1:10,000, somewhat beyond the upper limit that remote sensing imagery can accurately resolve. This comparison will be a good indicator of the accuracy of the satellite imagery for land/water use assessment. As the most recent MSS imagery is from 1987 (unless a new acquisition is requested), the comparison will not be perfect.

The estimated cost of this study would be R.O. 40,000. A national study should follow, relying upon the classifications developed in the pilot study rather than on further ground surveys. Since interpretation costs will primarily be in the pilot study, the main cost of the national study will be for acquiring and processing additional imagery and is estimated at R.O. 50,000 if the study is conducted by a contractor. It can be conducted in-house at some savings if the pilot study is successful and with the acquisition of expertise and equipment. However, if the pilot study indicates that land use cannot be estimated accurately, MWR should not develop in-house capabilities or conduct further land use assessments using satellite imagery.

Water use assessment. MWR's ultimate aim in any land use assessment would be to obtain estimates of current water use. Such an investigation would be more involved than a land use assessment. For example, although it may be fairly easy to establish the acreage of date palms within an area, actual water use can only be gauged from an analysis of their health and of images obtained at different times of the year. This investigation should be part of the pilot land use and would add approximately R.O. 15,000, for a total of R.O. 55,000. The additional cost to the national study would be R.O. 20,000, for a total cost of R.O. 70,000, if the study is entrusted to a contractor.

Stressed vegetation detection. Remote sensing imagery can be used to map areas of vegetation affected by salinity stress and moisture deficiency, although the process has not yet been applied to date palms. The maps could help in field investigations of salinization along the Batinah. The proposed water use study entails much of this work, although at limited precision. An MWR study with this specific focus is not recommended at this time.

8.1.2 Resource Assessment

Water use change mapping. Detailed land/water use change mapping should be performed for selected study areas in conjunction with hydrologic investigations. These maps would be useful in water use modeling and establishing management policies. A study should be undertaken as part of the regional assessment program for the eastern Batinah plain, which has the Sultanate's most extensive network of wadi and rain gauges. It will be necessary to compare TM and MSS images for proximate dates to establish the relative accuracy of MSS for this purpose. The estimated cost of an investigation using imagery from 10 different dates is R.O. 40,000. Studies for other areas in the regional assessment program, such as Wadi al Batha, should follow the study for the eastern Batinah if it is successful.

Watershed physiography, surface water monitoring, groundwater recharge and discharge zones, and groundwater pathways. Numerous surface and groundwater investigations of importance to the regional assessment program could be facilitated by in-house image processing capabilities. MWR should develop such capabilities following the successful completion of the pilot study and implementation of training and other necessary programs. An investigation of groundwater discharge into the ocean could be undertaken with the methods used for the UAE study (Section 4.3).

Weather satellite imagery reception. The Surface Water Department should either acquire weather satellite reception capabilities or enter into a cooperative arrangement with the Directorate of Meteorology, which already receives this information.

8.1.3 Water Resource Management

Development of management criteria. If MWR decides to establish water use management policies based upon land and water use at some selected historical date, it could consider evaluating remote sensing imagery from that period. The date selected would have a bearing on the accuracy of information. The most precise SPOT data are available only from 1986 on; the only pre-1984 information is from low-resolution MSS data. If MWR decides that agricultural land/water use in 1985 is to be the reference for setting use levels, Landsat TM imagery would be able to supplement and verify existing records by indicating the crop types and approximate water use within each management district. The cost of obtaining this information would be comparable with that of a land and water use assessment.

Land use monitoring. Remote sensing imagery can help detect areas where land use patterns have been altered recently and provide land management authorities with the information to enforce land use policies. The high resolution and ready availability of SPOT imagery would be particularly useful in this regard. Such a program is not recommended at this time but could be a long-term objective.

8.1.4 Geographic Information Systems

Remote sensing in GIS does not dovetail with any particular component of MWR's mission but could be put to general use. Obtaining imagery for general use is important. However, using it for digitizing ground features into vector format should be considered a lesser priority than for water use assessment. Digitized maps are being made available by the NSA, and such requirements as well locations are not readily met by remote sensing imagery. Map refinements from imagery could await the acquisition of in-house capabilities.

8.2 Administration

The users of remote sensing imagery will be spread throughout MWR. But the supervision of contract and in-house work, requiring very specialized knowledge, should be coordinated by a computing services department in collaboration with GIS operations. The person designated to oversee these activities should maintain close contact with the Regional Affairs, Assessment, and Management Directorates.

A planning process flow chart is presented in Figure 8-5. This study covered the intermediate steps of the process: reviewing needs, soliciting requests, evaluating project feasibility, and developing contract specifications. The remote sensing unit to be set up should follow these steps so that the designated individual can oversee the process through project approval and execution.

8.3 Training

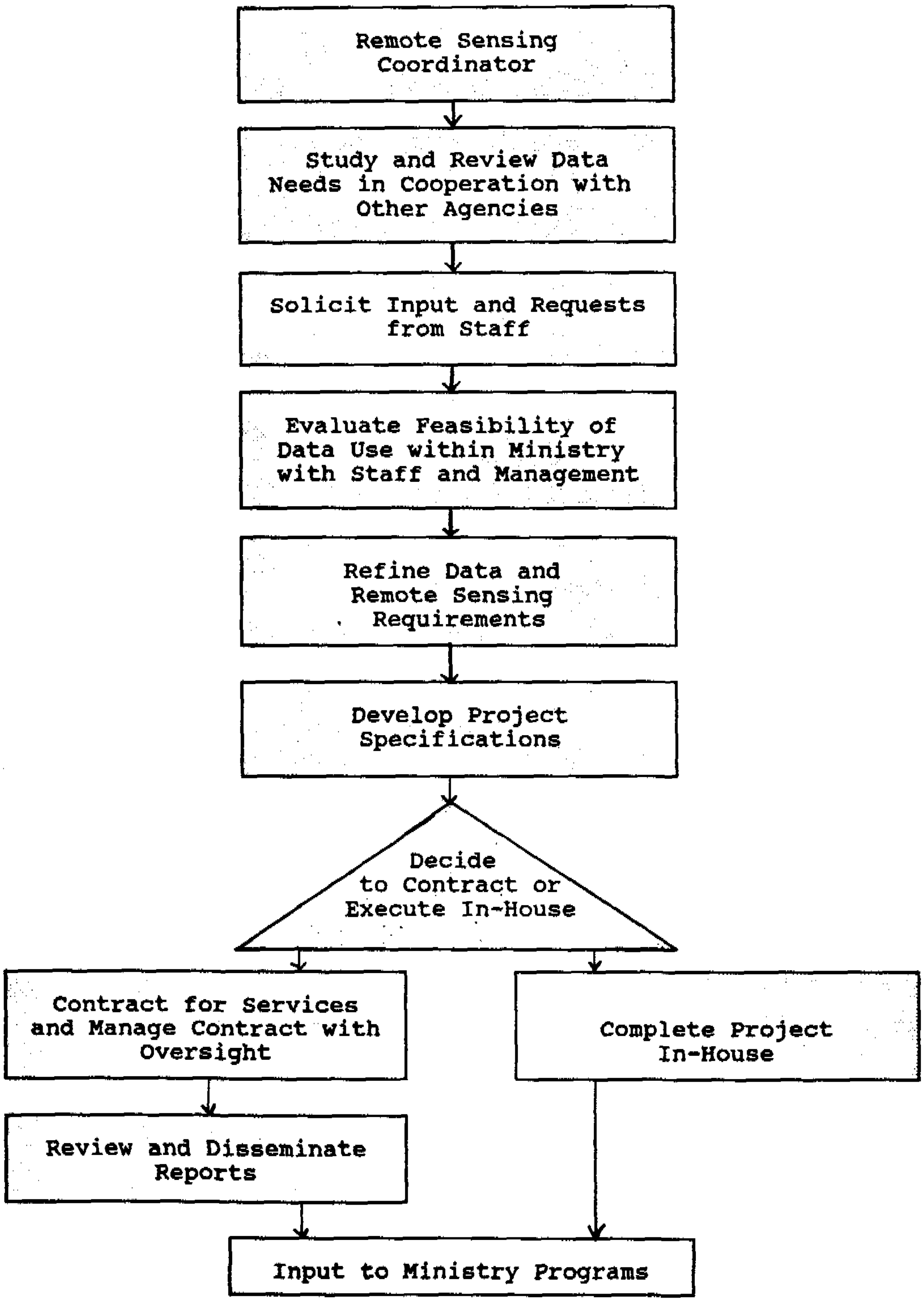
Image processing of remote sensing data is a highly specialized field, and it is important that the one responsible for coordinating contract work should be familiar with the capabilities and limitations of each method. Training will be necessary when MWR is ready to develop an in-house capability. One or two candidates with bachelor's degrees in technical disciplines should be selected in the near future for a training program such as that offered by the USGS or for a degree program. While they are being trained, a skilled contract specialist could begin work and later assist them upon their return.

8.4 Contracts

Mr. Roger Reinhold of ERIM has offered to prepare specifications for a tender document for the proposed land/water use pilot study. No further contracts should be considered until the pilot study has proved successful. Much future work could be done in-house but will not result in substantial cost savings as long as contract personnel are used. Table 8-5 presents

Figure 8-5

Remote Sensing Planning Process



specifications for a remote sensing and GIS workstation which could be procured upon the successful completion of the pilot study.

8.5 Cooperation with Other Agencies

Because of the specialized nature of remote sensing, MWR would benefit from cooperation with other agencies in Oman and with institutions elsewhere in the Gulf and in the world. MWR can especially benefit from information being obtained for MAF by FAO, and could also work with the Directorate of Meteorology, which already receives weather satellite imagery, and with the Ministry of Petroleum and Minerals, which is mapping the geology of the entire country. When MWR develops its own capability, it will be important to maintain close ties with other agencies involved in remote sensing and GIS to enable its staff to exchange ideas with their peers and also avoid duplication of effort.

Table 8-5

Specifications for Remote Sensing and GIS Workstation

Item	US$	R.O.
Sun SPARCstation 2 GX with 16 MB memory, 207 MB hard disk capacity, and 3.5" 1.44 MB diskette drive, and:	30,000	11,550
Sun OS		
150 mb 1/4" tape drive		
Sun 644 MB CD-ROM		
19" color monitor		
Sun 1/2" 9-track tape drive (reads 1600 and 6250 bpi tapes)	16,000	6,160
Calcomp 9548 Digitizing Tablet 36" x 48" with stand	6,000	2,310
Eikonix 1412 Scanning Subsystem	28,000	10,780
Tektronix Color Image Printer 4693DX	11,150	4,293
Connecting hardware	5,000	1,925
ERDAS software Version 7.4.1 for Sun including Core, Raster GIS Modeling, Image Processing, Tapes and additional features below:	18,000	6,930
ARC/INFO Live Link	1,000	385
Tablet digitizing	3,500	1,348
Image scanning	5,000	1,925
Thermal hard copy	2,000	770
Topographic	3,500	1,348
Multivariate image analysis	3,500	1,348
Full telephone support and software upgrades for one year	3,000	1,155
Installation	5,000	1,925
3 days on-site training	12,000	4,620
ARC/INFO version 5.0.1 GIS software	18,000	6,930
Shipping	1,000	385
Total	171,650	66,085

Including a Calcomp 68436 color electrostatic plotter (36", 400 dpi) would add $53,000 (R.O. 20,405) plus $5,000 (R.O. 1,925) for ERDAS support.
Switching to a PC-based system would save $6,600 on PC ERDAS and on hardware and ARC/INFO software.

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