FIELD REPORT

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

TASK 2A: LABORATORY UPGRADING

Field Report No. 326
February 1991

WATER AND SANITATION for HEALTH PROJECT

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WASH Field Report No. 326

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

Task 2A: Laboratory Upgrading

Prepared for the Omani-American
Joint Commission for Economic and Technical Cooperation
under WASH Task No. 177

by

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ACRONYMS

AC	alternating current
ACH	air changes per hour
AWC	automated wet chemistry
CFM	cubic feet per minute
COMB	combustion
DC	direct current
ECD	electron capture detector
FID	flame ionization detector
FTA	flow injected analysis
FTIR	Fourrier transformation infrared
IC	ion chromatograph
IR	infrared
H.H.	His Highness
H.E.	His Excellency
HVAC	heating ventilation and air-conditioning
KVA	kilo-volt amperes
LIMS	laboratory information management system
MBAS	methyl blue active substances
MWR	Ministry of Water Resources
NPD	nitrogen phosphorus detector

OAJC	Omani-American Joint Commission
PC	personal computer
PID	photo-ionization detector
QA/QC	quality assurance/quality control
R.O.	Omani rials
SOP	standard operating procedure
TOC	total organic carbon analyzer
UPS	uninterruptible power supply
USAID	United States Agency for International Development
WASH	Water and Sanitation for Health Project

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ABOUT THE AUTHORS

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EXECUTIVE SUMMARY

At the request of the Sultanate of Oman's Ministry of Water Resources (MWR), the Omani-American Joint Commission for Economic and Technical Cooperation contracted with the Water and Sanitation for Health Project (WASH) to assess and make recommendations for the upgrading of the MWR laboratory. A three-member WASH team worked in Oman and the United States during September and October 1990, with two other WASH teams that were evaluating the MWR's training and database needs respectively. These three tasks are the first of a six-part program to develop the newly established Ministry.

This report reviews the current status of the MWR analytical laboratory and its role in the planned nationwide inventory of wells; discusses the capabilities it should have; recommends database requirements; proposes a design for a new laboratory; and recommends the personnel, training, and major new analytical instrumentation that upgrading would call for.

Findings

- The MWR relies on its laboratory to analyze water samples from all over Oman and provide data used in managing the nation's water resources.

- The MWR has short-term needs that embrace ongoing projects and the upcoming national well inventory, and long-term needs that include the expansion of current projects and the development of new ones. All of these have an impact on the laboratory and its ability to support the MWR programs.

- The laboratory at present is housed in an inadequate building in an undesirable location, and is hampered by obsolescent and dysfunctional equipment and inadequate and inefficiently trained staff.

- Although some new equipment is expected by the end of 1990, it will still not be enough for the objectives the MWR has set.

- The MWR plans to begin its well inventory by the end of 1990, to have it fully operational by mid-1992, and to continue it for three or four years thereafter. If plans are now pursued aggressively, the new laboratory could be on-line in time to provide the analyses the inventory will need. Although the volume of water-quality analyses will decrease to a sustained long-term level after the inventory is over, it will still be greater than what it is today.

- The laboratory currently processes about five samples per day and has the capacity to increase this to 10 for some parameters. The equipment on order will permit a further increase to approximately 30 samples per day for some parameters. The new laboratory would be able to process about 50 samples per day for a wide range of parameters and about 10 samples per day for organics. It would be able to analyze as many as 250 samples per day during the inventory, using automated equipment and a second shift of staff. After the inventory, the load is expected to drop to a sustained level of 50 samples per day.

- No other government laboratory in Oman can meet the needs of the MWR, and the expense of having a commercial laboratory perform these analyses would be prohibitive.

Recommendations

- The MWR should build a new analytical laboratory in an appropriate location in the capital area, equipped with new and automated instrumentation and adequately staffed with qualified personnel.

- The MWR should distribute its analytical capabilities among the field crews, the district offices, the inventory field support facilities during the inventory, and the central laboratory. This will:

  — Disperse the load of water analysis

  — Ensure testing of constituents that must be analyzed soon after collection of the samples

  — Provide water quality training to a larger group of technicians within the Ministry

- The MWR should proceed with this plan as soon as possible and immediately hire key personnel to assist in the design, management, and implementation of the new laboratory.

- An updated laboratory information management system and appropriate standard operating and quality assurance/quality control procedures should be incorporated in all areas of MWR data collection. This holds for all types of physical and chemical measurements, analyses, and assessments.

Chapter 1

INTRODUCTION

1.1 Purpose of the Study

This study, funded by the Omani-American Joint Commission for Economic and Technical Cooperation (OAJC), was designed to upgrade the laboratory and analytical capabilities of the Omani Ministry of Water Resources (MWR). Its specific objectives were to:

- Review and assess the analytical equipment, staff, capabilities, quality assurance/quality control (QA/QC) procedures and future analytical needs of the present MWR laboratory

- Recommend improvements in equipment, parameter capability and capacity, staffing, training, and QA/QC standards

- Propose space requirements and a logistical and organizational structure for the laboratory

- Produce a conceptual design report embodying these recommendations as the basis for a modern environmental laboratory to support the mission of the MWR

1.2 Scope of Work

The scope of work (Appendix A) was prepared by Robert Thomas of Camp Dresser & McKee International who visited Oman in February 1990 and interviewed numerous MWR personnel to identify the key areas in which the Ministry needed assistance.

A two-and-one-half day Team Planning Meeting at the WASH Operations Center in Washington, D.C. on August 8, 9, and 10, 1990 discussed the interests of the project's beneficiaries and reviewed the scope of work in the light of comments and suggestions from United States Agency for International Development (USAID) personnel. A work plan, list of responsibilities and duties, schedule of implementation, and preliminary report outline were drawn up.

1.3 Conduct of the Study

A three-member study team arrived in Oman at the end of August and stayed throughout the term of the project through November 1, 1990. They were assisted at various times by others who came for one to three weeks and returned to finalize the report at the end of the project term.

The team interviewed numerous officials of various Omani government agencies (Appendix B) to assess the analytical capabilities in the country. A related WASH task conducted concurrently with the laboratory upgrading assignment provided recommendations for an MWR data base (WASH, 1990) to be interconnected with the laboratory information management system (LIMS).

Interviews conducted in the capital area were supplemented by field visits to MWR district offices in Sohar, Mudayrib, Seeb, and Salalah that permitted an insight into the problems in current and future sampling of wells, aflaj,[1] and wadis,[2] in sample shipping, and in QA/QC procedures, as well as the need for analyzing certain parameters in the field and at district offices. The team also visited related facilities and other Omani ministry offices and listened to a wide variety of needs, concerns, and opinions.

During the course of the project, the team met once a week with OAJC to keep it abreast of progress and plans, and to resolve any problems.

From mid to late October, the team prepared a preliminary report of its findings and presented these for review and discussion by key personnel in the OAJC and MWR. The comments received were incorporated in a final presentation to the Ministry on October 28, 1990, and the final draft report was presented to OAJC on November 1, 1990.

1.4 Laboratory Conceptual Design Report

The team developed a conceptual design report for the laboratory as the first phase of a four-phase process which typically culminates in the construction of a laboratory facility. A description of activities and deliverables generally included in each of these phases is presented in Table 1.

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

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

The conceptual design comprises the following elements:

- Evaluation of existing resources, including laboratory facilities, equipment and instrumentation, and personnel
- Evaluation of current workload, capabilities, and sample capacity
- Projection of future workload, capabilities, and sample capacity
- Estimation of facility space, personnel, and ancillary services needed to meet these projections
- Listing of generic instruments to efficiently support projected operations
- Identification of special electrical, cooling, and plumbing requirements

Table 1

LABORATORY DESIGN/CONSTRUCTION PROJECT OVERVIEW

PHASE	DESCRIPTION	DESIGN % COMPLETE	ACTIVITIES	DELIVERABLES
I	Conceptual Design	10	Define general space requirements. Develop adjacencies. Specify generic instrument types. Identify any special physical facilities requirement.	Adjacencies (bubble diagrams). Instrument descriptions.
II	Preliminary Design	30	Develop preliminary floor plan. Develop general instrument specifications. Develop preliminary laboratory design to include easework and materials of construction. Develop preliminary HVAC, electrical and plumbing.	Preliminary floor plan. General instrument specifications, preliminary instrument, equipment, easework layout. Preliminary utility plans.
III	Final Design	100	Prepare final lab design plan. List and locate all laboratory equipment. Prepare final HVAC, Electrical and plumbing plans. Prepare final bid specifications for all laboratory equipment and supplies.	Final floor plan. Final utility plans. Bid specifications for instruments, equipment and supplies.
IV	Construction	N/A	Prepare as-built drawings. Procure and install all laboratory equipment. Provide preliminary training to lab personnel and start up equipment.	As-built drawings

Chapter 2

BACKGROUND

2.1 General Background and Information

The Sultanate of Oman is highly dependent on groundwater resources to supply its domestic, agricultural, and industrial needs since precipitation averages less than 100 millimeters per year in most areas of the country. Despite the limited rainfall, the Sultanate has a productive agricultural base. The inhabitants of Oman traditionally have relied on an extensive network of aflaj to capture and transport groundwater. This network and the techniques it employs are thousands of years old, relying on dug wells to intercept shallow groundwater, and subsurface and above-ground aflaj to transport it to communities and villages for domestic and agricultural use.

This traditional system generally has sufficed, with the demand not exceeding the supply of water naturally replenished by rainfall. However, rapid modernization and a rising population in the last two decades have led to the explosive growth of mechanical pumps and drilled wells withdrawing large quantities of groundwater from greater depths. Some of the increased demand for water has been met by the construction of desalination plants, but these plants are capital intensive and have high construction, operation, and maintenance costs. The heavy demand on groundwater resources has resulted in serious declines in water levels and water supplies, and the degradation of water quality in many areas. Many communities have declined as centers of agriculture and population as a result.

2.2 Ministry of Water Resources Mandates

In November 1988, His Majesty Sultan Qaboos bin Said issued Royal Decree Number 82/88 (Appendix C) as the basis for conserving the nation's water resources. The decree states that "the Sultanate's water reservoir is considered as [a] public national wealth to be exploited ... according to the Government's instruction." Thus, this decree establishes that all groundwater and its extraction for any purpose may be regulated by the government.

In October 1989, the Sultan issued Royal Decree Number 100/89 (Appendix C) creating the Ministry of Water Resources and appointing H.E. Khalfan bin Nassir Al Wahaibi as its acting minister. The decree empowered the MWR to

- Formulate policies and regulations regarding water resources
- Monitor hydrologic systems

- Conduct surveys and perform water resource research
- Conduct hydrologic assessments
- Collect and analyze water samples
- Evaluate the potential for long-term, sustainable water resource supplies
- Establish and maintain a water resource data base
- Manage and preserve the nation's water resources through long-term planning and administration

Prior to the issuance of Royal Decree Number 100/89, water resources had been administered by various agencies and ministries—the Public Authority for Water Resources, the Ministry of Environment and Water, and the Ministry of Electricity and Water—none of which was concerned exclusively with water resource assessment and management. The creation of the MWR established an entity dedicated solely to water resources, and since its inception it has moved rapidly to fulfill its mission, establishing an infrastructure to execute all its areas of responsibility.

2.3 Water Laboratory Concept

The need for water sample collection and analysis was assessed through extensive consultations among the MWR staff and the WASH team. Opinions on the level of water sampling for the long-term needs of the Ministry as well as those related to the upcoming well inventory were obtained from nearly every member of the technical staff. One staff member pointed out that there were many areas in Oman with substantial water pollution caused by agricultural chemicals. Another pointed to a recent study by the Ministry of Health that indicated fecal coliform incidence in many of the aflaj. Field personnel showed cases of severe contamination of well water by oils and hydrocarbon fuels. The staff also discussed problems of water potability and agricultural suitability arising from wholly natural causes.

The reliability of the existing records of water quality was reviewed at the outset of this study. For the most part, the technical staff of the MWR agreed that these records were inaccurate because of improper collection and handling of samples. Historically, inadequate quality control procedures in testing laboratories and inaccurate data on exactly where samples originated have contributed to these deficiencies.

The study also reviewed the role of water chemistry information in the context of important problems in water resources. There are unanswered questions regarding the sources of groundwater salinization; the age, source, and recharge mechanism for groundwater in many areas is still uncertain; and the chemical evolution of the various waters of Oman is far from clear.

Beyond the need for accurate water chemistry data for current projects is the opportunity during the well inventory to provide as accurate and complete a record as possible of the water quality in Oman. The data collected during the inventory and subsequent special studies will more than prove their value in the long term for the assessment and management of the country's water resources.

The concept of the new MWR laboratory was formulated with this in mind. The laboratory will allow the MWR to conduct a significant number of water chemistry analyses on nearly every well visited by the well inventory personnel, and will be able to process approximately 200 samples per day (in addition to the normal load of 50 samples per day) to accommodate the projected peak sampling load of the national well inventory program. This capacity will be made technically and economically feasible by incorporating analytical automation, sampling robotics, and computerized data processing into the design, and by adding temporary evening and night shift personnel during periods when the inventory is at its peak.

The proposed laboratory will have analytical facilities available nowhere else in the country, and will be able to perform the full range of tests related to contamination by pesticides and herbicides as well as hydrocarbons and other exceedingly toxic substances, for some of the samples collected during the inventory.

Extensive consultations with the MWR staff and significant deliberation over questions of practicality suggest that the recommendations for the new laboratory are balanced, reasonable, and appropriate.

Two questions are fundamental to the conceptual design of the laboratory:

- What types of water chemistry analyses should the laboratory be able to perform?

- How many of each type should it be prepared to do for long-term needs and for the well inventory?

There are two elements of the sample load that will be encountered in the future: normal long-term operations and the well inventory. The laboratory must be prepared to process an increasingly large number of samples from normal long-term operations. As additional regional offices are activated and staffed, more routine water chemistry work will be required. In one sense, the level of routine sampling will bear some direct relationship to the number of professional staff members in the Ministry. Based on the sampling levels observed in the past and estimates provided by MWR staff, it appears that normal long-term operations and projects will increase the sample processing load to perhaps 1,000 samples per month or about 50 samples per day. This workload can be accommodated with a single shift of laboratory staff and by incorporating automated sample processing, analyses, and data reporting.

The well inventory is expected to begin in pilot projects toward the end of 1990. By the middle of 1992, the well inventory will be fully operational and will continue for another 4 to 5 years. During the well inventory, nearly all the wells of Oman will be located and registered as part of the process to determine the overall quantity, quality, and use of the water resources of the Sultanate. During the approximately 5-year inventory, the teams will visit well sites at a peak rate of about 150 to 200 sites per day. If samples are obtained at most of the sites, about 200 conceivably could be collected each day. By employing a limited number of temporary contract staff and utilizing the full automation capability of the analytical instrumentation, the laboratory should be able to accommodate the long-term assessment needs of the Ministry and the increased demand generated by the well inventory survey for a total peak workload of 250 samples per day.

2.4 MWR Short-Term and Long-Term Laboratory Needs

In order to meet the objectives of Royal Decree Number 100/89, sampling and analysis of water samples and an assessment of the results must be undertaken. A properly equipped, staffed, and managed laboratory is essential for this. The facility should be capable of analyzing a variety of chemical constituents, handling varying sample loads during special studies and inventories, and providing reliable results in a timely manner. Also, the instrumentation must have the sensitivity to accurately assess the concentration of analytes at or below the proposed new Omani water quality standards.

2.4.1 Short-Term Needs

The immediate needs of the MWR water analysis laboratory for approximately the next five years are to continue to provide analytical support for the Ministry's ongoing studies and assessments. This represents approximately 10 samples per day currently, increasing to about 50 per day at the end of this period. In addition, during this period the MWR plans to conduct a comprehensive inventory of the nation's wells and aflaj that is expected to generate as many as 200 additional samples per day.

2.4.2 Long-Term Needs

The long-term needs of the laboratory are to support the MWR in its evaluation, assessment, and preservation of Oman's water resources. These activities will undoubtedly include continuation and expansion of many of the current studies and the addition of new studies and assessments as demand on the nation's water resources is increased. Thus, it is expected that the 5 to 10 samples per day currently submitted to the laboratory for a relatively limited range of analyses will increase to about 50 samples per day covering a more comprehensive list of analytes by mid-1992. The long-term load is expected to be up to 100 samples per day after the completion of the inventory.

2.5 Need for Laboratory Upgrading

Water quality information is an essential element in water resource assessment, use, and management decisions. The MWR laboratory must be able to analyze the requisite range of parameters for current and future assessments, to provide reliable and timely results, and to serve as a repository of analytical data that users in the MWR and other government and nongovernment entities can draw on.

The present MWR laboratory is in need of upgrading in the following areas:

- Location—The laboratory occupies a converted two-story residence in the capital area. Although extensive remodeling has been done, the premises are not suitable for a quality laboratory. The house is not large enough and lacks the necessary power, ventilation, storage, and disposal facilities. A laboratory in a residential area is inappropriate, probably a nuisance to neighbors, and potentially dangerous. Therefore, a new site must be seriously considered.

- Capacity—The current demand on the laboratory is less than 2,000 samples per year, and yet, for various reasons, the turnaround time for results is often long. The planned inventory of the nation's wells will result in a dramatic increase in the number of samples to be analyzed over the next few years. In addition, ongoing and future assessments and studies will undoubtedly increase the day-to-day pressure on the laboratory. These demands can only be met with increased staff and automated equipment housed in a modern facility.

- Capability—The laboratory at present is capable of analyzing basic inorganic parameters, a limited number of metals, standard conventional parameters (such as pH, alkalinity, and hardness), and limited bacteriological and organic analytes. The instrumentation is 8 to 10 years old and incapable of production-laboratory capacity. Reliability of results is questionable at times (based on ion balances). The laboratory must be upgraded to support the well inventory and ongoing and future assessments with a well-trained and capable staff, and new instrumentation to analyze a broader spectrum of inorganic, organic, metal and trace metal, conventional, and radiological parameters and analytes. In addition, it must be adequately equipped for sample storage, data storage and retrieval, and QA/QC.

A detailed assessment of the existing laboratory, staff, capacity, and capabilities is presented in Chapter 3, and recommendations for upgrading in Chapter 4.

2.6 Other Laboratories Visited

As part of this study, the team visited other analytical laboratories in Oman to get an idea of the capabilities in the country and the day-to-day problems of operating a laboratory facility in Oman. The laboratories visited were operated by the Ministry of the Environment, the Ministry of Commerce and Industry, the Ministry of Electricity and Water, and the Ministry of Health. These visits provided guidance in overcoming operational and maintenance problems, and confirmed that sophisticated laboratory capabilities are not only possible but already exist in Oman.

Although these laboratories process various water-quality parameters, they are dedicated to the highly specialized needs of their own ministries, and amalgamating these facilities does not seem appropriate at this time. However, all the laboratory managers expressed an interest in participating in an inter-laboratory quality assurance program under which standardized samples could be cross-checked. Also, there are other areas where cooperation should be encouraged. For instance, uniformity imposed on the suppliers of chemicals, glassware, and analytical instrumentation would yield an immediate dividend in cost-effective procurement. Interagency work groups of instrument users (atomic adsorption analysts, for example) could share their analytical experience and discuss their successes and problems with various types of instrumentation. Such cooperation would foster the development of an expert technical network that would benefit all analytical entities in Oman.

Chapter 3

ASSESSMENT OF EXISTING MWR LABORATORY

3.1 Organization and Structure

The Ministry of Water Resources is divided into four directorates: Technical Services, Water Resources Assessment, Water Resources Management, and Finance and Administration. In addition, there are several small units directly under the Minister. Since the Ministry is a relatively new organization, the lines of responsibility are not always clear. However, at the time of this writing, the laboratory is considered to be, and is expected to remain, in the Water Resources Assessment directorate. The organizational structure of the laboratory is shown in Figure 1.

3.2 Budget and Financing

Until 1985, there were four professional staff and several technicians, and significant expenditures were made primarily for the purchase of equipment. From 1986 through 1989, a reduction in force cut the professional staff to one, reflecting the relatively low level of activity at the Ministry, and no new capital expenditures were made. However, beginning in 1990, there has been an increase in work at the Ministry, and plans for upgrading the capabilities, capacity, and staff of the laboratory include tenders of 40 to 50 thousand R.O. for new instrumentation.

3.3 Staffing

The laboratory is staffed by the following personnel, whose resumes appear in Appendix D:

- Dr. Mohamed Iqbal Mohamed Siddiq, acting chemist in charge of the laboratory. His doctorate is in analytical chemistry and he has been with the laboratory since January 1984.

- Jolly Zachariah John, chemist, who holds a master of science degree in inorganic chemistry and has worked for the laboratory since February 1983.

- Thureya Rashid Al-Riyami, Amal Jawad Sultan, and Jamila Salim Rashid, laboratory technicians, who hold diplomas in laboratory science from Oman Technical Industrial College and have worked in the laboratory since June 1988.

- Saleh Abdullah Al-Miskiry, laboratory technician, who has a higher secondary education and has worked in the laboratory since February 1984.

- Alice Jacob George, secretary, who holds a bachelor of science degree in chemistry/botany/zoology and has worked in the laboratory since February 1984.

This staff can handle the analysis of the 150 to 200 samples received per month. However, the rapid increase of samples expected as the well inventory gets underway, the parameter list is expanded, and the assessment of future water resources begins will require a corresponding increase in both technical and managerial staff.

3.4 Analytical Capabilities

The laboratory has the potential to analyze water samples for the constituents listed in Table 2. However, technical, practical, and equipment constraints limit it to parameters in the "partial" and "complete" groups. Parameters in the "special" group have been analyzed only rarely in the past. The table also shows the estimated daily current and potential capacity of the laboratory for analyses. The appropriate categories for sample analysis are selected by the district manager on the request-for-analysis form sent in with the sample.

The laboratory averages fewer than 200 requests for analyses per month, resulting in the reporting of approximately 3,800 constituents. It could probably handle an additional 100 samples per month if requested. An autoanalyzer expected by December 1990 will permit the analysis of approximately 800 samples per week for the "routine" parameters the laboratory currently analyzes, except for iron and manganese.

3.5 Sample Shipping and Storage

Samples are collected in the field and pH, temperature, and specific conductance are measured at the time of collection. Ideally, samples are placed in containers with proper preservatives and are kept in a cool box for delivery to the district office, where they are stored in refrigerators until a sufficient number of sample sets (usually 12) have been collected for shipment to the laboratory. This holding time may be anywhere from days to weeks and decreases the time in which the sample can be reliably analyzed.

Samples from all district offices, except the Dhofar (southern) district, are picked up by drivers and delivered to the laboratory in the capital. Samples from the Dhofar district are sent by air freight from the Salalah airport. Unfortunately, these samples have been reported to sit for days at the Seeb airport near the capital before being picked up and delivered to the laboratory. The reason for this is not clear, but inadequate communication and follow-up may be at fault. The delivery driver's route is probably not coordinated to accommodate timely pickup from the Seeb airport. Such delays are unacceptable, as the samples may "spoil" if not properly chilled.

After arriving at the laboratory, the samples are logged in and placed in refrigerators. Holding times are noted and samples are analyzed as soon as practical.

3.6 Facility Location and Functional Layout

The laboratory is housed in a converted two-story residence. However, the floors are connected by an outside stairway, making access inconvenient. The lower floor contains a reception area, the acting manager's office, a sample check-in and storage area, a room for the water distillation unit, a small stores and balance room, and a wet chemistry laboratory. The upper floor contains an organic laboratory, a microbiological room (for fecal coliform and total bacteriological counts), a metals analysis room, and a room where analytical results are entered on a personal computer. The total area of the laboratory is approximately 56 square meters. A schematic showing the functional layout is presented in Figure 2.

3.7 Laboratory Equipment

Table 3 lists the analytical equipment in the laboratory and gives the year of purchase and the condition of each item. Several pieces of equipment are currently on order and are expected to be delivered by December 1990. They are listed in Table 4.

Equipment is obtained either through local or overseas suppliers or directly from the manufacturer. Delivery time can be six months or longer because of internal processing, payment, and delivery constraints.

3.8 Water-Quality Field Equipment

Very limited analytical equipment is currently used in the field and at the district offices. Items of field equipment are: specific conductivity meters; pH meters; and thermometers for measuring the temperature of water samples and for compensating the conductivity meters. They vary in age from new to 8 to 10 years old. Many of the instruments are in disrepair or of questionable reliability. Approximately 30 percent of the field equipment is beyond repair; much of the rest requires frequent attention. Conductivity and pH probes are common items that need replacement. Even some of the new instruments, such as digital conductivity meters, are of questionable usefulness because of not being temperature compensating. It is quite apparent that functioning, standardized field equipment should be issued to each sampling team in each district office, and that appropriate training, follow-up, and standard operating procedures be implemented for its use.

3.9 Upkeep of Existing Equipment

The laboratory staff have had to repair and maintain equipment which, except for the most common and basic tasks, requires the highly specialized skills and tools used by qualified repair technicians. On occasion outside repair technicians have been used. However, this should be the rule not the exception. A maintenance contract was drawn up this year with a contractor in Oman. Unfortunately, replacement parts for some of the aging equipment are no longer available from the supplier or manufacturer, and even when parts are available, delivery times can be unacceptably long.

3.10 Supply Procedure

Supplies, such as reagents and glassware, are obtained from vendors both in Oman and abroad. Commonly used vendors in Oman are the Muscat Pharmacy and Hilal Marketing and Services; those from abroad are the major catalog suppliers in the United States, Germany, and the United Kingdom. Obtaining supplies is a lengthy process. Internal MWR processing of a request can take one to two months, and filling the request two to four more. Planning sufficient lead time when submitting a request, keeping close track of supplies on hand, and having backup systems for critical equipment, parts, and supplies are essential.

3.11 Analytical Methods Employed

The analytical methods employed at the laboratory are listed in Table 5 for each parameter or group of parameters. These methods are primarily the procedures detailed in the *Standard Methods for the Examination of Water and Wastewater* of the American Public Health Association.

3.12 QA/QC Standards and Practices

The laboratory also uses *Standard Methods for the Examination of Water and Wastewater* as a procedures manual for routine operations to provide a level of QA/QC. The existing data management system (KnowledgeMan) does provide for some rudimentary quality control measures, such as ion balances, percent recoveries, and control charts, which are used to assess data quality. Some representative MWR laboratory QA/QC information is presented in Appendix E.

Although the laboratory does follow some QA/QC practices, standard operating procedures (SOPs) for QA/QC must be established to ensure reliability and accuracy. This is extremely important since interpretations of water analyses performed at the laboratory will influence water resource management and policy decisions by the MWR.

The laboratory has participated in some quality assurance programs, including an international program operated by the U.S. Department of the Interior. Such participation, as well as inter-laboratory programs in Oman, should be encouraged. In addition, QA/QC policies and SOPs should be established for all field programs for water quality and quantity analyses and information.

3.13 Laboratory Information Management System

The laboratory uses a laboratory information management system (LIMS), which typically is a system employing computer hardware and software to monitor and track samples through a laboratory, to store and validate the results of analyses, and to produce data reports for users.

The current LIMS system employs an IBM XT personal computer and the KnowledgeMan database software program. The results of analyses are filed into the system daily and transferred to the main MWR computer system database via floppy disk every week. The laboratory database holds only the most recent year's data. The program is capable of performing an ion-balance check routine that is used to assess the accuracy of the analyses.

There is a definite need to upgrade the LIMS hardware and software to meet anticipated demands on the laboratory and to provide rapid transfer to, and interfacing with, the primary water-quality data users.

Table 2

CHEMICAL, PHYSICAL AND MICROBIOLOGICAL PARAMETERS WITHIN THE LABORATORY'S PRESENT ANALYTICAL CAPABILITY

Constituent	Schedule Group Type *	Estimated Current Parameter Volume Analyzed on a Regular Basis (per day)	Estimated Potential Parameter Volume Analyzed on a Regular Basis (per day)
pH	P,C,R	5	10
Acidity	C,R	0	10
Total Alkalinity	C,R	4	10
Carbonate Alkalinity	R	4	10
Bicarbonate Alkalinity	R	4	10
Hydroxide Alkalinity	R	4	10
Phenolphethalein Alkalinity	R	4	10
Conductance	P,C,R	5	10
Chloride	P,C,R	5	10
Sulfate	C,R	4	10
Fluoride	R	4	10
Bromide	S	1	1
Nitrate Nitrogen	C,R	3	10
Nitrite Nitrogen	S	1	10
Ammonia Nitrogen	S	1	1
Orthophosphate	R	1	10
Total Phosphate	R	2	4

Table 2 (cont.)

Constituent	Schedule Group Type *	Estimated Current Parameter Volume Analyzed on a Regular Basis (per day)	Estimated Potential Parameter Volume Analyzed on a Regular Basis (per day)
Total Solids	S	1	2
Total Dissolved Solids	C,R	3	6
Suspended Solids	S	5	10
Total Hardness	C,R	4	8
Calcium Hardness	C,R	4	8
Magnesium Hardness	C,R	4	8
Calcium	C,R	4	6
Magnesium	C,R	0	0
Sodium	C,R	4	6
Potassium	C,R	4	6
Boron	R	2	4
Soluble Sulfide	S	4	10
Total Sulfide	S	0	0
Chlorine Demand	S	0	0
Chlorine Residual	S	0	0
Carbon Dioxide	S	0	0
Ion Balance	C	4	10
Percent Sodium Ratio	S	4	8
Sodium Equivalent & Absorption Ratio	C	4	8

Table 2 (cont.)

Constituent	Schedule Group Type *	Estimated Current Parameter Volume Analyzed on a Regular Basis (per day)	Estimated Potential Parameter Volume Analyzed on a Regular Basis (per day)
Surfactant, Anionics (MBAS)	S	0	0
Turbidity	S	0	0
Dissolved Oxygen	S	0	0
Total Lithium	S	0	0
Soluble Lithium	S	0	0
Total Strontium	S	0	0
Total Barium	S	0	0
Soluble Barium	S	0	0
Total Chromium	S	0	0
Soluble Chromium	S	0	0
Hexavalent Chromium	S	0	0
Total Molybdenum	S	0	0
Soluble Molybdenum	S	0	0
Total Manganese	S	2	4
Soluble Manganese	R	2	4
Total Iron	S	2	4
Soluble Iron	R	2	4
Total Cobalt	S	0	0
Soluble Cobalt	S	0	0

Table 2 (cont.)

Constituent	Schedule Group Type *	Estimated Current Parameter Volume Analyzed on a Regular Basis (per day)	Estimated Potential Parameter Volume Analyzed on a Regular Basis (per day)
Total Nickel	S	0	0
Soluble Nickel	S	0	0
Total Copper	S	0	0
Soluble Copper	S	0	0
Total Silver	S	0	0
Soluble Silver	S	0	0
Total Gold	S	0	0
Soluble Gold	S	0	0
Total Zinc	S	0	0
Soluble Zinc	S	0	0
Total Cadmium	S	0	0
Soluble Cadmium	S	0	0
Total Mercury	S	0	2
Soluble Mercury	S	0	2
Total Aluminium	S	0	0
Soluble Aluminium	S	0	0
Total Silicon	S	0	0
Soluble Silicon	S	0	0
Total Lead	S	0	10

Table 2 (cont.)

Constituent	Schedule Group Type *	Estimated Current Parameter Volume Analyzed on a Regular Basis (per day)	Estimated Potential Parameter Volume Analyzed on a Regular Basis (per day)
Soluble Lead	S	0	10
Total Arsenic	S	0	3
Soluble Arsenic	S	0	3
Total Selenium	S	0	3
Soluble Selenium	S	0	3
M.P.N. Coliform	S	0	0
M.P.N. Fecal Coliform	S	0	0
M.P.N. Total Bacterial Count	S	0	0
Sulfite	S	0	0
Herbicides	S	0	0
Pesticides	S	0	0
Volatile Organics	S	0	4
Hydrocarbons	S	0	2
ABNs	S	0	0
VOAs	S	0	4
Semi-Volatiles	S	0	0
PCBs	S	0	0

* P = Partial Group
R = Routine Group
C = Complete Group
S = Special Group (by request only)

Table 3

ANALYTICAL EQUIPMENT IN THE LABORATORY

Instrument	No. of Units	Year of Purchase	Remarks
UV/Vis. Spectrophotometer	1	1982	Performing satisfactorily. To be backed-up with an autoanalyzer to be acquired this year
Atomic Absorption Emission Spectrophotometer	1	1982	The graphite furnace is broken and beyond repair
Gas Chromatograph	1	1985	Performing satisfactorily
Specific Ion Meter	1	1984	-do-
Memo Titrator	2	1982 & 1984	-do-
pH Meter	1	1988	-do-
Turbidimeter	1	1982	-do-
Conductivity Meter	1	1982	In need of replacement
Ion-Chromatograph	1	1981	Out of order
Oven	2	1982 & 1984	Performing satisfactorily

Table 3 (cont.)

Instrument	No.of Units	Year of Purchase	Remarks
Analytical Balance	2	1982 & 1984	-do-
Incubator	2	1984	-do-
Microscope	1	1984	-do-
Semi-Automatic Dilutors & Dispensers	4	1984	-do-
Water Bath	2	1984 & 1988	-do-
Automatic Dilutor	1	1985	Performing satisfactorily
Muffle Furnace	1	1985	-do-
Rotary Evaporator	1	1985	-do-
Single Distillation System	2	1984	-do-
Quartz Distillation Unit	1	1985	-do-
Computer PC XT	1	1985	-do-

Table 4

NEW EQUIPMENT ANTICIPATED FOR DELIVERY
BY DECEMBER 1990

Description	Number of Units
Autoanalyzer	1
Specific Conductivity Meter	1
Water Distillation Unit	1
Digestion Block	1
Trace Elements Analyzer	1

Table 5

ANALYTICAL METHODS USED BY THE LABORATORY

Partial Analyses

Method	Constituent	Ref	Method No	Page
Electrometric	pH value	(3)	423	70
Electrometric	Specific conductance	(3)	205	402
Titrametric	Chloride	(3)	407A	270

Complete Analyses

Method	Constituent	Ref	Method No	Page
AA Spectrophotometric	Potassium	(3)	303A	152
AA Spectrophotometric	Sodium	(3)	303A	152
Electrometric	Fluoride	(3)	413B	335
Electrometric	pH value	(3)	423	402
Electrometric	Specific conductance	(3)	205	70
Titrametric	Bicarbonate (CaCO3)	(3)	403	253
Titrametric	Calcium	(3)	314B	195
Titrametric	Carbonate (CaCO3)	(3)	403	253
Titrametric	Chloride	(3)	407A	270
Titrametirc	Total hardness (CaCO3)	(3)	407A	270
Turbidimetric	Sulfate	(3)	426C	439

Table 5 (cont.)

Microbiological Analyses

Method	Constituent	Ref	Method No	Page
Membrane filter	Coliform	(3)	909A	806
Membrane filter	Fecal coliform	(3)	909A	806
Membrane filter	Total coliform	(3)	909A	806

Trace Constituents

Method	Constituent	Ref	Method No	Page
AA Spectrophotometric	Copper	(3)	303A	152
AA Spectrophotometric	Lithium	(3)	303A	152
AA Spectrophotometric	Strontium	(3)	303A	152
AA Spectrophotometric	Cadmium	(3)	303B	156
AA Spectrophotometric	Chromium	(3)	303B	156
AA Spectrophotometric	Cobalt	(3)	303B	156
AA Spectrophotometric	Iron	(3)	303B	156
AA Spectrophotometric	Gold	(3)	303B	156
AA Spectrophotometric	Lead	(3)	303B	156
AA Spectrophotometric	Manganese	(3)	303B	156
AA Spectrophotometric	Nickel	(3)	303B	156
AA Spectrophotometric	Silver	(3)	303B	156
AA Spectrophotometric	Zinc	(3)	303B	156
AA Spectrophotometric	Aluminium	(3)	303C	157
AA Spectrophotometric	Barium	(3)	303C	157
AA Spectrophotometric	Molybdenum	(3)	303C	157
AA Spectrophotometric	Silicon	(3)	303C	157
AA Spectrophotometric	Selenium	(3)	303E	160
AA Spectrophotometric	Arsenic	(3)	303E	160
AA Spectrophotometric	Mercury	(3)	303F	164
Spectrophotometric	Chromium, hexavalent	(3)	312B	187

Table 5 (cont.)

Reference material available in laboratory:

Inorganic:

(1) Methods for Chemical Analyses of Water and Wastes, 1979 U.S. Environmental Protection Agency, U.S. Environmental Protection Agency EPA-600/4-79-020, Cincinnati, xxx p.

(2) Methods for determination of inorganic substances in water and fluvial sediments, M.W. Skougstad, M.S. Fishman, L.C. Friendman, D.E. Erdmann, and S.E. Duncan, eds., 1979, U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chapter A1, 626 p.

(3) Standard Methods for the Examination of Water and Waste Water, 15th Edition, American Public Health Association and others, 1980, Washington, D.C., American Public Health Association, p xxx.

Microbiological:

(3) Standard Methods for the Examination of Water and Waste Water, 15th Edition, American Public Health Association and others, 1980, Washington, D.C., American Public Health Association, p xxx.

Organic:

(3) Standard Methods for the Examination of Water and Waste Water, 15th Edition, American Public Health Association and others, 1980, Washington, D.C., American Public Health Association, p xxx.

Written procedures are available at appropriate benches.

Methods used come from (3) Standard Methods for the Examination of Water and Waste Water, 15th Edition, American Public Health Association and others, 1980, Washington, D.C., American Public Health Association, p xxx.

Figure 1

MINISTRY OF WATER RESOURCES ORGANIZATIONAL CHART
OF THE CURRENT MWR LABORATORY

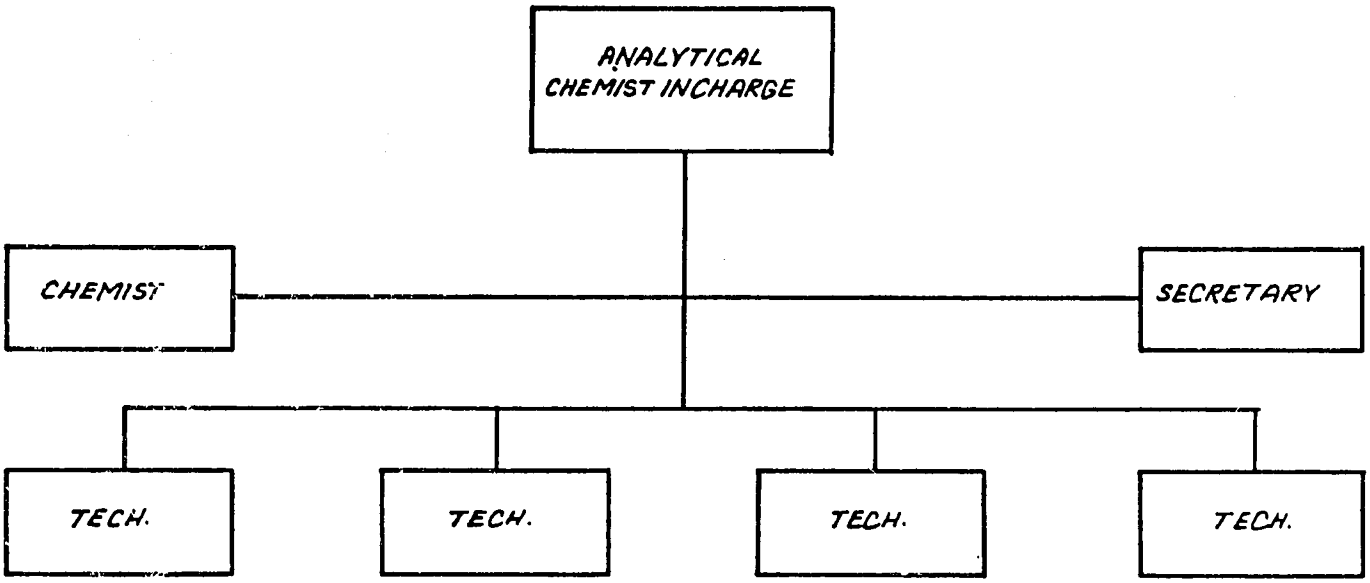


Figure 2

MINISTRY OF WATER RESOURCES FUNCTIONAL LAYOUT OF THE PRESENT
MWR WATER QUALITY LABORATORY GROUND FLOOR

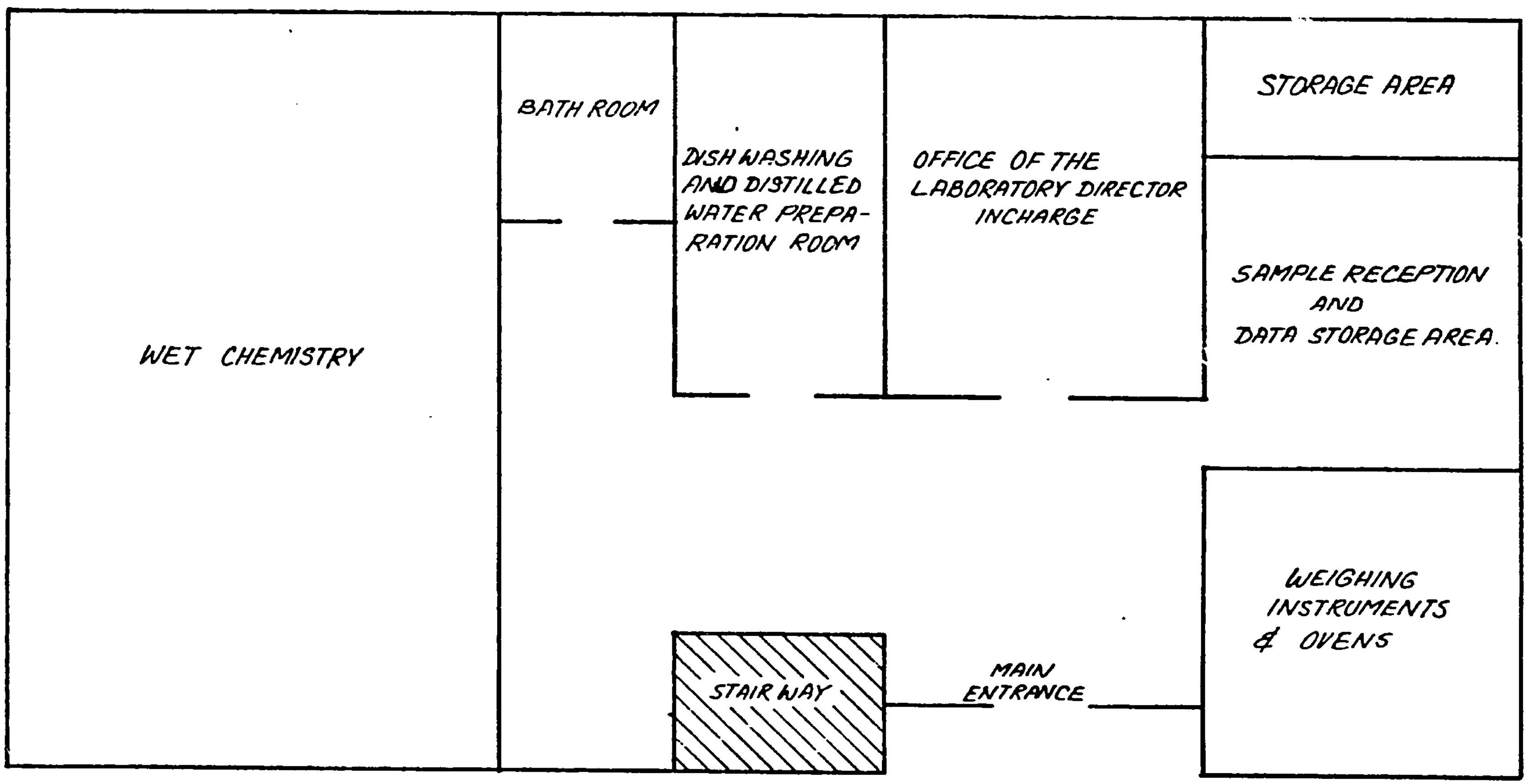
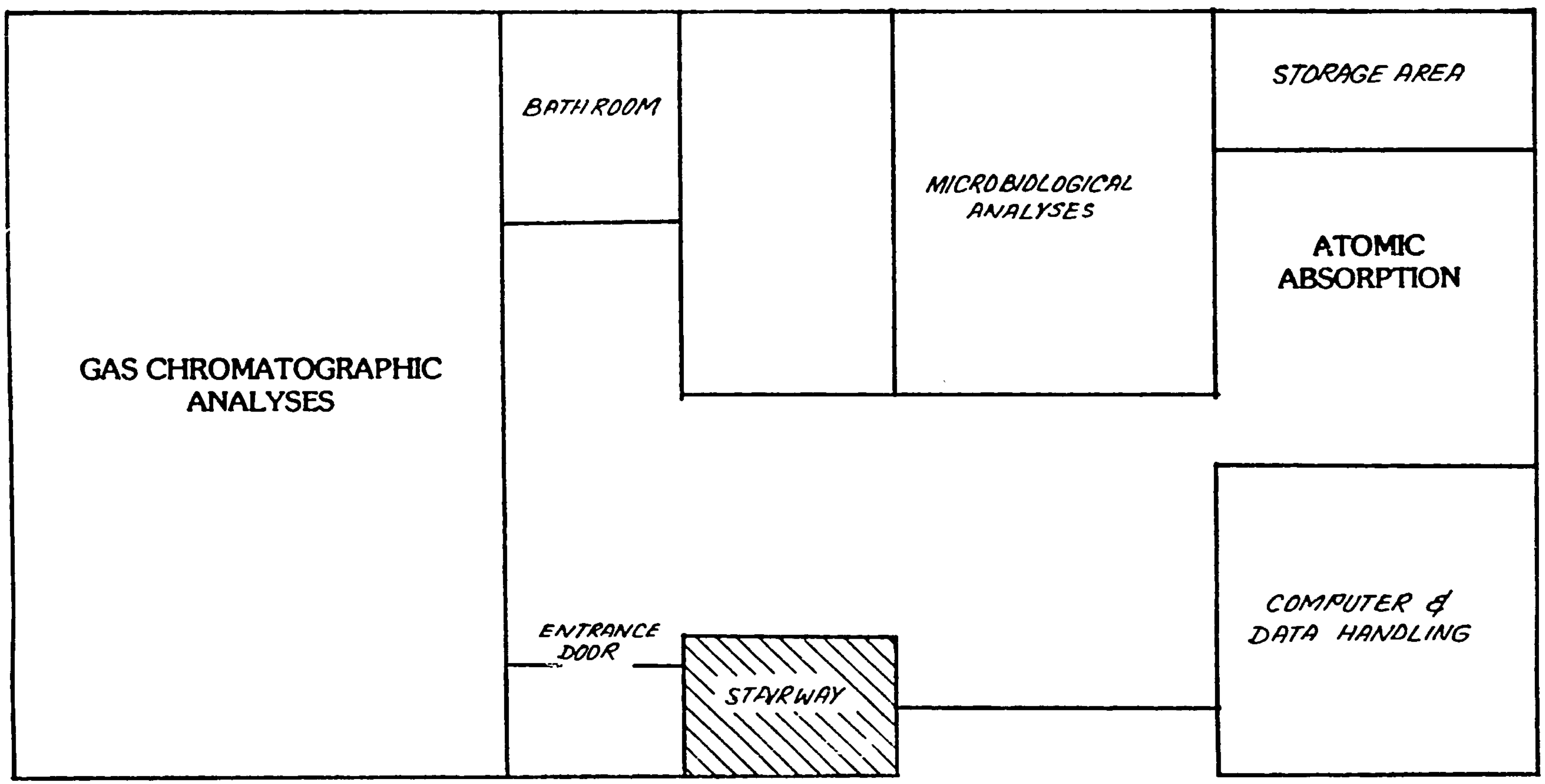


Figure 2 (cont.)

MINISTRY OF WATER RESOURCES FUNCTIONAL LAYOUT OF THE PRESENT MWR WATER QUALITY LABORATORY FIRST FLOOR



Chapter 4

RECOMMENDED MWR LABORATORY UPGRADING

4.1 Types of Laboratories Needed

The need for MWR to upgrade its laboratory and analytical capabilities has been explained earlier. There are a number of options by which this can be achieved. These options and the recommended mixture of facilities chosen from these options to best accomplish MWR's goals are presented below.

4.1.1 Field Laboratories

Some crucial analytical parameters can be analyzed accurately only at the point of sample collection. Since the results of these analyses are also used in determining other parameters analyzed at the central laboratory, sample collection crews must be trained to measure key parameters at the point of collection. These parameters are elaborated upon in Section 4.5, Recommended Analytical Capabilities.

4.1.2 Regional Office and Inventory Field Support Analytical Facilities

There is a current and future need for limited analytical capabilities at regional offices. The parameters to be analyzed at these facilities are in two categories: analytes with holding times less than 6 to 24 hours after collection, and simple physical or chemical parameters that require minimal skills and less sophisticated equipment for analysis.

Performing these analyses at regional offices would decrease the load on the central laboratory and would provide valuable training for regional office personnel, some of whom in time would qualify for transfer to technician positions at the central laboratory.

Regional office facilities need not be spacious or sophisticated. They should all, however, be equipped, instrumented, and staffed adequately. The number of samples requiring analysis during the well inventory will exceed their capabilities, and the travel time to reach them may prohibit timely delivery and analysis of the samples. Thus, it is recommended that inventory teams be backed up by mobile field support facilities.

The parameters to be analyzed at the inventory field support facilities and at the regional offices are the same and are described in Section 4.5.

4.1.3 Satellite Laboratories

Satellite laboratories would duplicate all or some of the capabilities of a central laboratory in various regions of the country and would be justified by the need for getting samples to a laboratory without delay. After careful consideration and consultation with MWR personnel, however, it was concluded that the duplication of central laboratory capabilities would not be advisable at present from financial and staffing standpoints. Satellite laboratories may be justified in the future if the volume of samples in a region increases significantly, or if an outside development committee wishes to expand its regional base of capabilities in order to attract growth and development (such as in Salalah).

4.1.4 Central Laboratory

A central facility in the capital is recommended as the primary analytical laboratory for the MWR. It should be capable of analyzing the full range of parameters for the well inventory and for all but the most unusual parameters for other special projects. It must be staffed, equipped, and managed to provide timely and reliable results for water-quality data users. It is fully described in Section 4.5.

4.2 Budget and Financing

The MWR has approximately 1.5 million R.O. to design, construct, and equip a new analytical laboratory between late 1990 and the third quarter of 1992. The Omani-American Joint Commission may be willing to provide up to 600,000 R.O. more.

4.3 Recommended Central Laboratory Organization

Figure 3 shows the proposed organizational chart for the central laboratory. Under the manager are specialized personnel, such as a QA/QC director and senior chemists heading the laboratory sections. Several junior and entry-level chemists and technicians complete the organization. Positions shown are not necessarily full-time under normal single-shift operations but are functions that need to be fulfilled. For instance, technicians could provide support to more than one chemist, and some chemists may serve a dual function. Positions designated by a shaded block are not full-time.

4.4 Recommended Staffing and Qualifications

The recommended staffing levels and personnel qualifications are presented in the following sections.

4.4.1 Staffing Levels

Table 6 shows the staffing levels to meet the projected workload for the next five years. The three categories of analyses to be conducted in the new laboratory are designated routine (R), comprehensive (C), and special (S). Tables 7 and 8 present the staffing requirements for routine (R) and comprehensive (C) analyses respectively for both normal (50 samples/day) and inventory (250 samples/day) conditions. It should be noted that the automated analytical equipment is somewhat under-utilized in normal operations. It will be used more effectively with multiple shifts to cope with the demands of the national well inventory program (250 samples/day).

A different approach was used to estimate the staffing requirements to process the projected sample load for the special (S) parameters. For conventional, microbiological, and physical parameters, staffing levels were estimated as for the routine (R) and comprehensive (C) analyses. For the organic analytical work, dedicated staff will be assigned to produce an average of 8-12 analyses/day (normal operations) and 32-60 analyses/day (multiple shifts) based on the complexity of the analyses. Table 9 shows the dedicated staffing level for special parameter analyses, and Table 10 shows the total staffing levels for the laboratory. In addition, nine senior technical and administrative staff positions will be required. The estimated grand total for the new laboratory is:

	Normal	Inventory
Administrative/Senior Technical	9	9
Chemists	9	16
Technicians	14	35
Total Staff	32	60

This staff should provide a fully functional facility capable of meeting the MWR's analytical needs for most projects. The well inventory is a special case. The magnitude of the task it would impose would require maximum use of automated sample processing and analytical instrumentation and the hiring of temporary contract staff, primarily midlevel chemists and laboratory technicians.

The field, inventory support, and regional office personnel responsible for performing analytical tasks should be appropriately trained and have at least a secondary education and preferably some post-secondary school training. Follow-up training and checks will be necessary and could be performed by the laboratory QA/QC advisor and the laboratory field chemist section leader.

4.4.2 Recommended Qualifications

The recommended qualifications and experience for laboratory personnel shown in Figure 3 are described below. Only credentials from internationally recognized universities and educational institutions will be accepted.

- Laboratory Director—The laboratory director should be a senior analytical chemist with at least 10 years of experience in analytical chemistry and 5 years in laboratory management and must have strong administrative and managerial skills. Preferred educational background would be a Ph.D. in analytical chemistry and an MBA. Relevant experience in technical management of state-of-the-art environmental or water-quality laboratories will also be essential.

- Assistant Laboratory Director—The assistant laboratory director should be a senior analytical chemist with 10 years of experience in analytical chemistry and 5 years in laboratory management. The candidate must have a strong technical orientation and experience in all aspects of analytical chemistry and provide technical guidance for the laboratory as well as administrative assistance to the director. Preferred educational background would be a Ph.D. in analytical chemistry. Relevant experience in environmental chemistry, including gas chromatography/mass spectrography, inductively coupled plasma, and atomic adsorption analyses, is essential.

- QA/QC Advisor—The QA/QC advisor should be a senior analytical chemist with 5 to 10 years of experience in analytical chemistry and quality assurance and quality control program design and implementation. The candidate will also be responsible for coordinating and performing regular QA/QC checks in the field and at the district offices. Preferred educational background would be an M.S. or Ph.D. in analytical chemistry.

- Systems Analyst—The systems analyst should be a management information system and database management expert familiar with laboratory information management systems and having 5 to 10 years of experience. The candidate must be capable of maintaining the LIMS and interfacing effectively with the MWR database and graphical information system. Preferred educational background would be an M.S. in computer science with a minor in chemistry.

- Senior Chemists—The senior chemists should be analytical chemists with 5 to 10 years of experience, with special emphasis on the specialty of the section each will lead. Preferred educational background would be an M.S. or Ph.D. in analytical chemistry emphasizing the specialized area of the section.

- Chemists—The chemists should be an even mixture of junior and entry-level analytical chemists with 1 to 5 years of experience. Educational background should be an M.S. in analytical chemistry at a minimum.

- Laboratory Technicians—The laboratory technicians should be an even mixture of junior and entry-level analytical chemistry technicians with 0 to 5 years of experience. They should have a secondary education or an associate degree and a laboratory technician training certificate at a minimum, with a B.S. in chemistry preferred.

- Secretaries—The laboratory secretaries will be responsible for reception, report preparation, sample receiving and tracking, and data entry. They should have 2 to 5 years of secretarial experience with emphasis on personal computer use, word processing, data entry, and office management. Educational background should be secondary education at a minimum, with post-secondary training preferred.

4.5 Recommended Analytical Capabilities

The MWR needs several analyses in order to manage the water resources of the nation effectively. Some of these will be useful in determining the suitability of water for drinking or agricultural purposes. Others will be used to evaluate the impacts of agriculture and industry on groundwater in the form of salinity, nitrates, pesticides, and hazardous wastes. Still others will assist in evaluating the quality, source, movement, and age of groundwater reserves. The recommended distribution of analytical capabilities for the Ministry are described below.

4.5.1 Recommended Field Analytical Capabilities

The field crews that collect samples either for the district office or the inventory program should be able to analyze several parameters at the well since these parameters change very rapidly after samples have been drawn. (Ideally, parameters should be analyzed in the well.) These analyses should be run every time a water sample is collected for any reason. The analytical capabilities needed are listed in Table 11.

4.5.2 Recommended Regional Office Analytical Capabilities

The district offices must have the capability to analyze certain parameters which must be measured within four to six hours of sample collection. They should also be capable of performing several other simple analyses, such as turbidity measurements and filtering samples for metal analysis, to reduce the load of labor-intensive analyses at the central laboratory.

4.5.3 Recommended Inventory Field Support Analytical Capabilities

The inventory field support facilities will be responsible for analyzing the same parameters as the district offices during the well inventory. The list of analytes and their analysis frequency groups for both the district office and the inventory field support facilities are listed in Table 12.

4.5.4 Recommended Central Laboratory Analytical Capabilities

The central laboratory must be capable of performing analyses for the constituents listed in Table 13. It should be designed so that each section can be expanded if necessary to accommodate additional constituents for in-house analysis. For example, the MWR is greatly interested in isotope age analyses of groundwater, primarily using carbon-14, deuterium, and tritium, to assist in management decisions. Although it is presently impractical to perform these analyses in Oman, the laboratory should be built with enough space in its radiological analytical section to accommodate isotope analyses should it become practical to run these in the future. Table 13 lists these parameters as the future group (F).

The conclusion about present impracticality is based on the large volume of samples, sample pretreatment, analytical instrumentation, and ancillary support required to accurately assess these radiological constituents. For example, determination of carbon-14 usually requires the collection of a sample of approximately 20 liters. Dissolved carbonates in the sample are precipitated, using borium sulfate in a batch reactor, and the resultant precipitate is filtered and analyzed, using sophisticated low-background liquid scintillation counters. Special expertise is required to operate this equipment and to interpret the results. In addition, the same procedure must be conducted to assess the carbon-13 concentration of the sample. Carbon-13 is a stable (non-radioactive) isotope that can be analyzed only by mass spectroscopy. To perform this test, the dissolved carbon dioxide of the sample must be accurately measured at the time of collection.

Tritium (H-3) is a radioactive isotope of hydrogen that is used for short-term isotopic dating of waters less than 30 years old. Although tritium is less complicated to analyze, substantial pretreatment (fractional distillation) is required to remove background interference from other beta emitters in order to obtain an accurate and representative result. A low-background liquid scintillation counter is necessary to obtain the requisite sensitivity for accurate results and interpretation.

4.6 Recommended Sample Capacity for the Various Analytical Locations

The capacity of a laboratory is the number of samples it can process while maintaining an acceptable level of QA/QC. The new MWR laboratory will be designed to support the current and short-term and long-term projects of the Ministry. Special studies, such as the upcoming well inventory, can be accommodated by using automated instrumentation and additional contract staff.

The frequency with which parameters are to be analyzed in the field, at the regional offices and inventory field support facilities, and at the central laboratory are listed in Tables 11-13. respectively. The parameters are grouped by factors such as the importance of the parameter and the difficulty, cost, and labor involved in measuring it. These tables also indicate that the central laboratory and the regional offices need to have the capability to analyze the field and regional office parameters, too. However, since these parameters are most appropriately measured at the well head, they would be considered special parameters if analysis was requested at the central laboratory.

4.6.1 Recommended Analysis Groupings

- Routine Analyses Group (R)—Routine analytes are parameters that are considered relatively easy to process, are commonly considered important to quantify, and can be analyzed in a relatively high volume. Routine analyses are recommended every time a water sample is collected.

- Comprehensive Analyses Group (C)—Comprehensive analytes are parameters that are analyzed less frequently because of the difficulty or expense of performing these analyses, and the relatively low throughput capacity of the instrumentation. However, the comprehensive group should not be run without the routine group.

- Special Analyses Group (S)—Special analytes are parameters analyzed by request only because of labor-intensive and reagent-consuming sample preparation procedures. The instrumentation required is highly specialized and expensive, and typically has a low throughput capacity. This is especially true for the organic analytes. Some parameters, such as microbiological tests, are considered to be in the special group when analyzed at the central laboratory, since they should have been processed at the regional office. Requests for special group analyses must be coordinated and scheduled with the laboratory director prior to implementing a special study dependent on them so that the laboratory can anticipate, plan, and distribute the sample load appropriately.

- Future Analyses Group (F)—Future analytes are parameters of interest to the Ministry but beyond the laboratory's present capability to analyze. The need for these constituents (radium 226 and 228, asbestos, or such exotic analytes as the stable or radioactive isotopes) to be analyzed at the laboratory has not yet been justified. All of them require highly specialized and expensive instrumentation and expert personnel. They should be sent out of the country for processing until such time as there is a recognized problem in Oman that warrants these analyses of radium, for example, based on the results of gross alpha and gross beta analyses conducted during the inventory, or the number of isotope analyses is so great that it becomes economically necessary to have these exotic capabilities at the central laboratory. With this eventuality in mind, it is highly recommended that the new laboratory be designed with sufficient space to accommodate the instrumentation needed for the future analyses group.

4.6.2 Recommended Sample Analysis Criteria Policy

- All wells will be analyzed for routine parameters each time they are sampled.

- All potable water supplies and well fields serving several families will be analyzed for routine, comprehensive, and special parameters.

- Approximately 10 percent of the nonpotable water supply wells will be analyzed for routine and comprehensive parameters.

- All wells in the vicinity of suspected sources of contamination, such as landfills, mines, and chemical and industrial processing facilities, will be analyzed for routine, comprehensive, and special parameters.

- Five to 10 percent of the remaining wells will be analyzed by request and by prior approval of the laboratory director for special parameters. It should be noted that the analytical output for some of the organic analytes is as low as 10 samples per day for single-shift (normal) operations.

- Samples for future parameters will be collected and shipped out of the country for analysis only by request and with prior agreement for special projects undertaken by the MWR.

4.6.3 Resulting Sample Capacity Demand on the Central Laboratory

The laboratory currently receives approximately 200 samples a month for processing, or about 10 samples per day based on a five-day work week. According to MWR projections, future and ongoing studies are expected to increase this load approximately five times by mid-1992.

The well inventory, scheduled for pilot projects at the beginning of 1991, is a one-time special assessment expected to increase significantly the number of samples received by the laboratory. Inventory activities should reach a peak by mid-1992 and are expected to continue at that level for at least four more years.

After extensive discussions with MWR personnel involved in the well inventory planning, four assumptions have been made in estimating the additional sample load on the laboratory:

- There are approximately 200,000 wells to be inventoried and sampled.

- All wells will be sampled and analyzed for the field parameters, the inventory field support facility parameters, and the central laboratory routine parameters as listed in Tables 11-13.

- There are four years of peak loads in the inventory during which most of the wells will be visited.

- There are 250 working days in a year.

Thus, it is anticipated that the inventory will add as many as 200 samples per day to the laboratory's long-term base load of 50 samples per day, causing an increase of about 1,000 samples per week or 4,000 per month. Also, the 50 teams necessary to inventory an average of four wells per day will require additional analytical support to process the inventory field support facility parameters.

To adequately accommodate the well inventory, it is recommended that the central laboratory make maximum use of autoanalyzers and autosampling equipment and supplement the full-time staff with contract personnel. The contract personnel should work a second shift that overlaps the first shift by about two hours, providing adequate sample preparation for the automated instruments and cross-training with the full-time staff.

The contract personnel should duplicate the full-time laboratory technicians, some of the mid-level chemists, and perhaps a few senior staff members. Table 14 shows the capacity of the central laboratory on a parameter-by-parameter basis for both the normal (one-crew) and inventory support (two-crew) scenarios.

The load on the laboratory during the inventory can be moderated still further. MWR personnel estimate that 25,000 to 40,000 wells will be fitted with discharge meters within one year of being inventoried and will be visited several times a year thereafter so the meter can be read. These wells could be sampled during the meter installation or during one of the subsequent visits rather than during the actual inventory, thus reducing the peak load on the laboratory. Should this procedure be followed, it is recommended that samples from wells receiving meters be collected within six months of the inventory. This will allow a more immediate observation of water quality in the areas represented by both metered and non-metered wells.

4.7 Recommended Process for Sample Collection, Field Analysis, Filtration, Storage, and Shipping

Samples must be collected in appropriate containers with the proper preservatives. Correct collection procedures are described in various manuals and references, including several listed in the References section of this report by Barcelona, et al. (1985), Scalf, et al. (1981), and the National Water Well Association (1986). It is recommended that samples intended for analysis of metals be filtered, unless the person requesting the analysis is interested in the suspended metals load as well as the dissolved metals concentration. Sample filtering should be performed in the regional office facility to achieve consistency, to reduce the requirements imposed on the field sampling crew, and to decrease the workload of the central laboratory.

Several sample bottle must be filled to obtain accurate water quality analyses, since different analytes require different container materials, such as glass or plastic, different volumes for sample concentration and processing, and different preservatives, such as nitric acid, for stabilizing the sample. These bottles are part of a sample kit.

Containers should be divided into identical routine, comprehensive, and special kits. All containers should be filled properly each time a sample is collected, regardless of the constituents to be analyzed. This consistency is necessary to simplify field operations, to minimize miscommunications, and to provide the standardization to fulfill QA/QC requirements.

The procedure described will ensure the maximum efficiency in collection, considering the effort to fill a complete set is no greater than to fill a partial set and is insignificant when compared with the cost and effort of mobilizing sampling or inventory crews, vehicles, and equipment at a well site.

Special analytes, such as samples for isotopic dating, require the collection of large volumes of water in a very specific manner. These samples will be collected only on an as-needed basis for special MWR projects.

The field parameters listed in Table 11 should be measured at the time of sample collection, ideally in the well itself. It is more practical, however, to measure them in-line while the sample pump is running.

After the parameters have been measured and the sample container set filled, the sample kit should be placed in a cool box, preferably at 4°C, and transported to the regional office or an inventory field support facility so that measurements there can be completed within a maximum of four to six hours from the time of sample collection. The regional office and inventory field support facility parameters are listed in Table 12.

After these parameters have been measured, the remaining containers should be stored in refrigerators at 4°C until either enough sets have accumulated for dispatch to the central laboratory or one week has elapsed since sample collection, whichever occurs first. No sample should ever be held longer than one week.

Samples should be shipped in cool boxes or, preferably, a refrigerated vehicle and delivered to the central laboratory within one day. If one vehicle cannot do this, more vehicles must be provided or more frequent deliveries made. Vehicles should be under the control of the MWR and dedicated to sample pick up and delivery. Back-up vehicles and personnel must be available to handle unforeseen contingencies, breakdowns, vacations, and similar problems. In northern Oman samples can be delivered by road. In the southern region they will have to be taken to the Salalah airport and sent by air freight. The samples from the southern region should be shipped with sufficient ice to maintain the interior of the boxes at 4°C for several days, picked up immediately at the Seeb airport, and delivered promptly to the central laboratory.

4.8 Recommended Location, Construction Requirements, and Conceptual Schematic for the New MWR Laboratory

The recommended location, construction requirements, and a conceptual schematic for the new laboratory are presented in this section. A conceptual design analysis and report are required as the first phase of construction. Subsequent phases must describe in detail the laboratory's construction and equipment, and will eventually result in blueprints and specifications.

4.8.1 Location Requirements

The new laboratory should be located in an area central to the sample distribution in the country, suitable for the recruitment, housing, and retention of qualified staff, and within easy reach of support services and utilities. The capital area meets these criteria best and would be the ideal location.

The MWR has already obtained a site on the hill above its own headquarters building in Ruwi. But it is accessible only by a circuitous path through the MWR complex and sits on fill material unlikely to be suitable for a building foundation. There is no sanitary sewer at the site, and the water pressure may not be adequate for the needed control systems. Further, the land-use designation may not be appropriate for a laboratory.

It is therefore recommended that the MWR look for a suitable site in the Al-Rusyal industrial area, which is near the roadways along which incoming samples from the interior, the northern region, and the southern region via the Seeb airport will be delivered.

4.8.2 Requirements for Power Supply

The power supply must be sufficient for lighting, air conditioning, analytical instrumentation, ovens, refrigeration, and any other laboratory needs. It should be backed up by a fuel-driven generator capable of maintaining the facility's cooling, refrigeration, lighting, and critical or sensitive instrumentation at the minimum, but preferably of supplying all power to operate the laboratory without interruption.

The power supply must be configured to protect sensitive laboratory equipment and computer systems against electrical disturbances that include:

- Under-voltage or over-voltage
- Voltage sags and swells
- Spikes, impulses, and surges
- Short-term outages and power failures
- Electrical noise and harmonic distortions

An uninterruptible power supply (UPS) system will guarantee this. Power to the UPS is supplied normally by commercial line power, or by a generator in the event of a power failure. Either source of alternating current (AC) is then rectified to charge the internal batteries of the UPS system. The direct current (DC) output of the batteries is in turn inverted to provide a consistent AC power supply to preselected laboratory equipment and computers. Commercial UPS systems are available with output as high as 3,600 kilovolt amperes (KVA) to routinely supply 4,000 amperes at 480 volts AC (three-phase).

To optimize the use of the UPS system, laboratory equipment is divided into three categories:

- Devices requiring complete UPS supply protection
- Devices requiring power conditioning only and for which short-term outages (less than one minute) are acceptable
- Devices requiring voltage regulation only and for which long-term outages (less than 10 minutes) are acceptable

Devices are powered by dedicated electrical circuits providing only the appropriate protection and conditioning.

4.8.3 Heating, Ventilation, and Air-Conditioning Requirements

The laboratory will require specialized heating, ventilation, and air conditioning (HVAC) systems. The laboratory must be maintained at a constant temperature near 25°C with fluctuations of no more than ±3°C. The ventilation must be adequate and provide several rooms with slightly positive or negative air pressure to minimize cross-contamination between various areas of the laboratory.

In general, the codes and standards below, with the latest addenda and supplements, should be followed.

- Omani HVAC design standard
- Building Officials and Code Administrators International, Inc. (BOCA) National Geotechnical Code
- American Society of Heating, Refrigeration, and Air Conditioning Engineers, Inc. (ASHRAI) Handbook Series or equivalent British standards
- Industrial Ventilation—A Manual of Recommended Practice by the American Conference of Governmental Industrial Hygienists
- American Gas Association Codes
- National Fire Protection Association (NFPA) Codes and Standards or equivalent British standards

Design criteria for the laboratory facility are described below and are listed in Table 15 for temperature, noise, ventilation, and humidity.

- Maximum winter design temperature 30°C
- Maximum summer design temperature 44°C
- Wind—Average Speed 10 Knots

  —Prevailing Direction variable N, S, E

- Noise

  —Night-time (7p.m. to 7a.m.) noise transmitted to the nearest facility fence line abutter should not exceed 36 decibels (dBA), so that when combined with a 36 dBA ambient background the noise level will not exceed 39 dBA

  —Day-time (7a.m. to 7p.m.) noise transmitted to the nearest fence line abutter from the facility should not exceed 36 dBA

  —Indoor criteria as listed in Table 15

Ventilation for the laboratory will be provided by air-supply handling units and exhaust fans with a capacity to meet the following design criteria:

- Temperature control in occupied spaces
- Temperature and humidity control for make-up air
- Filtration of all outdoor air intakes

Air for laboratories, toilet facilities, locker rooms, and hazardous materials storage areas will not be recirculated. In other areas, recirculation is allowed for that portion of the air supply in excess of the outdoor air make-up requirements.

A minimum of two exhaust systems (fume hoods and/or vents) are required in each analytical laboratory room. Fume hoods approximately equal to the linear footage of bench space are required in the sample preparation laboratory rooms. Preparatory laboratory rooms should be maintained under negative pressure, while connecting analytical laboratory rooms are maintained under positive air pressure. This configuration will prevent odors and vapors in the preparatory rooms from contaminating the adjacent analytical areas. Microbiological laboratory rooms should also be maintained under negative pressure with respect to all adjacent spaces.

The air-handling units should be designed to maintain appropriate positive and negative pressures with the aid of fume hoods, since the number of hoods operating at one time is not specified in a conceptual design report. However, the air-handling units should be designed to adjust automatically to desired room pressures when pressure changes from a varying number of operating fume hoods occur.

Fume hoods will be used to exhaust potentially harmful vapors from all analytical and preparatory laboratory rooms. A minimum of two exhaust systems (fume hoods or exhaust vents) are required for each analytical laboratory room, and fume hoods are required over all work benches in all preparatory laboratory rooms. Exhaust ducts from every fume hood will be placed in dedicated exhaust shafts strategically located in the building. Fume hood exhaust ducts should be isolated from exhaust systems in other parts of the building. The exhaust design must preclude the possibility of re-entry of fume hood exhausts.

Fume hoods will be either of bypass or supplied-air design, depending on the hood's application. For the more economical supplied-air design, adequate filtered and tempered air will be obtained from an external supply. All fume hoods and exhaust ducts will be vented to the outside of the building. Horizontal routing of the exhaust ducts from the fume hoods should be kept to a minimum.

General air-conditioning systems will be provided for all areas as required in the preliminary design phase of construction. These systems will utilize chilled water provided by remote air-cooled chillers for cooling the air in the air-handling units. Chilled-water pumps and system appurtenances will be located in the mechanical room of the laboratory.

4.8.4 Requirements for Water, Wastewater, and Reagent and Sample Disposal

The laboratory will have special requirements for water, wastewater, and reagent and sample disposal. The supply must be continuous and suitable for analytical and personal use, and the water lines for analytical use must be chilled to ambient room temperature since water from the municipal supply can be far too hot for direct use in analyzing samples.

The laboratory should be connected to the municipal sewage lines for disposal of sewage and nontoxic wastes only. Wastes from processing samples, such as reagents, acids, solvents, and discarded samples, must be disposed of by environmentally sound methods. These methods may include special handling and disposal using storage tanks and biological or chemical treatment, fixation, incineration, stabilization, or neutralization. Guidelines and regulatory requirements are provided by the Sultanate's Ministry of Environment. The MWR laboratory must always comply with these regulations.

4.8.5 Other Special Requirements

The laboratory will require many special construction features. Among these are high-pressure and low-pressure rooms, specialized built-in equipment, vents, fume hoods, ducting, plumbing, emergency showers and eye wash facilities, chemically resistant drains and sinks, chemically resistant and slip-proof flooring materials, floor drains, loading docks, storage rooms, refrigerated storage rooms, and special explosion-proof chemical and solvent bunkers with non-spark-generating electrical switches, cooling, and appliances. Special construction requirements for the laboratory will be specified during the design phase which will follow this conceptual design report.

The location of the utilities will be finalized during the design phase so that adequate space for piping and tanks is provided in the laboratory units where they are required. The following utilities must be provided for individual laboratory units from local systems:

- Liquid argon
- Compressed air
- Distilled water
- Laboratory grade gases (nitrogen, helium, and argon)
- Vacuum lines
- Acetylene
- Nitrous oxide
- P-10 mixture (5% methane, 95% argon)

4.8.6 Approximate Floor Space Required and Conceptual Schematic of the Laboratory

The estimated floor space for the laboratory is 1,500 square meters, which will accommodate the facilities as presently conceptualized and also provide for expansion. Space requirements for individual rooms are presented in Table 16.

A conceptual schematic is presented as a bubble diagram in Figure 4. The figure indicates the position and area of each unit relative to the units around it. A conceptualized process flow-through diagram is presented in Figure 5 to show showing how a sample is moved through the laboratory.

4.9 Conceptual Laboratory Design Recommendations, Considerations, and Instrumentation

This section describes the instrumentation and equipment required to perform the analyses for the parameters listed in Table 13. The equipment requirements are summarized in Table 17, which lists the types of the major instrumentation, the parameters each is capable of analyzing, how many samples it can process per hour, and approximate costs.

For presentation purposes, operations have been grouped in the following units based on the instrumentation and support facilities required to perform specific analyses :

- Radiological Laboratory
- Metals Laboratory
- Organics Laboratory
- Microbiological Laboratory
- Wet Chemistry Laboratory
- Inorganic Instrumentation Laboratory

The conceptual design has been guided by a number of criteria that will also be used in the preliminary design of the facility:

- Separating preparation areas from analysis areas in order to minimize cross-contamination
- Separating incompatible work areas, such as trace volatile organic analyses from the organic preparation laboratory
- Providing adequate bench space and hood work space for projected sample workload
- Taking into account laboratory interactions and sample traffic control when proposing unit adjacencies
- Locating storage rooms and sample repositories near areas that need continuous access
- Providing semi-private office space for each professional employee

- Ensuring that a separate secure area for hazardous waste storage is provided near loading docks

- Providing each laboratory with adequate fume hoods to support all anticipated activities, with an exhaust system density of at least two fume hoods per work unit and additional ventilation in exhaust-intensive areas

- Providing interim cold storage of samples in individual work areas

- Providing sensitive electronic instrumentation and computer systems with a climate-controlled work space

The analyses to be performed, the major capital equipment to be procured, and special design considerations for each laboratory are presented below.

4.9.1 Radiological Laboratory

- Space

  — Radiological laboratory 47 sq.m
  — Radiological preparation laboratory 30 sq.m

  The radiological laboratory is designed for future expansion. Future analyses may include radionuclides and isotopic dating.

- Analyses Performed

  — Gross alpha
  — Gross beta

- Major Capital Equipment and Vendors

  — Low-level gas proportional counter system

    - Multiple detection system
    - Automatic sampler
    - PC data station

  — Vendors

    - Princeton Gamma-Tech, Inc.
      1200 State Road, Princeton, NJ

- Tennelec/Nucleus, Inc.
  601 Oak Ridge Tpk., Oak Ridge, TN

- EG+G Ortec, Div of EG+G, Inc.
  100 Midland Road, Oak Ridge, TN

- Production Rate

— Process rate	24 samples/hour
— Productivity factor	0.7
— Production rate	17 samples/hour

- Special Considerations

  — Lab security is essential because of radiation hazards

4.9.2 Metals Laboratory

- Space

— Metals computer/report room	30 sq.m
— Metals instrument laboratory	65 sq.m
— Metals preparation laboratory	58 sq.m

The metals laboratory is designed to separate sample pretreatment, filtration, and digestion from analysis, which is conducted in a temperature-controlled instrument laboratory. The preparation laboratory, with its extensive ventilation requirements, is designed to have negative pressure in relation to the metals instrument laboratory.

- Analyses Performed

  — 25 metals (Table 14)

- Major Capital Equipment

  — Inductively coupled plasma spectrophotometer (ICP)

  - Simultaneous (25 metals)
  - Ultrasonic nebulizer
  - Automatic sampler

- Built-in sequential analyzer
- PC data station

— Atomic absorption spectrophotometer

- Multi-lamp turret
- Graphite furnace
- Automatic sampler
- PC data station

— Atomic absorption spectrophotometer

- Hydride generator
- Automatic sampler
- PC data station

— Atomic absorption spectrophotometer

- Flameless mercury hydride generator
- Automatic sampler
- PC data station

— Vendors

- Fisons Instruments
  Riverside Way, Uxbridge, Middlesex, UK

- Varian Instrument Group
  220 Humboldt Court, Sunnyvale, CA

- Philips Analytical Division of Philips
  BLOG HFK, NL-5600 MD Eindhoven, Netherlands

- Production Rate

  — See Table 18

- Special Considerations

  — Design of duct work must allow for fumes from metal digestion processes that can be quite corrosive.

- Each instrument is serviced by a PC data station and data are compiled using report server software. The compiled data files are directed to the LIMS. Figure 6 is a graphic representation of the interactive data system.

4.9.3 Organics Laboratory

- Space

  - Volatile organics laboratory 56 sq.m
  - Semi-volatile organics laboratory 56 sq.m
  - Pesticide laboratory 56 sq.m
  - Organics preparatory laboratory 46 sq.m
  - Organics laboratory computer/report room 28 sq.m

  The organics laboratory is designed to separate sample pretreatment from analysis. All analyses are conducted in climate-controlled rooms. The preparatory laboratory, which uses large volumes of organic solvents, has extensive ventilation requirements and is designed to have negative pressure in relation to the instrument laboratories. The volatile organics laboratory, which is most susceptible to cross-contamination, is segregated from all other laboratories and is designed to have the highest ambient pressure.

- Analyses Performed

  - Volatile organics
  - Semi-volatile organics
  - Pesticides
  - Herbicides
  - Petroleum hydrocarbons

- Major Capital Equipment

  - Volatile organics GC/MS

    - Multi-channel purge and trap
    - Data station

  - Semi-volatile organics GC/MS

    - Automatic sampler
    - Data station

- Gas chromatograph dual-channel ECD (two units required)
    - Automatic sampler
    - Data station

- Gas chromatograph dual-channel NPD
    - Automatic sampler
    - Data station

- Gas chromatograph HALL/PID
    - Multi-channel purge and trap
    - Automatic sampler
    - Data station

- High-performance liquid chromatograph (HPLC)
    - UV detector
    - Fluorescence detector
    - Automatic sampler
    - Data station

- Gas chromatograph PID/FID
    - Multi-channel purge and trap
    - Auto sampler
    - Data station

- FTIR spectrophotometer
    - Data station

- Vendors
    - Fisons Instruments
      Riverside Way, Uxbridge, Middlesex, UK

    - Varian Instruments
      220 Humboldt Court, Sunnyvale, CA

    - Hewlett-Packard Co.
      Mailstop 20B AE, Palo Alto, CA

- Production Rate

  — Based on chromatographic retention times, the processing rate for organic analyses is approximately one sample per hour.

- Special Considerations

  — An uninterruptible power supply (UPS) is an essential requirement of this laboratory.

4.9.4 Microbiological Laboratory

- Space

  — Microbiological laboratory 46 sq.m

  The nature of the testing conducted in this laboratory does not require the separation of analytical and sample preparation activities. The laboratory should have positive ambient pressure in relation to adjoining spaces to avoid cross-contamination.

- Analyses Performed

  — Total coliform
  — Fecal coliform
  — Fecal streptococcus
  — Total plate count

- Major Capital Equipment

  — None

- Special Considerations

  — Analyses conducted in this laboratory are labor-intensive and require aseptic conditions.

4.9.5 Wet Chemistry Laboratory

- Space

  — Wet Chemistry Laboratory 93 sq.m

Analyses conducted in this laboratory are labor- and space-intensive and require permanent setup of laboratory apparatus.

- Analyses Performed

  - Total dissolved solids
  - Total suspended solids
  - Surfactants (MBAS)
  - Sulfides
  - Carbon dioxide
  - Iodides

- Major Capital Equipment

  - None

- Production Rate

  - The processing rate for these manual analyses depends on the manpower assigned. A single analyst may produce 5 to 10 results per hour depending on the complexity of the particular test.

- Special Considerations

  - The laboratory will provide sample preparation support for the high-volume inorganic instrument laboratory. It will also provide calibration verification of the following parameters in support of field activities:

    - pH
    - Electrical conductivity
    - Dissolved oxygen
    - Oxidation/reduction potential
    - Temperature

4.9.6 Inorganic Instrument Laboratory

- Space

  - Inorganic instrument laboratory 56 sq.m

- Analyses Performed

  - Anions
  - Conventional/wet chemistry

  A list of anion analyses and production rates is presented in Table 19. A list of conventional/wet chemistry analyses and production rates is presented in Table 20.

- Major Capital Equipment

  - Ion chromatograph (IC)

    - Automatic Sampler
    - Data station

  - Total organic carbon analyzer (TOC)

    - Auto sampler
    - Data station

  - Automated wet chemistry analyzer (FTA) (three instruments required)

    - Automatic sampler
    - Data station
    - Multi-channel (six analyses)

  - Vendors

    - Ion chromatographs (IC)

      Dionex Corp.
      1228 Titan Way, Sunnyvale, CA

      Waters Chromatography Div.
      34 Maple St., Milford, MA

      Hewlett-Packard Co.
      Mail Stop 20B AE, Palo Alto CA

- Total organic carbon (TOC)

  Dohrmann Corp.
  3240 Scott Blvd.
  Santa Clara, CA

  OI Analytical
  Graham Road at Welbourn Street
  College Station, TX

- Production Rate

  — See Tables 19 and 20

- Special Considerations

  — This laboratory will be the highest production laboratory and will require substantial logistical support.

4.10 Recommended Field Equipment

Portable, durable, and accurate analytical equipment will be required at the wells, at the district offices, and at the inventory field support facilities. Spare parts and adequate supplies and reagents should also be readily available at district offices and inventory field support facilities.

The field parameters (temperature, specific conductivity, pH, oxygen reduction potential, and dissolved oxygen) should be measured at the well head. The measurements should be made either in the well with a down-hole probe, or with a flow-through cell as the well is pumped. Instruments should be able to withstand a wide range of operating temperatures (0 to 50°C), be automatically temperature compensating, and be able to run numerous hours on replaceable or rechargeable batteries. The instruments preferably should include an internal data logger or be able to interface easily with an external data logger through an RS232 computer link.

4.11 Recommended Procurement and Maintenance

Laboratory equipment should be procured through tenders from approved and qualified vendors either domestic or foreign. Equipment should be purchased only from major manufacturers experienced in producing and maintaining the product offered and should be accompanied by an extended parts inventory and an extended warranty. A maintenance contract with the manufacturer's representative at the time of purchase for long-term maintenance, repair, and service is strongly recommended.

As far as practical, the new equipment should be from the same manufacturer, or at least be of the same technology, as equipment that other Omani ministry laboratories have purchased recently. This could be beneficial in the event that cross-training of personnel is desired, or if backup equipment, parts, supplies, and repair technicians are needed at some point.

Major capital equipment purchases from a limited number of manufacturers will facilitate consistency, maintenance, repair, training, and technical support. It would also help if all the equipment could be obtained from as few as three vendors. If purchases could be coordinated with those of other ministries, a major instrument manufacturer might be encouraged to establish a supply and repair center in Oman or nearby.

4.12 Supply Recommendations

As indicated earlier, obtaining supplies in Oman can take up to six months. Therefore, tight inventory control on all laboratory consumables, supplies, reagents, and glassware is essential to prevent unexpected shortages. Stocks should be replenished at least six months ahead.

A centralized government chemical supplies storehouse responsible for obtaining and keeping sufficient stocks for all government laboratories in Oman is recommended. The storehouse probably could get a discount if it ordered in bulk, and the response for larger orders from a regular customer probably would be faster.

Another recommendation would be to establish a glass-making and glass-blowing facility for making and repairing analytical glassware. This facility could be located in the storehouse and similarly service all government laboratories in the country. Analytical glassware can be extremely expensive but often is repairable.

4.13 Recommended Analytical Methods

The laboratory should continue to follow the methods and procedures outlined in *Standard Methods for the Analysis of Water and Wastewater* augmented by procedures promulgated by the U. S. Environmental Protection Agency (USEPA) for compliance with the Safe Drinking Water Act. A list of analyses and the procedures for performing them is presented in Table 21, and a list of organic constituents cross-referenced with the appropriate USEPA procedure number appears in Appendix F.

4.14 Recommended QA/QC Standards, Policies, and Operating Procedures

The MWR as soon as possible should retain a specialist to design and maintain QA/QC standards, policies, and operating procedures for all its analytical programs. This includes field, regional office, and central laboratory activities. It is also recommended that a retroactive QA/QC analysis be performed on existing water chemistry data, some of which are several years old and were collected under varying degrees of quality assurance and quality control.

The laboratory would benefit from participation in a cooperative program with the laboratories of other ministries. Such a program would allow the analyses of test samples by one laboratory to be cross-checked by all the other participating laboratories, revealing individual weaknesses that could be corrected for the betterment of standards and levels of accuracy in laboratories throughout Oman. The MWR laboratory should also participate in internationally recognized laboratory testing programs.

The continued professional development of laboratory personnel should be encouraged through in-house seminars, lectures, and classes; opportunities for attending outside seminars, short courses, and professional conferences; and membership in professional and technical organizations.

A typical QA/QC plan for a water quality laboratory is presented in Appendix G.

4.15 Laboratory Safety

Although all personnel have a share in preserving a safe working environment, laboratory safety must be made the responsibility of a single individual with experience in industrial hygiene, public health, or industrial safety who carries out an approved chemical hygiene plan. The chemical hygiene officer (CHO), generally a senior member of the technical staff, is required to:

- Work with management to implement appropriate chemical hygiene policies
- Monitor procurement, use, and disposal of chemicals
- See that continuing safety audits are conducted
- Seek ways to augment and improve the chemical hygiene plan
- Provide continuing safety instruction to laboratory staff

- Report violations of the chemical hygiene plan directly to management

A chemical hygiene plan includes:

- General Principles
  - Minimize all chemical exposures
  - Avoid underestimation of risk
  - Provide adequate ventilation
  - Institute a chemical hygiene program
  - Observe the PELs and TLVs
- Responsibilities
  - Chief executive officer
  - Supervisor of administrative staff
  - Chemical hygiene officer
  - Laboratory supervisor
  - Project director
  - Laboratory worker
- The Laboratory Facility
  - Design
  - Maintenance
  - Usage
  - Ventilation
- Components of the Chemical Hygiene Plan
  - Basic rules and procedures
  - Chemical procurement, distribution, and storage
  - Environmental monitoring
  - Housekeeping, maintenance and inspections
  - Medical program
  - Personal protective apparel and equipment
  - Records
  - Signs and labels
  - Spills and accidents
  - Training and information
  - Waste disposal

- General Procedures for Working With Chemicals

  - General rules for all laboratory work with chemicals
  - Allergens and embryotoxins
  - Chemicals of moderate chronic or high acute toxicity
  - Chemicals of high chronic toxicity
  - Animals work with chemicals of high chronic toxicity

- Safety Recommendations

- Material Safety Data Sheets

4.16 Laboratory Information Management System

The LIMS should be compatible with MWR's proposed groundwater database, since water quality results will be used by groundwater and surface water departments in the MWR and may also be made available to other agencies.

The system should provide the following functions:

- Centralized laboratory log-in

- Bar-code control of samples through various laboratory units

- Electronic data transfer from various analytical units to a central data file

- Electronic data validations and identification of deficiencies

- Electronic transfer of sampling data from service areas to central data repository

- Bar-code control for sample traffic control to assure chain of custody

- Read-only and data-entry-only controls on system users

In addition, the system should conform to the following requirements:

- It should be based or internally interfaced with the ORACLE database system

- It should have a local support structure

- It should have maintenance agreements that are drawn up during the tender process.

- It should be implemented on a Unix environment and operate on a client/server network

Figure 7 presents an information flow diagram for the laboratory, and Appendix H has a master list of data management system vendors and a description of a LIMS system (VG LIMS) available from VG Laboratory Systems, Ltd., Altrincham, Cheshire, U.K. The description of this system is not intended as an endorsement.

4.17 Approximate Cost of Upgrading Laboratory

A preliminary planning budget for the next 10 years is presented in Appendix I. Items A through G provide the approximate costs of elements for the laboratory as it is now envisioned, and a budget summary follows. During the development years, annual capital outlays of over 1 million R.O. will be necessary; thereafter they will decline to about 700,000 R.O. and then to about 450,000 R.O. after the inventory. Assuming an annual interest rate of 9 percent, the annual cost of these capital outlays will be about 400,000 R.O. over the life of the laboratory and equipment.

Annual recurrent costs for staff and consumables will be about 720,000 R.O. during each year of the inventory, making the total cost of owning and operating the laboratory during the inventory period approximately 1.1 million R.O. per year. This figure is the rounded-off sum of the amortized capital cost plus the annual costs.

Assuming the laboratory during the inventory period will be able to process an average of 200 routine samples and 25 comprehensive samples each day and that it can operate 200 days a year, it would process 45,000 samples a year. Thus, each sample tested will cost between 22 R.O. and 25 R.O. if nearly all the wells visited during the inventory are sampled. This is much less than the current rate charged by water laboratories in Oman.

The substantial labor requirements for special parameters would greatly increase the operational costs of the laboratory. If these parameters were phased in after the inventory, the cost per sample would be substantially reduced. However, the results of special analyses during the inventory would provide invaluable data about the incidence of toxins in the waters of Oman.

4.18 Conceptual Laboratory Implementation Process

Figure 8 presents a project implementation process diagram. Once the design concept has been approved, the construction, planning, and execution track can be initiated by contracting the service of a design consultant to

- Develop a preliminary floor plan
- Determine space and utility requirements in coordination with the acquisition manager and suppliers
- Develop preliminary design criteria suited to the Omani setting in coordination with the architect and engineers
- Prepare a plan of sufficient detail so that the architect and engineers can draw up a design

Simultaneously, the Ministry should engage a consultant as an equipment acquisition manager to complete the specifications, purchase, and delivery of equipment. This consultant would

- Prepare an acquisition plan
- Make preliminary contacts with qualified equipment manufacturers to provide suitable equipment and related support and training
- Develop task-specific specifications for equipment training and support
- Arrange and coordinate any necessary factory training
- Coordinate and supervise the timely delivery of equipment

At the earliest stage of project implementation, the MWR may wish to engage a recruitment advisor—who could be the same person as the equipment acquisition manager—to recruit laboratory staff by

- Preparing advertisements for staff positions
- Reviewing the resumes of applicants

- Assisting the MWR in interviewing candidates
- Assisting in the final selection of staff

After completing these tasks, the advisor would turn over responsibility for future recruitment and staff development to the laboratory director who with one or two senior personnel would be required before the opening of the laboratory to

- Develop a laboratory budget and staffing plan
- Coordinate any necessary factory training
- Arrange parallel training programs
- Operate the existing laboratory during the transitional phase

4.19 Follow-On Consultancy and Assistance

During the start-up phase the laboratory will require external support and guidance for

- Development of standard operating procedures
- Development of QA/QC programs
- Implementation of the laboratory information management system (LIMS)
- Development of safety procedures
- Development of in-house training programs

These services are best provided by consultants familiar with the design and mission of the laboratory. Once the laboratory is fully operational and safety and QA/QC procedures are in place, a continuing external compliance review would assure MWR that the laboratory was producing analytical data of acceptable quality in a safe work environment.

Figure 3

PROPOSED ORGANIZATIONAL CHART FOR THE NEW FULL-TIME MWR LABORATORY (NORMAL OPERATION)

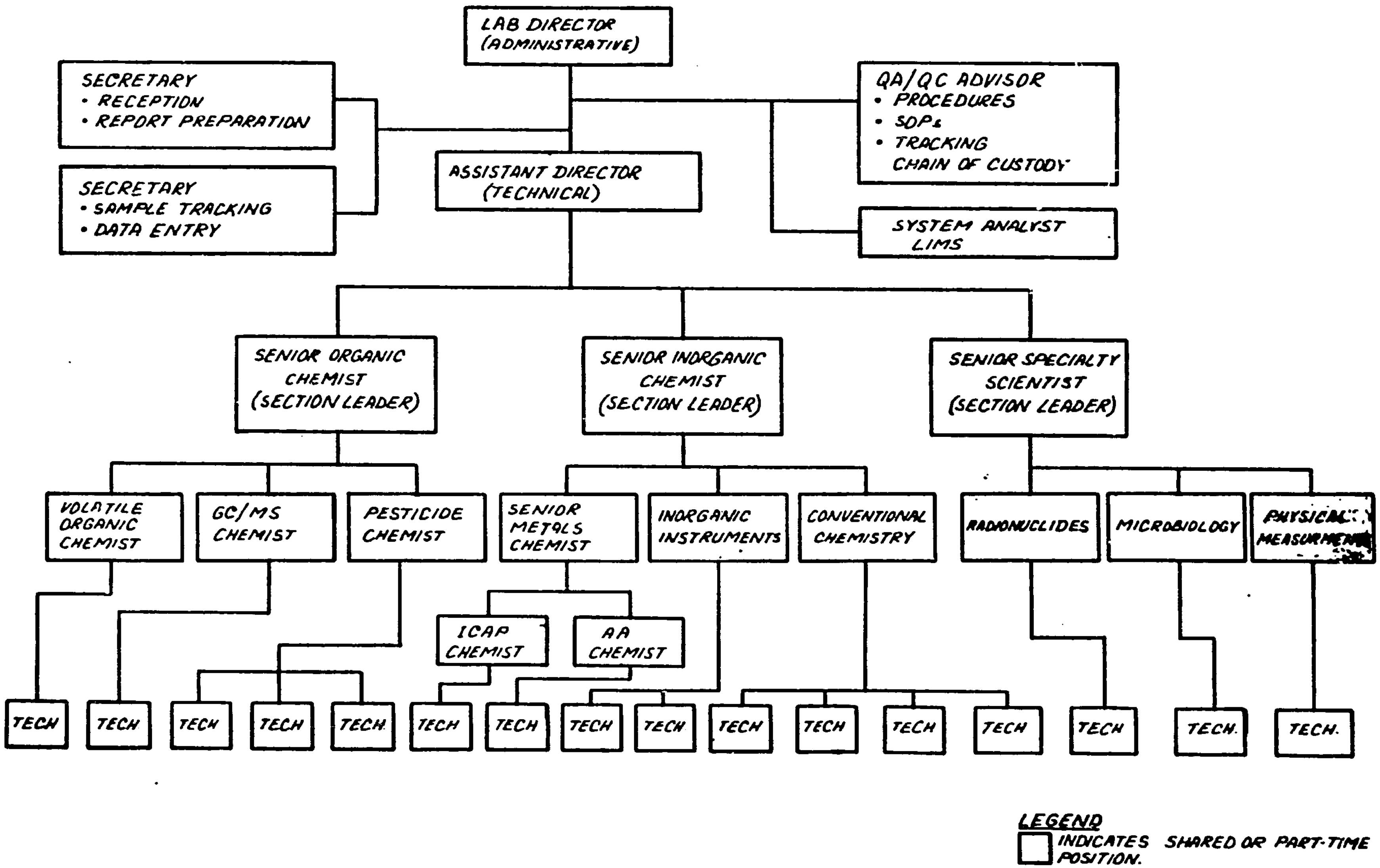


Table 6

FIVE-YEAR PROJECTED WORKLOAD FOR THE LABORATORY

Year	Samples	Lab Staff	Type of Analyses	Notes
1990	10	7	Limited Routine (R)	Existing Laboratory
1991	20-30	12	Limited Routine (R)	Existing Laboratory New Staff and Equipment
1992	50	30	Routine (R), Comprehensive (C) and Special (S)	New Laboratory
1993	250	50 *	Routine (R), Comprehensive (C) and Special (S)	Peak Inventory
1994	250	50 *	Routine (R), Comprehensive (C) and Special (S)	Peak Inventory
1995	250	50 *	Routine (R), Comprehensive (C) and Special (S)	Peak Inventory
(1996) **	100	35 ***	Routine (R), Comprehensive (C) Special (S) and Future (F)	Isotopes, Asbestos and other new parameters

*   20 temporary contract staff
**   estimated workload
***   5 temporary contract staff

Table 7

ROUTINE ANALYSES LABOR REQUIREMENTS

Parameter	Method	Normal No.	Normal Tech	Normal Chem	Inventory No.	Inventory Tech	Inventory Chem
Anions (6)	AWC	50	1.0	1.0	250	3	2.0
Conventional (4)	AWC	50	1.0	0.5	250	3	1.0
Total Organic Carbon`	IR/COMB	50	0.5	0.5	250	2.5	1.0
<u>METALS</u>							
ICP Metals (2I)	ICP	50	1.5	1.0	250	3	2
Mercury	FLAMELESS	50	0.5	0.5	250	2	1
Arsenic and Selenium	HYDRIDE	50	1.0	0.5	250	1.5	1
LEAD	GRAPHITE	50	0.5	0.5	250	2.5	1
Total		X	6.0	4.5	X	17.5	9.0

Table 8

COMPREHENSIVE ANALYSES LABOR REQUIREMENTS

Parameter	Method	Normal			Inventory		
		No.	Tech	Chem	No.	Tech	Chem
Soluble Silica	AWC	5	0.25	0.25	25	0.5	0.25
Ammonia (N)	AWC	5	0.25	0.25	25	0.5	0.25
Total Recoverable Phenolics	DIST/AWC	5	0.5	0.25	25	1.5	0.25
Gross Alpha and Beta	CONC/AGPC	5	0.5	0.25	25	1.5	1.0
TOTALS		X	1.5	1.0	X	4.0	1.0

Table 9

DEDICATED PRODUCTION STAFF TO SUPPORT SPECIAL PARAMETER ANALYSES

Analytical Work Group	Normal Tech.	Normal Chem.	Inventory Tech.	Inventory Chem.
GC Laboratory	2	1	4	1.5
GC/MS Volalite Laboratory	1	1	2	1.5
GC/MS Semi-Volatile Laboratory	1.5	1	3.5	1.5
Wet Laboratory (conventional analyses)	1.0	0.25	2	1
Micro-Biology Laboratory	0.5	0.25	1	0.5
Speciality Laboratory (Physical Well Inv. Parameters)	0.5	0	1	0
Total	6.5	3.5	13.5	6

Table 10

TOTAL LABORATORY PRODUCTION STAFF LABOR REQUIREMENTS

Category	Level of Samples at well heads	No. of Samples per day	No. of Analyses (Per Day) Normal/Inventory	Normal Staff level Tech.	Normal Staff level Chem.	Inventory Total Staff Tech.	Inventory Total Staff Chem.
Routine Parameters	100	50/250	1800/9000	6	4.5	17.5	9.0
Comprehensive-Parameters	10	5/25	25/125	1.5	1.0	4.0	1.0
Special Parameters	5	as required	Personnel/Equipment Limited	6.5*	3.5*	13.5*	6*
Total Production Staff				14	9	35	16

* Dedicated staff to provide support in the analysis of special parameters. Analysis of special parameters will be scheduled based on production capacity of dedicated staff.

Table 11

ANALYTICAL PARAMETERS AND FREQUENCY OF MEASUREMENT TO BE PERFORMED IN THE FIELD

Parameter	Frequency Group *
Temperature	R
pH	R
Specific Conductivity	R
Dissolved Oxygen	R
Oxygen Reduction Potential (Eh)	R
Apparent Odor	R
Carbon Dioxide	S

* R Routine Group

S Special Group (by request only)

Table 12

ANALYTICAL PARAMETERS AND FREQUENCY OF MEASUREMENT TO BE PERFORMED AT REGIONAL OFFICES AND INVENTORY FIELD SUPPORT FACILITIES

Parameters	Frequency Group *
Temperature	S
pH	S
Specific Conductivity	S
Dissolved Oxygen	S
Oxygen Reduction Potential (Eh)	S
Apparent Odor	S
Carbon Dioxide	S
Total Dissolved Solids	R
Specific Gravity	S
Color	R
Turbidity	R
Total Coliform	R
Fecal Coliform	R
Fluorescent Dye	S
Settleable Solids	S

* R Routine Group
S Special Group (by request only, or has already been measured in the field)

Table 13

ANALYTICAL PARAMETERS AND FREQUENCY OF MEASUREMENT TO BE PERFORMED AT THE CENTRAL LABORATORY

Parameters	Frequency Group
1. Conventional, Wet Chemistry & Physical Properties:	
All Field, Near-Field & District Parameters	S
Total Alkalinity	R
Bicarbonate Alkalinity	R
Hardness	R
Acidity	R
Total Suspended Solids	R
Total Organic Carbon	R
Soluble Silica	C
Asbestos	F
Sulfides	S
Ammonia (N)	C
Total Recoverable Phenolics	C
Surfactants (MBAS)	S
Cyanide	S
Sediment Volume	S
Grain-Size Distribution	S
2. Anions:	
Bromide	S
Chloride	R
Fluoride	R

Table 13 (cont.)

	Parameters	Frequency Group
	Iodide	S
	Nitrate	R
	Nitrite	R
	O-Phosphate	R
	Sulfate	R
3.	Microbiological:	
	Total Coliform	S
	Fecal Coliform	S
	Total Plate Count	S
	Fecal Streptococcus	S
4.	Radiological:	
	Gross Alpha	C
	Gross Beta	C
	Radon	F
	Radium 226 and 228	F
	Strontium 90	F
	Tritium	F
	Carbon 14/13	F
	Deterium/018	F
	Other Isotopes	F
5.	Metals:	
	Aluminium	R
	Arsenic	R

Table 13 (cont.)

Parameters	Frequency Group
Barium	R
Beryllium	R
Boron	R
Cadmium	R
Calcium	R
Chromium	R
Cobalt	R
Copper	R
Iron	R
Lead	R/C +
Magnesium	R
Manganese	R
Mercury	R
Molybdenum	R
Nickel	R
Potassium	R
Selenium	R
Silver	R
Sodium	R
Strontium	R
Thallium	R
Vanadium	R
Zinc	R

Table 13 (cont.)

	Parameters	Frequency Group
6.	Organics:	
	Herbicides	S
	Pesticides	S
	Volatile Organics	S
	Hydrocarbons	S
	AVNs	S
	VOAs	S
	Semi-Volatiles	S
	PCBs	S

* R Routine Group

C Comprehensive Group (approximately 10% of samples)

S Special Group (by request only, or has already been measured in the field, regional offices, or the inventory field support facilities)

F Future Group (to be sent out of Oman for analysis until such time that MWR is justified in performing them in Oman)

\+ R/C Routine Group under normal operations, Comprehensive Group (10%) during the inventory

Table 14

ESTIMATED CAPACITY OF THE CENTRAL LABORATORY TO ANALYZE CONSTITUENTS FOR NORMAL LOAD AND INVENTORY CONDITIONS

Parameters	Estimated Current Capacity per day	Estimated Current Maximum Capacity per day	Estimated Transition Capacity per day (1)	Estimated Normal Capacity per day (2)	Estimated Inventory Capacity per day (3)
1. Conventional, Wet Chemistry & Physical Properties:					
All Field, Near-Field & District Parameters					
Total Alkalinity	4	10	30	50	250
Bicarbonate Alkalinity	4	10	30	50	250
Hardness	4	10	30	50	250
Acidity	0	10	30	50	250
Total Suspended Solids	5	10	30	5	25
Total Organic Carbon	0	10	30	50	250
Soluble Silica	0	10	30	5	25
Asbestos	0	0	0	0	0
Sulfides	4	10	30	10	25
Ammonia (N)	1	1	1	5	25

Table 14 (cont.)

Parameters	Estimated Current Capacity per day	Estimated Current Maximum Capacity per day	Estimated Transition Capacity per day (1)	Estimated Normal Capacity per day (2)	Estimated Inventory Capacity per day (3)
Total Recoverable Phenolics	0	0	0	5	25
Surfactants (MBAS)	0	0	4	4	8
Cyanide	0	0	0	2	10
Sediment Volume	0	0	0	1	5
Grain-Size Distribution	0	0	0	1	4
2. Anions					
Bromide	1	1	2	10	25
Chloride	5	10	30	50	250
Fluoride	4	10	30	50	250
Iodide	0	0	2	10	25
Nitrate	3	10	30	50	250
Nitrite	1	10	30	50	250
O-Phosphate	1	10	30	50	250

Table 14 (cont.)

Parameters	Estimated Current Capacity per day	Estimated Current Maximum Capacity per day	Estimated Transition Capacity per day (1)	Estimated Normal Capacity per day (2)	Estimated Inventory Capacity per day (3)
Sulfate	4	10	30	50	250
3. Microbiological:					
Total Coliform	0	0	0	1	4
Fecal Coliform	0	0	0	1	4
Total Plate Count	0	0	0	1	4
Fecal Streptococcus	0	0	0	1	4
4. Radiological:					
Gross Alpha	0	0	0	5	25
Gross Beta	0	0	0	5	25
Radon	0	0	0	0	0
Radium 226 and 228	0	0	0	0	0
Strontium 90	0	0	0	0	0

Table 14 (cont.)

Parameters	Estimated Current Capacity per day	Estimated Current Maximum Capacity per day	Estimated Transition Capacity per day (1)	Estimated Normal Capacity per day (2)	Estimated Inventory Capacity per day (3)
Tritium	0	0	0	0	0
Carbon 14/13	0	0	0	0	0
Deuterium 1/018	0	0	0	0	0
Other Isotopes	0	0	0	0	0
5. Metals:					
Aluminium	0	0	0	50	250
Arsenic	0	3	10	50	250
Barium	0	0	0	50	250
Beryllium	0	0	0	50	250
Boron	2	4	4	50	250
Cadmium	0	0	8	50	250
Calcium	4	6	8	50	250
Chromium	0	0	8	50	250

Table 14 (cont.)

Parameters	Estimated Current Capacity per day	Estimated Current Maximum Capacity per day	Estimated Transition Capacity per day (1)	Estimated Normal Capacity per day (2)	Estimated Inventory Capacity per day (3)
Cobalt	0	0	8	50	250
Copper	0	0	8	50	250
Iron	2	4	8	50	250
Lead	0	10	25	50	150
Magnesium	0	0	0	50	150
Manganese	2	4	8	50	250
Mercury	0	2	2	50	250
Molybdenum	0	0	0	50	250
Nickel	0	0	8	50	250
Potassium	4	6	8	50	250
Selenium	0	3	10	50	250
Silver	0	0	0	50	250
Sodium	4	6	8	50	250
Strontium	0	0	0	50	250

Table 14 (cont.)

Parameters	Estimated Current Capacity per day	Estimated Current Maximum Capacity per day	Estimated Transition Capacity per day (1)	Estimated Normal Capacity per day (2)	Estimated Inventory Capacity per day (3)
Thallium	0	0	0	50	250
Vanadium	0	0	0	50	250
Zinc	0	0	8	0	250
6. Organics:					
Herbicides	0	0	0	6	18
Pesticides	0	0	0	6	18
Volatile Organics	0	4	4	6	15
Hydrocarbons	0	2	2	8	18
ABNs	0	0	0	6	18
VOAs	0	4	4	6	15
Semi-Volatiles	0	0	0	6	18
PCBs	0	0	0	6	18

Table 14 (cont.)

Notes:

1) Capacity during the transition period while the new laboratory is being constructed (January 1991 to June 1992).

2) Normal or everyday, long-term capacity in the new laboratory after construction completed (June 1992).

3) Second shift of laboratory personnel needed to accommodate the inventory sample volume in the new laboratory during the peak inventory period (June 1992 to June 1995).

Table 15

INDOOR DESIGN CRITERIA

Area	Temperature Summer Degrees C	Temperature Winter Degrees C	Ventilation Max/Outdoor (Cubic Ft/Min)	Relative Humidity	Noise (Max)	Comments
Conference Rooms	26	21	35 CFM/Person	50 Max	NC 3C	
Interior Offices	N/A	21	0-25 CFM/SF	N/A	NC 35	
Electrical Rooms	30	15	3 ACH	50 MAX	NC 40	
Laboratories	26	21	35 CFM/Person	50 MAX	NC 35	Plugs Fume Hood
Requi-						
Locker Rooms	26	21	3 CFM/SF	50 MAX	N/A	rements
Lunch Rooms (Smoking allowed)	26	21	35 CFM/Person	50 MAX	NC 45	
Mechanical Rooms	40	21	3 ACH-Winter 6 ACH-Summer	N/A	NC 50	Calculated to 10 feet above
floor						
Offices	26	21	35 CFM/Person	50 MAX	NC 35	

Table 15 (cont.)

Area	Temperature Summer Degrees C	Temperature Winter Degrees C	Ventilation Max/Outdoor (Cubic Ft/Min)	Relative Humidity	Noise (Max)	Comments
Storage Areas	40	N/A	0-25 CFM/SE	N/A	NC 40	See Note 4
Lavatories	27	21	75 CFM/Fixture	N/A	NC 40	

Notes:

1. Noise Criteria (NC) Levels indicate acceptable level of audible HVAC System noise within the space
2. ACH = Air Changes per hour
3. Filtration - All filtration shall be 30% efficiency (ASHRAE Dust Spot) unless otherwise indicated
4. For large areas, such as warehouses or where required for proper air circulation, provide total ventilation of 6 ACH in non-hazardous areas. the portion of ventilation air above 0 25 CFM/SF outdoor air may be recirculated

Table 16

SPACE REQUIREMENTS FOR PROPOSED LABORATORY

Room Designation	Usable Floor Area (Sq. Meters)
1. Sample Receiving/Reception	65
2. Sample Storage (Repository)	47
3. Sample Storage (4°)	37
4. Volatile Organics Laboratory	56
5. Semi-Volatile Organics Laboratory	56
6. Pesticide Laboratory	56
7. Organic Prep. Laboratory	47
8. Organic Computer/Report Room	28
9. Metals Instrument Laboratory	65
10. Metals Prep. Laboratory	56
11. Metals Computer/Report Room	28
12. Wet Laboratory (conventional analyses)	93
13. Inorganic Instrument Laboratory	56
14. Radiological Laboratory (expansion for isotopes)	47
15. Radiological Prep. Laboratory	28
16. Microbiological Laboratory	47
17. General Prep./Bottle Repository	93
Total Laboratory/Storage/Support Area	905
SC Chemical Storage Area	37
SS Supplies Storage Area	56
SG Gas Storable Area	28
Total Storage Area	121
Administrative Support Area	465
TOTAL LABORATORY AREA	1491

Figure 4

MINISTRY OF WATER RESOURCES
WATER LABORATORY CONCEPTUAL LAYOUT

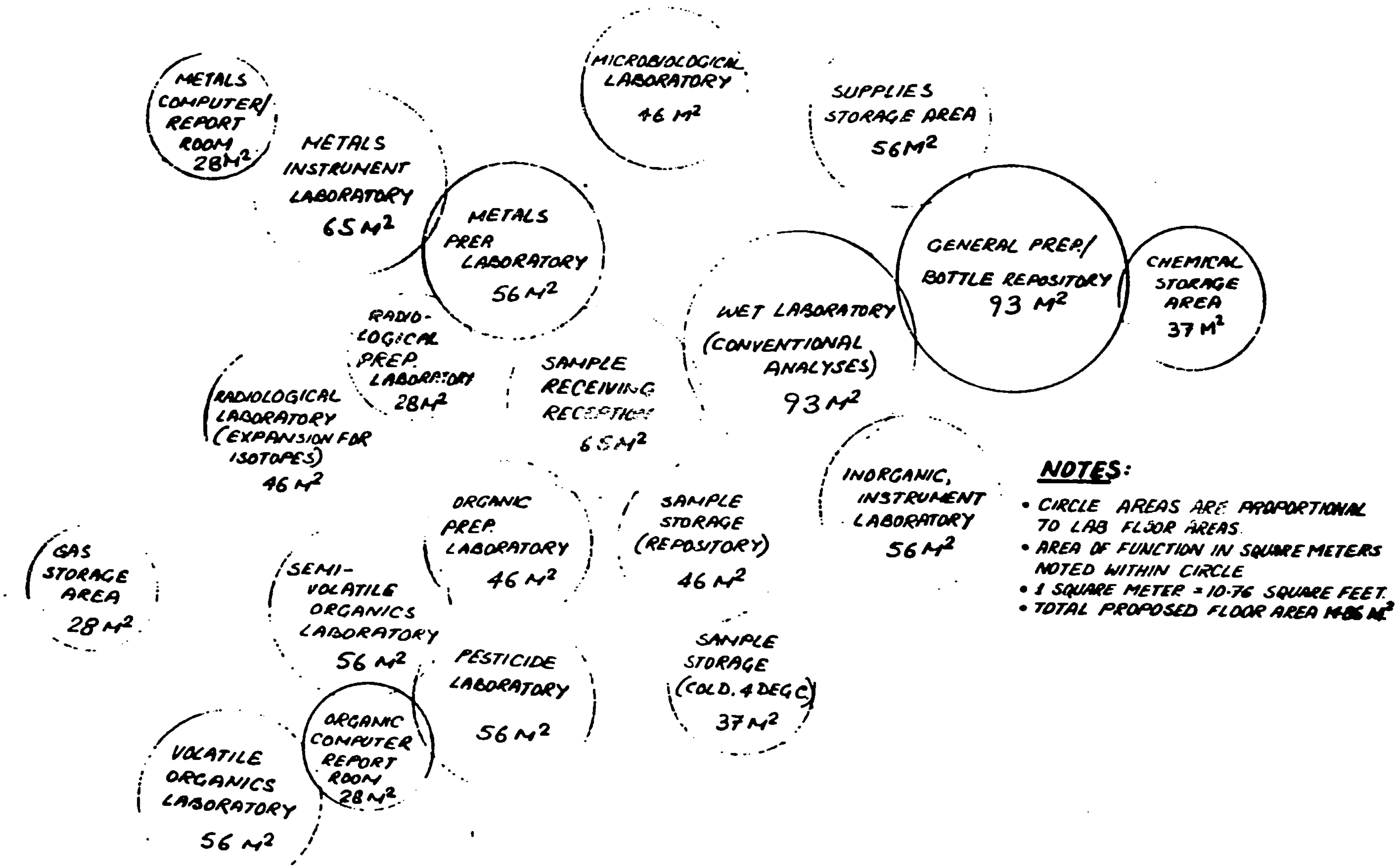


Figure 5

MINISTRY OF WATER RESOURCES
MWR LABORATORY CONCEPTUALIZED PROCESS DESIGN

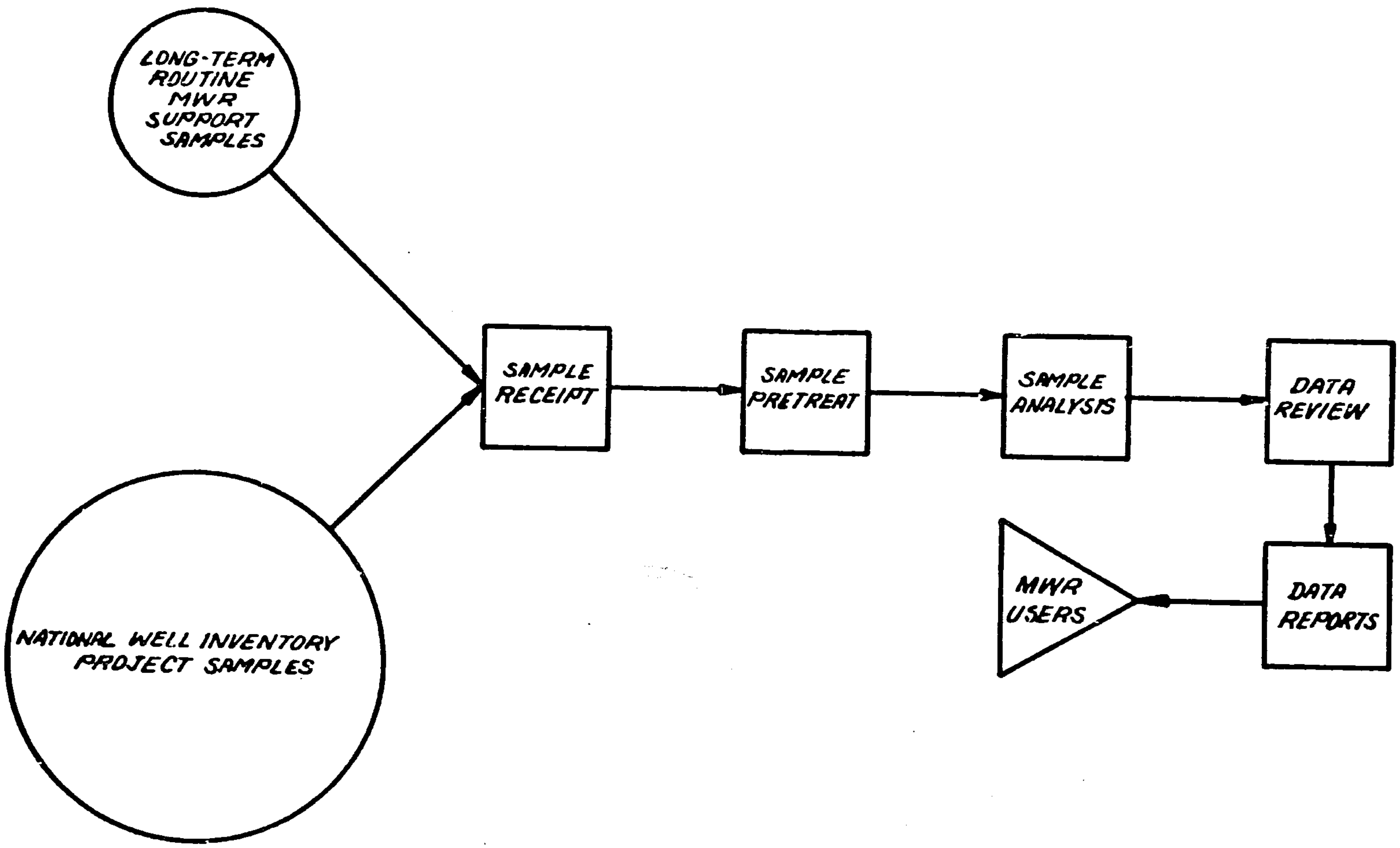


Table 17

LIST OF MAJOR CAPITAL EQUIPMENT

Equipment	Analysis	Production Rate	Quantity	Approx. Cost (R.O.1000)*
Low-Level Gas Proportional Counter System	Gross Alpha Gross Beta	17/Hr	1	30
Inductively Coupled Plasma Spectrophotometer(ICAP)	Trace Metals (21)	36/Hr	1	105
Atomic Absorption Spectrophotometer/ Hydride Generator	Arsenic and Selenium	15/Hr	1	30
Atomic Absorption Spectrophotometer/ Graphite Furnace	Lead	10/Hr	1	30
Atomic Absorption Spectrophotometer/ Flameless Mercury	Mercury	30/Hr	1	30
Gas Chromatograph/ Mass Spectrometer	Volatile Organics	0.6/Hr	1	70
Gas Chromatograph/ Mass Spectrometer	Semi-Volatiles	0.5/Hr	1	75
Gas Chromatograph/ Dual ECD	Pesticides, PCBs Herbicides	0.5/Hr	2	20

* Note: Costs are very approximate

Table 17 (cont.)

Equipment	Analysis	Production Rate	Quantity	Cost (R.O.1000)
Gas Chromatograph/ Dual NPD	Pesticides	0.5/Hr	1	20
Gas Chromatograph/ Hall/PID	Chlorinated and Aromatic Compounds	0.6/Hr	1	20
Gas Chromatograph/ PID/FID	Aliphatic and Aromatic Hydrocarbons	0.6/Hr	1	20
FT Infrared spectrophotometer	total petroleum Hydrocarbons	6/Hr	1	15
Ion Chromatograph	Anions	4/Hr	1	13
Total Organic Carbon Analyzer	Total Organic Carbon	15/Hr	1	12
Automated Flow Injected Analyzer (6 channel)	Conventional Parameters and Anions	54/Hr	3	95
Laboratory Information Management System (LIMS)	Data Processing	N/A	1	80 (Not included in Laboratory Budget)
Total Cost				582

Table 18

METAL ANALYSES PRODUCTION RATE

Instrument	Process Rate	Productivity Factor	Production Rate*
Simultaneous ICAP (21 Metals)	60/Hr	0.6	36
Graphite Furnace (Pb)	20/Hr	0.5	10
Hydride (AS, Se)	30/Hr	0.5	15
Cold Vapor	60/Hr	0.5	30

* Production Rate = Process Rate x Productivity Factor

Figure 6

METALS LABORATORY INTERACTIVE DATA SYSTEM

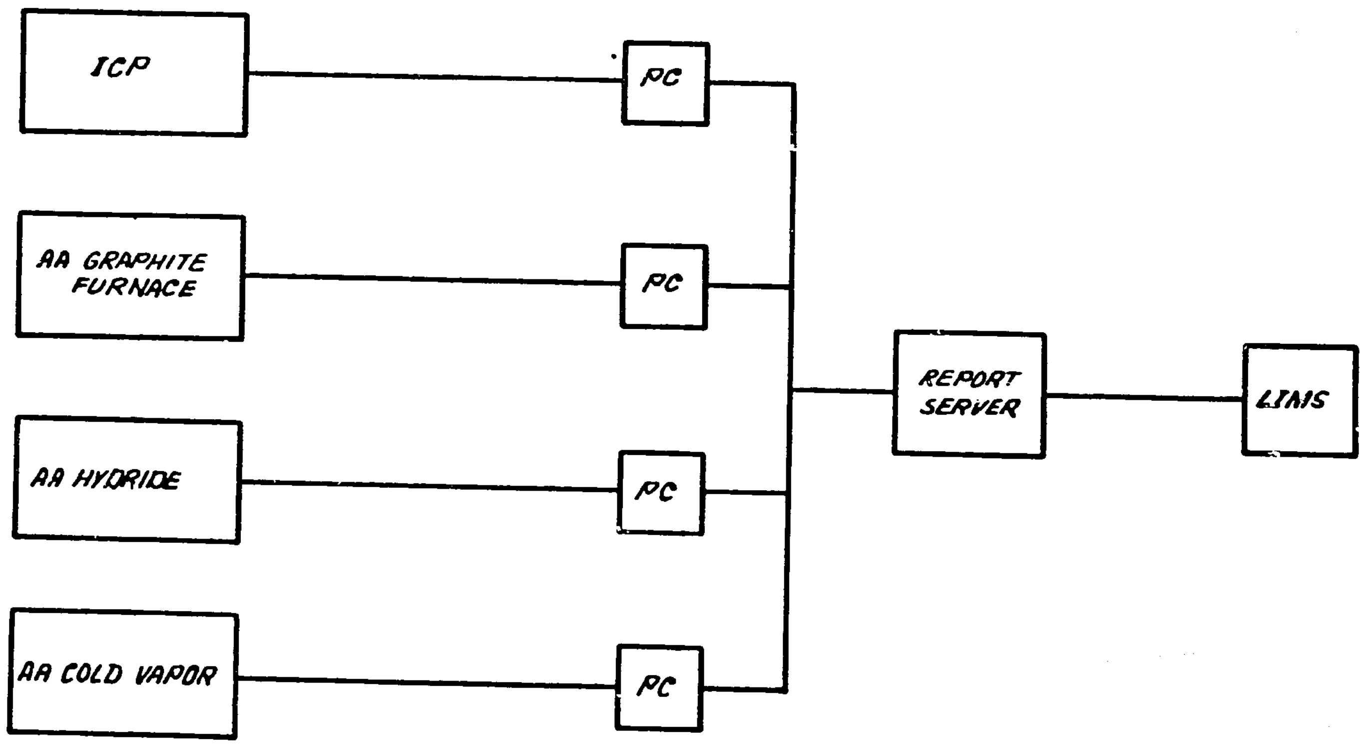


Table 19

ANION ANALYSES PRODUCTION RATES

Analyte	Ion Chromatography	Automated Wet Chemical
Bromide	X	
Chloride	X	X
Fluoride	X	X
Nitrate	X	X
Nitrite	X	X
O-Phosphate	X	X
Sulphate	X	X
Process Rate	6/Hr	90*
Productivity Factor	0.6	0.6
Production Rate	4	54

* 6 Channel System

Table 20

CONVENTIONAL/WET CHEMICAL ANALYSES PRODUCTION RATES

Analyse	Method Description	Process Rate	Productivity Factor	Production Rate
Total Alkalinity	AWC	90/HR	0.6	54
Bicarbonate Alkalinity	CALCULATION	90/HR	0.6	54
Total Recoverable Phenolics*	AWC	90/HR	0.6	54
Ammonia	AWC	90/HR	0.6	54
Hardness	AWC	90/HR	0.6	54
Total Organic Carbon	COMB/IR	20/HR	0.4	8
Cyanide*	AWC	90/HR	0.6	54
Silica, Soluble	AWC	90/HR	0.6	54

* Requires pretreatment

Table 21

PROPOSED PROCEDURES FOR VARIOUS CATEGORIES OF ANALYSES

Conventional Wet Chemistry	Standard Methods for Analysis of Water and Wastewater (APHA)
Automated Wet Chemistry	USEPA 300 Series (Automated Procedures) Methods for Analysis of Water and Wastes
Microbiological	Standard Methods for the Analysis of Water and Wastewater (APHA)
Radiological	Prescribed Procedures for Measurement of Radio-Activity in Drinking Water EPA/600/4-80/332 August 1980)
Organics	Methods for the Determination of Organic Compounds in Drinking Water EPA/600/4-88/039 (December 1988)
Metals	Standard Methods for the Examination of Water and Wastes (APHA) Method 305; USEPA Statement of Work for Contract Laboratory Program (CLP)
Anions	USEPA method 300.0 (A) Methods for Analysis of Water and Wastes
Total Organic Carbons	Standard Methods for Analysis of Water and Wastes (APHA) Method 505B

Figure 7

LABORATORY INFORMATION MANAGEMENT SYSTEMS INFORMATION FLOW DIAGRAM

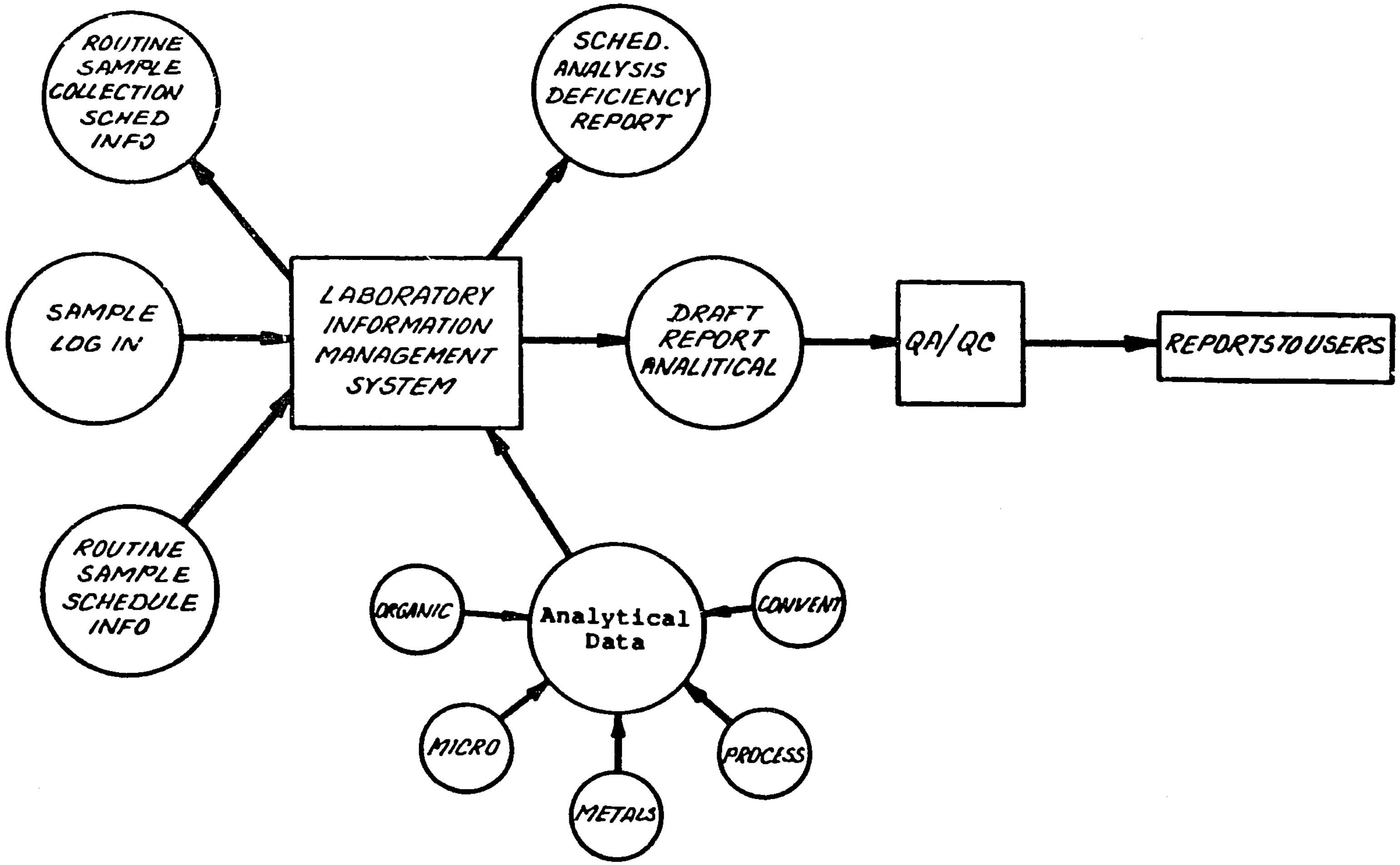
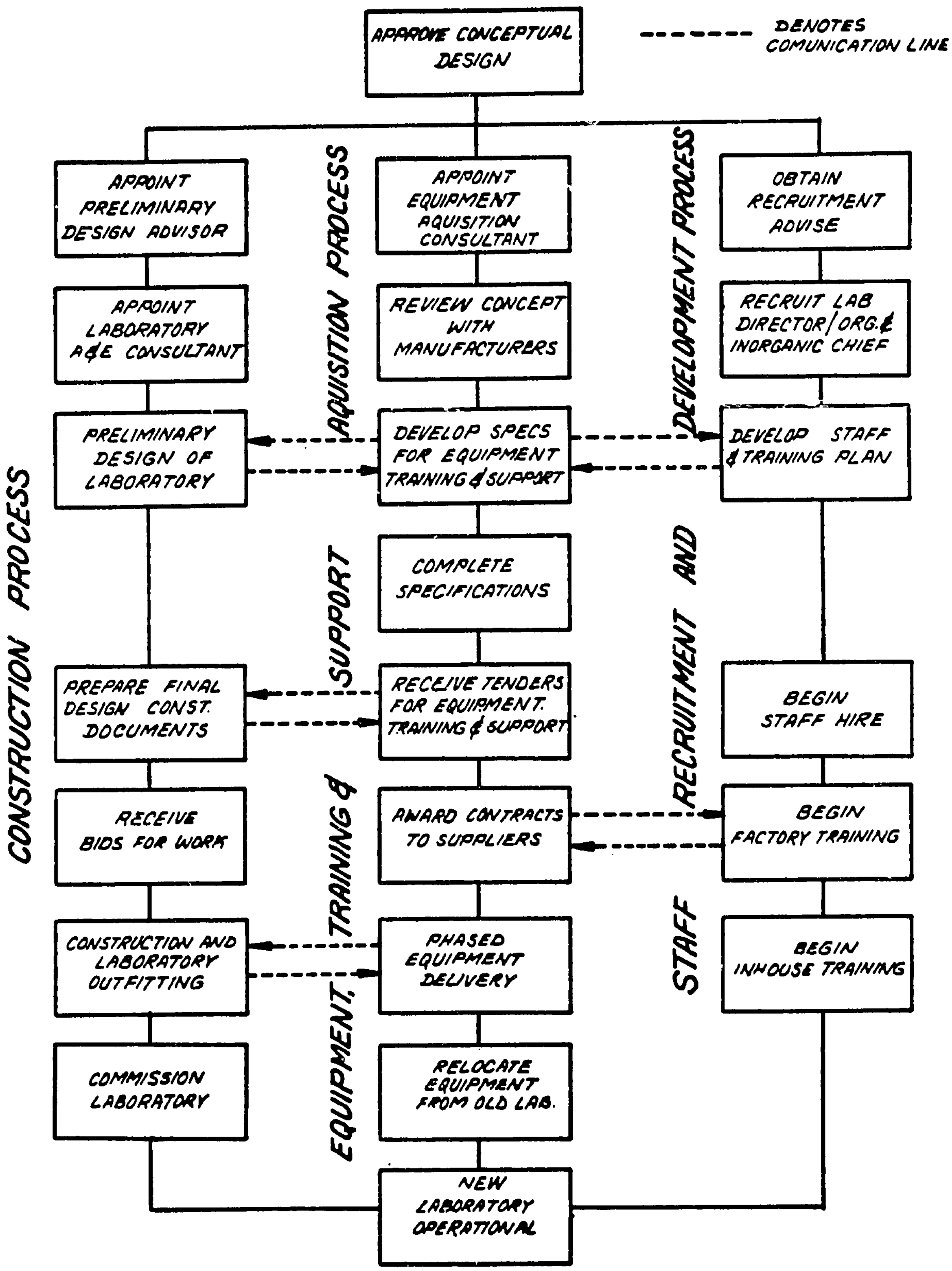


Figure 8

WATER CHEMISTRY LABORATORY PROJECT IMPLEMENTATION PROCESS



Chapter 5

TRAINING STRATEGY

When the new laboratory opens in 1992, it must be ready with a full complement of qualified staff, some of whom will have to be expatriates on short-term contracts. The post of laboratory director should be filled as soon as possible to enable the appointee to participate in the design and planning of the laboratory and in selecting and training the staff. The MWR should arrange with the Oman Technical and Industrial College (OTIC) to train the laboratory technicians, who would start classes in the fall of 1991 and would be ready for employment in the summer of 1993. If technicians are needed earlier, the OTIC or the Sultan Qaboos University should be able to find qualified candidates. Based on the courses these students have had at school, a certain amount of on-the-job training will be necessary once they are hired.

The university is also very keen on having some of its chemistry majors participate in a summer cooperative program at the laboratory in much the same way as OTIC students presently do. This would involve not more than three or four students and could start in the summer of 1991. It would be an excellent opportunity to introduce chemistry majors to the laboratory and might motivate some to seek employment after they graduate. The university is prepared to take care of all logistics, including student housing and transportation to and from the laboratory.

For technicians who show promise, there are several schools in the United Kingdom that offer undergraduate, postgraduate, and refresher courses in laboratory procedures. Candidates should have had from six months' to a year's experience in the laboratory. Factory training in some of the more sophisticated analytical instrumentation, such as the GC/MS or ICAP, must be integrated into the training programs of both domestic and expatriate staff.

Once the laboratory is up and running, it can offer its own seminars, in-house lectures, and on-the-job training, Professional enrichment can come from attending courses at the university or abroad. Probably the most cost-effective way to train laboratory personnel is by having them rotate through all sections of the laboratory, learning as they go along about the different procedures in each section.

Field and regional office personnel should be technically qualified and adequately trained before they start work. They should be evaluated regularly for effective quality control of the data collected and also for identifying training opportunities to upgrade their skills. Those showing promise could be transferred to the central laboratory or selected to receive further academic training before such a transfer.

PHOTOGRAPHS

Photo 1. Existing Ministry of Water Resources Laboratory in modified residential building.

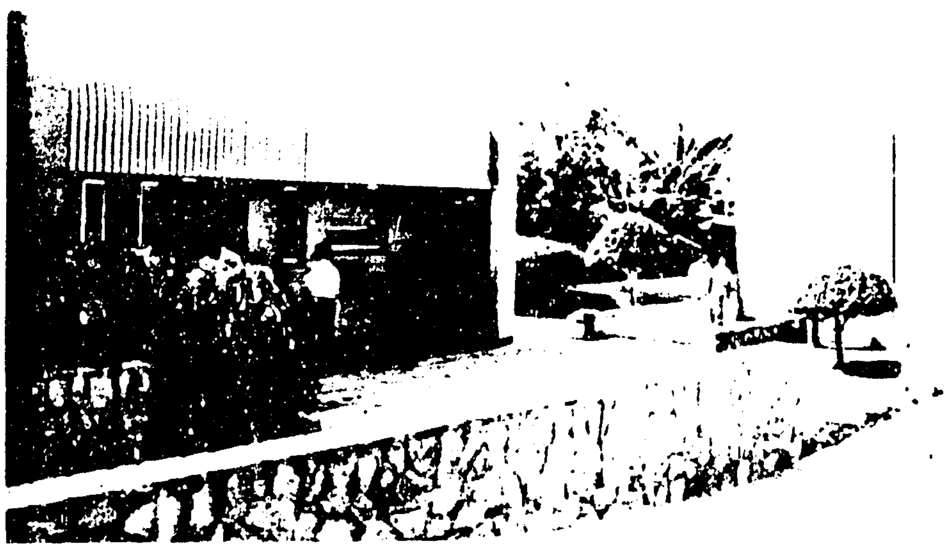
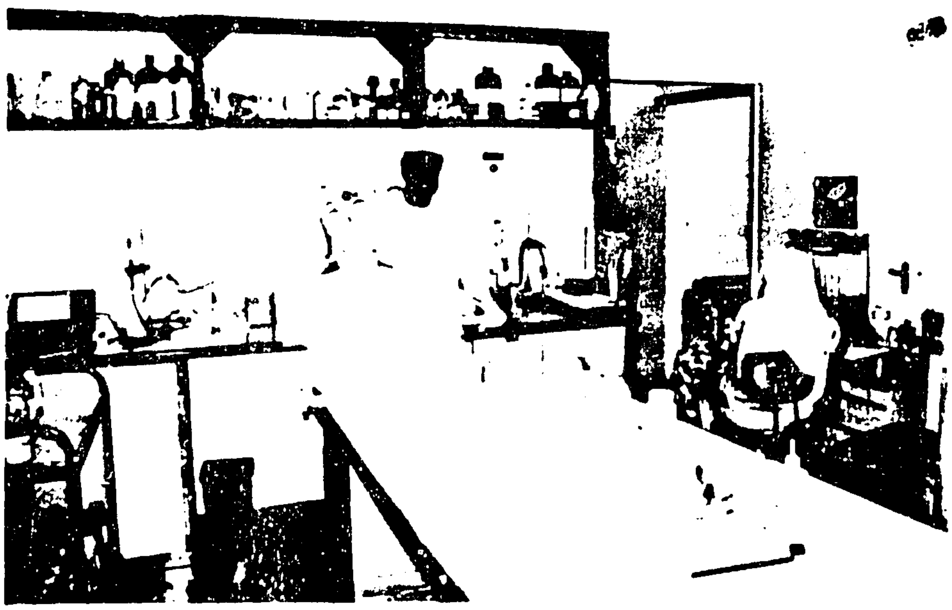
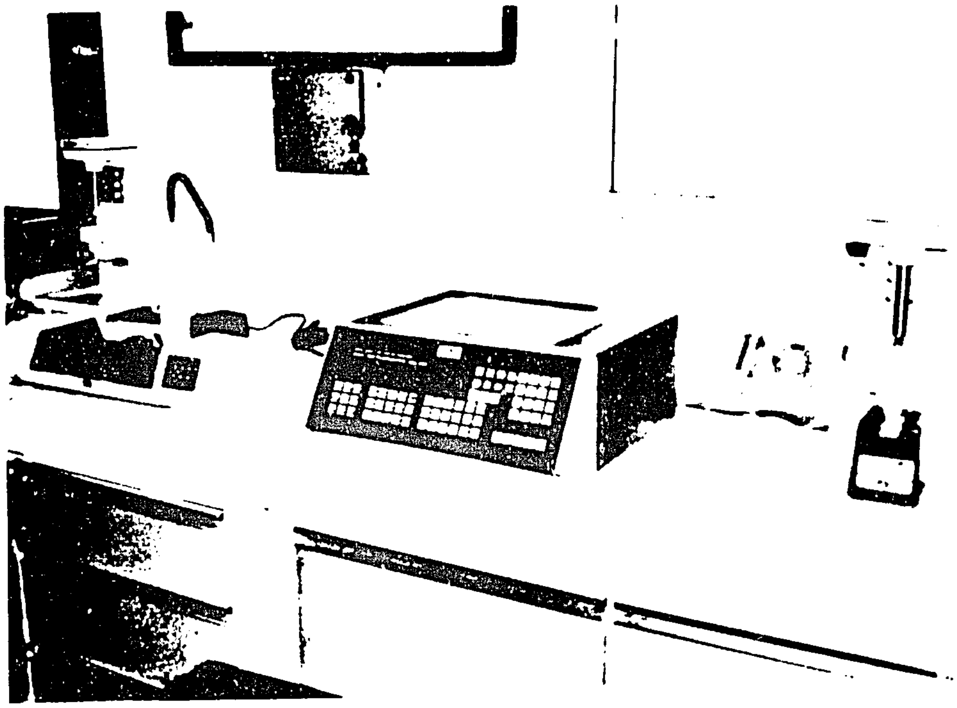


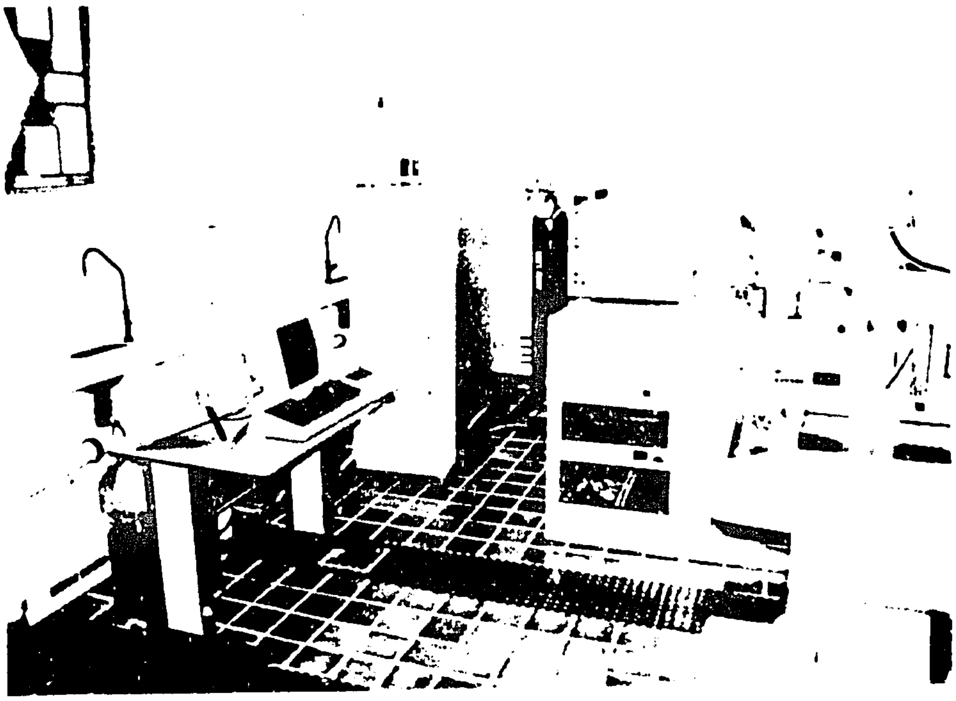
Photo 2. Existing testing laboratory at Oman's Ministry of Commerce and Industry.

Photos 3 and 4. Views of interior of existing Ministry of Water Resources Laboratory. Note predominance of older "manual" testing equipment.





Photos 5 and 6. Part of the interior of the existing Ministry of Commerce and Industry Laboratory. Note the use of more modern automated and computerized equipment for testing.



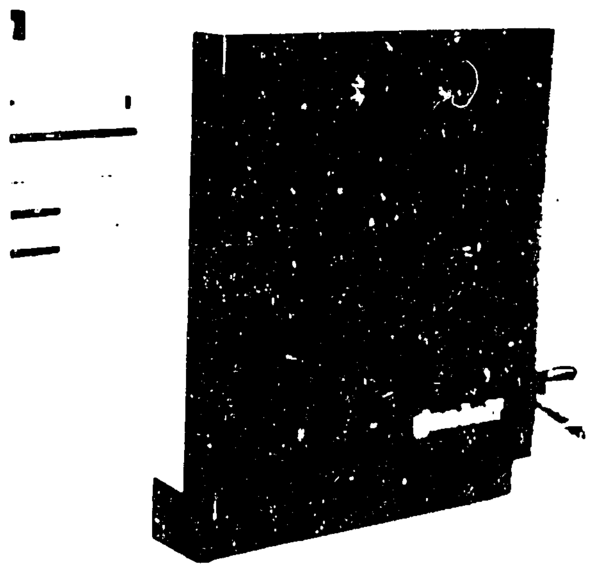


Photo 7. Mini computer forming the cornerstone of the Ministry of Commerce and Industry's Laboratory information management system. The unit is less than 1 meter in heights and installed in a simple, but adequate air conditioned room.

Photo 8. Ministry of Commerce and Industry clerk operating the laboratory information management system.

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Appendix A

SCOPE OF WORK FOR THIS ASSIGNMENT

TECHNICAL ASSISTANCE TASK DESCRIPTION TASK 2 - WATER QUALITY AND TRAINING

ACTIVITIES

This task comprises two activities:

(a) Laboratory Upgrading
(b) Training

BACKGROUND

General

The water resources of Oman are limited. Their conservation and management are critical to the nation's economic development. The principal water resource of Oman is groundwater. Currently utilized groundwater exists primarily in the alluvial beds of wadis on the slopes of the coastal mountains in the north and southeast. These are recharged seasonally.

Much of the withdrawal, especially in the Batinah and the northern mountains, is by way of aflaj (plural of falaj). The falaj is a traditional tunnel access to and channel distributory of alluvial groundwater. The increasing construction of borehole wells in upper areas has impaired or interrupted the use of many aflaj. The estimated proportion of water supplied by aflaj has fallen from about three quarters in 1972 to about half today.

Current use of groundwater exceeds the average rate of recharge throughout the Batinah, in the Capital Area around Muscat, and in the Salalah area. Urban and institutional well supplies are supplemented by expensive desalinated seawater in the Muscat and Batinah coastal strip areas. In the Batinah plain, even local domestic and agricultural uses of water are seriously impaired near the coast because of sea water intrusion caused by over-withdrawal upstream. There is also saline intrusion due to the declining water table in the Salalah area.

While the overall rate of recharge of alluvial aquifers is not known, it is believed to be substantially less than the rate of withdrawal.

In order to provide a basis for taking control of the situation, the Government of Oman in 1979 established the Public Authority for Water Resources (PAWR) as a data gathering entity. Since 1985, various institutional arrangements for water resources management were put in place and subsequently changed. In October 1989, a new Ministry of Water Resources (MWR) was established. This incorporates the resources of the former PAWR and has the mandate to take preparatory steps towards effective management of the water resource.

MWR intends to undertake a program of augmented monitoring, management preparations and improvement of its own technological and personnel infrastructure. UK consultants are preparing a national water management strategic plan for MWR. This will be presented in April 1991. In parallel with these efforts, the Ministry of Agriculture and Fisheries (MAF) is undertaking a vigorous program of installation of recharge dams in the lower reaches of wadis in the Batinah.

OAJC intends to assist MWR in the development and implementation of (a) supplementary data collection programs that are focused towards future resource management activities, (b) resource management preparatory activities that can be undertaken in parallel with the completion and initial implementation of the water resources master plan, (c) strengthened MWR resources for the purpose of water resources management.

MWR intends to undertake the above major program elements over the next 12-18 months. The initial assistance mode intended is to provide teams of specialist contractor personnel to assist MWR in the preparation of specific programs. OAJC would provide follow-on financing for host-country consultant contracts, procurement of equipment, software and/or imagery, and offshore training costs.

Laboratory Upgrading

The MWR laboratory performs water quality analyses on groundwater and surface water samples. It is located in a residential area in a converted house that is inadequate, inconvenient and a source of actual or potential nuisance to neighbors. Most of the equipment is eight to ten years old. MWR intends to construct a new laboratory. It will retain an architectural firm to perform the building design but first must establish the analytical and equipment needs. This determination is needed urgently.

The operations of the laboratory include: wet chemistry; ultraviolet and atomic absorption/emission spectrophotometry; gas chromatography; specific ion, pH and turbidity metering; and limited bacteriological and other types of testing. Maintenance services are available locally for most of the equipment. The present staff of the laboratory is two chemists, four technicians and a secretary.

The laboratory has a microcomputer and uses it to run ion balance checks and to maintain current year data, which are downloaded annually to the central system.

With the start of the proposed well inventory program, there is expected to be a very great increase in the number of samples to be analyzed, raising such questions as whether automatic analyzers should be used for certain functions. Decisions are also needed about such methodological issues as sample storage, field analyses, satellite laboratories, and the possible desirability of extending or reducing the range of analyses and/or the information presented in reports.

Isotope age analysis samples are currently sent overseas. It may be more economical to perform, say, tritium analyses in the MWR laboratory. This needs to be evaluated.

Routine quality assurance checks are performed internally within the laboratory but it is important that sampling, internal analytical and possible international quality assurance procedures be reviewed for appropriateness.

Training

MWR is a new organization that is about to expand its activities and staffing levels rapidly. It has very few professionally qualified Omani staff and depends heavily on its senior expatriate staff, currently numbering 13 and expected to increase. Its technical staff also are supplemented by expatriate personnel.

Four MWR Omani staff members are currently attending associate degree courses in the USA and two or three are then expected to go on to undertake bachelor's programs. Two others are to start preparatory work for associate courses in 1990 and two more in 1991. One person will begin bachelor's studies in 1991. One graduate will start a master's program in September 1990 and a second will start in 1991. MWR will probably be requesting OAJC assistance with funding of these studies.

MWR also plans to have 6 graduates and 18 technicians attend short courses in USA in 1990-92, and expects to request OAJC funding of this also.

A restructuring of MWR is now under consideration to deal with the expanded staffing needed to cope with the new proposed data collection and water resources management programs. As part of the expansion program, MWR intends to hire approximately 100 technicians during the next three years. These will be high school or vocational school graduates with little directly relevant technical training. MWR intends to appoint a training officer to administer a training program for them but does not expect to have any Omani staff suitable for training as trainers.

Assistance is needed in outlining a coherent technician training plan that will be effective given MWR's particular circumstances.

OBJECTIVES

Laboratory Upgrading

General objectives of the laboratory upgrading activity are to (a) establish the technical basis for upgrading of the water quality analysis program to support the well inventory program and (b) facilitate the early re-establishment of the central laboratory in a new location.

Specific objectives are:

- Establish the analytical, equipment, storage and staffing needs for upgraded laboratory services as input to architectural design and construction of a new facility
- Establish the needs for integration of field analyses into the analytical program and for satellite laboratory capability
- Prepare specifications for the procurement of new laboratory equipment that OAJC might provide
- Develop adequate and appropriate quality assurance procedures for water quality sampling and analysis

Training objectives are to prepare:

- A plan for training of technicians
- The scope of services for contract training of technicians

SCOPE OF WORK

A Technical Assistance (TA) Team is required to visit Oman, visit relevant project areas, and advise MWR on the subject matters of the two listed activities.

Regarding laboratory upgrading, the Team will:

- Review and evaluate the water quality information needs and capabilities of MWR, including expected future needs and capability requirements in view of the proposed well inventory and other programs
- Evaluate the analytical, equipment and storage needs for upgraded laboratory services and prepare a proposed concept and a list, with general information as to scale, of major equipment items as input to architectural design by others of a new central facility and of satellite laboratories
- Assist in the preparation of specifications for the procurement of new major items of laboratory equipment that OAJC might provide

- Evaluate the relative advantages of continuing to send samples for isotope age analysis offshore for testing and of performing some such tests, such as for tritium, in the central laboratory

- Review current and available procedures for quality assurance for water quality sampling and analysis, including both in-house and international controls on laboratory procedures and standard materials, and propose appropriate measures, including a timetable for implementation

Regarding training, the Team will:

- Assist MWR to develop a coordinated plan for training of technicians that will include provision for training at offshore short courses, by equipment suppliers, by onshore providers, and by a training contractor

- Assist MWR to prepare terms of reference for a contractor to provide onshore technician training and to provide advisory services in relation to offshore technician training for a period of four years; the terms of reference will include:

  - Numbers of persons, subject matters and timing of training, expected participants' backgrounds, training methodologies, and length of training

  - Management and staffing to be provided by the contractor, including provision for a planning/needs assessment visit before any training takes place

  - Equipment and training materials to be provided by the contractor

  - Home office support services to be provided, and services in relation to offshore training

The Team will work in close coordination with the Ministry and the OAJC. It will prepare a report or reports (see Deliverables) covering all of its activity areas summarizing its work and presenting its recommendations with justification. The contents of these reports will be reviewed with the OAJC and appropriate Ministry staff and draft copies will be left with the OAJC before the Team leaves Oman.

Specifications being prepared with the assistance of the TA Team will, to the extent required by any delays in receipt of information from suppliers or other outside information sources, be contributed to and finally reviewed in the contractor's home office.

Prior to its departure for Oman, the Team will participate in a team planning meeting involving contractor and AID/Washington personnel. Among the outputs of this meeting will be a preliminary work plan, including team member assignments and outputs, a proposed agenda for a task startup meeting to be held with OAJC and MWR on arrival in Oman, and preliminary report outline(s) for review in the task startup meeting. The objectives of the task startup meeting will be to reach agreement on the Team's scope of work, work plan, data sources, persons to be contacted, field trips and report outline(s). On completion of the assignment, the Team Leader and Training Advisor will participate in a debriefing meeting in the Washington, DC area.

DELIVERABLES

The required deliverables include:

- Two reports ([a] Laboratory Upgrading and [b] Technician Training) each of which will address the background, key issues in the activity scope of work, summary evaluations of the options considered, and recommended actions, including implementation procedures and schedules; the reports will address the feasibility and relative merits of each alternative considered and will provide justification for any proposed follow-up assistance; descriptions of any follow-up consultancy assistance will be included.

- Where so indicated in the Scope of Work above, Specifications, prepared by MWR with the assistance of the TA Team, for the indicated equipment

SCHEDULE

The Team is required to mobilize as quickly as possible because of the urgency of the issues to be addressed in this task. A mid June 1990 start is anticipated. The duration of the field activity is expected to be 2.5 months.

PERSONNEL

The personnel to be provided by the contractor will consist of:

- A Team Leader/Laboratory Methods and Equipment Advisor to review the demands upon and evaluate the operational and equipment needs of the central laboratory, and to assist in the preparation of equipment specifications (2.5 person-months)

- A Laboratory QA Procedures Advisor to review the current and proposed laboratory procedures and recommend a sampling and analysis quality control program, including a staged implementation plan (2.0 person-months)

- A Training Advisor to be responsible for all aspects of the contractor's training assistance to the MWR (1.0 person-month)

- Task Management (professional) for the recruitment and mobilization of the Advisor, coordination of project office support, and for quality oversight of report finalization (0.5 person-month)

- A Team Planning Facilitator to plan and facilitate the team planning meeting (0.25 person-month)

- Task Management (support) for provision of project office administrative support and final report typing (1.0 person-month)

The total personnel input required is estimated to be 7.25 person-months.

The above times include 6 days for the Team Leader and 5 days for other team members for travel, team planning and (in the case of the Team Leader) debriefing. Work weeks in Oman will be six 8-hour days per week, Saturday through Thursday. (Note that MWR offices are closed Thursdays and Fridays.)

QUALIFICATIONS

The required qualifications of the proposed personnel are as follows:

- Team Leader/Laboratory Methods and Equipment Advisor - a senior analytical chemist with experience in water quality laboratory design and/or management

- Laboratory QA Procedures Advisor - a senior chemist with at least ten years experience in laboratory management, including in the application of in-house and international QA procedures

- Training Advisor - a trainer with at least 10 years of experience including training management and development of training plans, and the preparation of scopes of work.

- Task Technical Coordinator - a senior water resources specialist with at least 15 years experience

- Home Office Instrumentation/Specifications Engineer - a water resources engineer with at least 5 years experience

- Team Planning Facilitator - a human resources development specialist with at least 5 years' experience including facilitating team planning meetings

Appendix B

LIST OF PERSONS CONTACTED

Ministry of Agriculture and Fisheries

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

Ministry of Commerce and Industry

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

Ministry of Education

- Nasser bin Issa Al-Ismaili, Director of Computer Services

Ministry of Electricity and Water

- Ribhi Moh'd Ihmoud Hamdan, Plant Manager
- Subramaniam, Chief Engineer, Water Department
- P.K. Mukerjee, Chief Chemist
- Adel Al-Harthy, Site Engineer

Ministry of Environment

- Firdaus bint Al-Harthy, Laboratory Director

Ministry of Health

- Dr. Suliman Al-Alfee, Director of Public Health Laboratories

- Ali Mohammed Al-Rashdy, Director of Environmental Health
- Abdul Rashid Al-Mandhry, Occupational Health/Toxic and Hazardous Chemicals
- Salim Mohammed Al-Behlany, Water and Sanitation

Ministry of Water Resources

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

Office of the Minister of State and Wali of Dhofar

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

Omani-American Joint Commission

- Dr. Duncan Miller, Mission Director
- Anjab Sajwani, Project Officer
- Murl Baker, Deputy Mission Director
- Musa Al Mazuri, Project Engineer
- Mark Pickett, Training Officer
- Roger Russell, Chief Engineer

Planning Committee for Development and Environment in the Southern Region

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

Supreme Committee for Town Planning

- Donald Ritson, Advisor
- Terek El Ghamrawy, GIS Implementation

Others

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

Appendix C

ROYAL DECREES 82/88 AND 100/89

Royal Decree No. 100/89
for the establishment of the Ministry
of Water Resources and designation of its
duties & responsibilities

We, Qaboos bin Said, Sultan of Oman,

After reviewing the Royal Decree No.26/75 issuing the State Administrative Machinery Organization Law and it's amendments,

And the Royal Decree No.82/88 considering the water reservoir as national wealth,

And the Royal Decree No.44/89 for the establishment of Public Authority for Water Resources,

We decreed the following:

Article 1

Establishment of a ministry for water resources under the name of "Ministry of Water Resources".

Article 2

Khalfan bin Nassir Al Wahaibi, Minister of Electricity and Water shall be the Acting Minister of Water Resources.

Article 3

PAWR funds, records and reports shall be transferred to the Ministry of Water Resources together with its personnel and those working in it.

Article 4

Ministry of Water Resources' duties and responsibilities shall be designated according to the attached appendix.

Article 5

The duties and responsibilities of other ministries and government units in water field shall remain the same without

contradiction with the duties and responsibilities of MWR mentioned in above article.

Article 6

The Minister of Water Resources shall prepare the organisation chart of the Ministry in coordination with the concerned units.

Article 7

The Royal Decree No.44/89 and all that contradict with this Decree or its rules shall be cancelled.

Article 8

This Decree shall be published in the official Gazette and shall be in effect as from the date of it's issuance.

Qaboos bin Said
Sultan of Oman

issued on: 10 Rabia Al Awal, 1410
10 October, 1989

Duties & Responsibilities of The Ministry of Water Resources

The Ministry of Water Resources is concerned with the development of water resources in the Sultanate, conservation and proposal of general policies for the preparation of long term plans, to be in consistance with the economic and social development plan of the Sultanate and presentation to us for approval.

The Ministry shall have all the appropriate authorities for he achievement of its objectives particularly the following:

1. Undertaking of the general plan for the development of water resources and its conservation after coordination with other ministries and government units.

2. To establish information and data centre for water resources and connected programmes related to its development and perfect utilization of water resources.

3. To collect data and information about ground and surface water resources and springs and computation, classification and filing of these data for use in the related studies.

4. The undertaking of researches, studies and surveys which are aiming at the exploration of other water resources and finding out the best methods as well as the related studies for the conservation and use of the available water resources.

5. The operation, development & maintenance of the hydrologic and hydrogeologic monitoring networks in the Sultanate and to record, review and analysis of its information for use in the evaluation of available resources for different uses.

6. The assessment of water balance and water availability in various areas of the Sultanate.

7. Collection of water samples from wells, aflaj and analysis of these samples to determine salinity rate and its treatment methods and its suitability for different uses.

8. To undertake site visit to new agricultural lands to ensure water availability in these lands and its suitability and to coordinate with Ministry of Agriculture & Fisheries in order to ensure soil suitability for agricultural development.

9. The issuance of permits for the construction of new wells with the consideration of the adopted regulation in regard to ban areas and the distance from the mother wells.

10. To provide technical assistance and views to government units in the water field and the methods of its use.

11. Preparation of the regulation according to this decree after coordination with the concerned authorities.

12. To undertake the training and qualifying of Omani employees who are working in this Ministry.

14 November 1988

Royal Decree No. 82/88

considering Water Reservoir as National Wealth

We, Qaboos bin Said, Sultan of Oman

After reviewing the Royal Decree No.26/75 issuing the Law of State Administrative Machinery and its amendments,

And as we wish to conserve the Sultanate's water resources which is considered as national wealth for the future generations of our beloved country,

And as necessitated by the public interest,

We promulgated the following:-

Article 1

The Sultanate's water reservoir is considered as public national wealth to be exploited in the interest of agricultural and development plans according to the government's instruction. The existing aquifers and those to be explored after the enforcement of this Decree, no matter who is the owner of the land overlying these aquifers or using them for irrigation, are considered water reservoir.

Article 2

The use of the Sultanate's water reservoir will be subject to the regulations issued for the utilization of the reservoir in a manner that will not affect the available water resources. These regulations will determine the aquifers, the areas that benefit from them, groundwater flow paths of these areas and the bases of distribution and use of these water resources.

Article 3

The Ministry of Environment and Water Resources and the Ministry of Agriculture and fisheries shall prepare in coordination with the Office of the Deputy Prime Minister of

Legal Affairs the necessary regulations for the enforcement of the rules of this Decree.

Article 4

All that contradict with this Decree or its rules shall be cancelled.

Article 5

This Decree shall be published in the Official Gazette and shall be enforced as from the date of its issuance.

Qaboos bin Said
Sultan of Oman

Appendix D

CURRICULA VITAE OF CURRENT MWR LABORATORY STAFF

CURRICULUM VITAE

DR. MOHAMMAD IQBAL
WATER QUALITY LABORATORY
MINISTRY OF WATER RESOURCES
P.O.BOX 5575, RUWI,
SULTANATE OF OMAN

Date of birth : 12 August 1955

Marital Status : Married

Pass Port No. : R 874308

Nationality : Indian

Address : Burma medical stores
Jagdishpur, 227809
Dist. Sultanpur, UP
INDIA

Contact Tel.No. : Office 968 561905/914
Residence 968 702867

EDUCATIONAL QUALIFICATION

Degree	Year	University	Division	Subject
B.Sc(Hons)	1974	Aligarh Muslim University	I	Chem,Zool,Bot,
M.Sc	1976	-do-	I	Chemistry
M.Phil	1978	-do-		Analytical Chemistry
Ph.D*	1980	-do-		Analytical Chemistry

* Title of Thesis : Studies on synthetic inorganic ion-exchangers and determination of some substances.
Guide : Dr J.P.Rawat
Department of Chemistry,
Aligarh Muslim University,
Aligarh.

RESEARCH EXPERIANCE

Year	Position	Sponser	Work Place
Nov.1976–Oct.1978	Junior research Fellow	Council for Scientific and Industrial Research	Deptt.of Chem A.M.U.Aligarh
Nov.1978–Feb.1981	Senior Research Fellow	–do–	–do–
Mar.1981–Jan.1982	Post Doctoral Fellow	–do–	–do–
Feb.1982–Dec.1983	Research Associate	–do–	–do–

EMPLOYMENT HISTORY

Jan.1984 - to date : As Analytical Chemist at Water Quality Laboratory, Ministry of Water Resources, Sultanate of Oman.

: Incharge of water quality laboratory since 1986

Water Quality: Supervison of water analysis comprising of inorganic anions and major cations, trace metals (both essential and non essential) using flame and flameless techniques of atomization.

Bacteriological Analysis: Analysis of fecal coliform, total coliform and total bacterial counts using impregnated specific Millipore samplers.

Quality Assesment: Making comments and recommendation as to the suitability of the water submitted for analysis for drinking, irrigation or industrial use.

Water Pollution: Participated in studies related with effect of industrial discharges on ground and surface waters. Appointed member of the committee constituted to study pollution of wadi and wells in the viscinity of Oman mining company.

Monitoring of inorganic and organic pollutants in water supplies in Oman with special emphasis on trihalomethanes in chlorinated water samples.

Actively participated in choosing sampling cites, sample types, determining sampling frequency and final execution of sampling plans.

Marine Pollution: Carried out analysis of heavy metals in sediments, rock oysters and fish samples from Oman's coastal regions as part of the ROPME (Regional Organization for Prevention of Marine Environment) sponsored '18-month programme.

Analytical Instruments Operated: Atomic Absorption Spectrophotometer; Instrumentation Laboratories, IL 951 for flame operations, IL655 for electrothermal mode and IL440 for hydride generation technique PYE UNICAM atomic absorption, PU9000 and its accessories.

Gas Chromatograph, VARIAN Vista 6000 & 6500 operated via a microprocessor unit vista 402 using FID, ECD, TSD and HECD (Tracor 700) detectors. A purge and trap system, Tekmar LSC2 was used for concentration of trihalomethanes.

Dionex IC 16 for determination of organic & inorganic anions.

Metler Memo titrator, DL 40 for semi automated titrations.

SUPPLEMENTARY INFORMATIONS

HONOURS : Given the "best paper presentation" award in the Analytical Chemistry Section of the Indian Chemical Society, at its annual conference held at IIT Powai, Bombay in Dec.1980.

Given the "Outstanding Performance" prize by the Public Authority for Water Resources, S.of OMAN

NATIONAL SYMPOSIA/ CONFERENCES ATTENDED : Presented a paper entitled, "Stannic Diethanolamine as a new chelating material for analytical separations" at the annual conference of the Indian Chemical Society, 1980 held at IIT, Powai Bombay, India.

: Presented a paper entitled, "Redox studies on Hydrazine sorbed zinc silicate" at the Symposium of Analytical Chemists Society, 1981 held at Santiniketan, West Bengal, India.

INTERNATIONAL WORK EXERCISE :Participated in ROPME sponsored "Intercalibration exercise on toxic metals analysis" at Environment Protection Department, Kuwait, 15 to 19 Nov.1987

PUBLICATIONS

Synthesis of Zirconium Phosphoiodate and its use as an electron-ion-exchangers.

J.P. Rawat and M. Iqbal, Annali di Chimica, 69, 241 (1979).

Separation and recovery of some metal ions using PAN sorbed zinc silicate as chelating ion exchanger.

J.P. Rawat and M. Iqbal, J. Liq. Chrom. 3(4), 591 (1980).

Metal ions chelation chromatography on complexon sorbed stannic silicate.

J.P. Rawat and M. Iqbal, J. Liq. Chrom. 3(11), 1657 (1980).

A new chelating material for analytical separations.

J.P. Rawat and M. Iqbal, Annali di Chimica,431 (1981).

Spectrophotometric determination of Vanadium(V) with brucine.

J.P. Rawat and M. Iqbal, Proc. Nat. Acad. Sci., India.

Zinc silicate as a new adsorbent for paper chromatographic separation of phenols.

J.P. Rawat, M.Iqbal, and M. Alam J. Liq. Chrom. 5(5), 967(1982).

Ligand exchange separation of phenols on alumina in Fe(III) form.

J.P. Rawat, M.Iqbal and Chitra , Chromatographia, 17 12 (1983).

Chromatography on papers impregnated with zinc silicate: a new adsorbent for qualitative and quantitative separation of amines.

J.P. Rawat, M.Iqbal, and M.A.Khan, J. Liq. Chrom. 6 5 (1983).

Redox studies on Hydrazine sorbed zinc silicate .

J.P. Rawat, M.Iqbal, H.M.A. Abdul Aziz. J. Indian. Chem. Soc., LX-10, 993 (1983).

A new chelating material prepared by modification of an anion exchanger.

J.P. Rawat, M.Iqbal, and S.Ali, J. Indian. Chem. Soc. LX1,185 (1984).

A new modified inorganic ion exchanger for the separation of anions.

J.P. Rawat, M.Iqbal, and M. Alam , Ann. Chem. (Rome) 75(1-2) 87-99(1985).

TECHNICAL REPORTS

Ground water in Oman with fluoride concentrations greater than 1.5 mg/l.

M.Iqbal, G.Thompson and A.Y.Al Azry. PAWR report, Dec. 1986.

Bacteriological contamination in Oman's aflaj.

M.Iqbal, A.I.Sheikh and D. Davison , PAWR report July, 1986.

Baseline studies on organic and inorganic pollutants in Omani coastal waters (1983 to 1987).

I. Badawy, M. Iqbal, F.T.Al Harthy and I.S. Al Majeiny, Dec.1988.

Served as member of the committee constituted by MEWR to study the pollutants discharges from Oman Mining Company,Sohar into ground and surface water sources.

CURRICULUM VITAE

Name	Jolly Zachariah John............
Husband's Name	John Mathew.....................
Job Title	Chemist.........................
Date of birth	....
Marital status	Married.........................
Nationality	Indian..........................
Address	P.O.Box 5575, Ruwi,............. Sultanate of Oman............... Tel 561914...................... ....

Educational Qualification

Degree	Year	Div/Grade	Institution	Subject
B.Sc	1976	I	Poona,India	Chemistry Botany Geology
B.Ed	1977	II	Jabalpur University	English Science Educational Psychology
M.Sc	1979	I	Jabalpur University	Chemistry

Experience

1981 to 1982 — Worked as Science teacher in Indian Central School, Muscat.

1983 to date — Working as Chemist at Water Quality Laboratory, Ministry of Water Resources.

Nature of work includes analysis of fecal coliform, total coliform and total bacteria counts using impregnated specific Millipore samplers.

Water analysis of both anions and major cations, trace metals etc using classical as well as automated methods.

Analytical instruments operated

UV/Vis spectrophotometer, turbidimeter, Ion-Selective analyzer, atomic absorption and automatic titration system.

CURRICULUM VITAE

Name	Amal Bint M.Jawad A.Sultan......
Father's Name	M. Jawad......................
Job Title	Laboratory Technician...........
Date of birth	....
Marital status	Married........................
Nationality	Omani..........................
Address	P.O.Box 6, Muscat,............... Sultanate of Oman............... Tel 564604...................... ....

Educational Qualification

Exam Passed	Year	Div/Grade	Institution	Subject
Secondary School	1985	--	Al-Khuwair	-
Diploma	1988	B	Oman Technical Industrial College	Chemistry

Experience

1988 to date

Working as laboratory technician at Water Quality Laboratory, Ministry of Water Resources.

Nature of work includes analysis of inorganic constituents in water using classical as well as automated methods.

Analytical instruments operated.

UV/Vis spectrophotometer, automatic titration system, ion-selective analyzer and atomic absorption.

CURRICULUM VITAE

Name	Jamila Salim Rashid Al-Rawahy...
Father's Name	Salim Rashid Al-Rawahy..........
Job Title	Laboratory Technician...........
Date of birth	....
Marital status	Married.........................
Nationality	Omani...........................
Address	P.O.Box 4021, Ruwi,............. Sultanate of Oman............... Tel 602434...................... ....

Educational Qualification

Exam Passed	Year	Div/Grade	Institution	Subject
Secondary School	1986	-	Al-Khuwair	-
Diploma	1988	B	Oman Technical Industrial College	Chemistry

Experience

1988 to date

Working as laboratory technician at Water Quality Laboratory, Ministry of Water Resources.

Nature of work includes analysis of inorganic constituents in water using classical as well as automated methods.

Analytical instruments operated.

UV/Vis spectrophotometer, automatic titration system, ion-selective analyzer and atomic absorption.

CURRICULUM VITAE

Name	Thureya Bint Rashid Al-Riyami...
Father's Name	Rashid.........................
Job Title	Laboratory Technician..........
Date of birth	....
Marital status	Married........................
Nationality	Omani..........................
Address	P.O.Box 4425, Ruwi,............. Sultanate of Oman............... Tel 537328...................... ....

Educational Qualification

Exam Passed	Year	Div/Grade	Institution	Subject
Secondary School	1985	-	Al-Khuwair	-
Diploma	1988	B	Oman Technical Industrial College	Chemistry

Experience

1988 to date

Working as laboratory technician at Water Quality Laboratory, Ministry of Water Resources.

Nature of work includes analysis of inorganic constituents in water using classical as well as automated methods.

Analytical instruments operated.

UV/Vis spectrophotometer, automatic titration system, ion-selective analyzer and atomic absorption.

CURRICULUM VITAE

Name	Saleh Abdalla Mohd Al-Miskiry...
Father's Name	Abdalla Mohd Al-Miskiry.........
Job Title	Laboratory Technician...........
Date of birth	....
Marital status	Single..........................
Nationality	Omani...........................
Address	P.O.Box 2328, Seeb,............. Sultanate of Oman............... Tel 697858...................... ....

Educational Qualification

Exam Passed	Year	Div/Grade	Institution	Subject
Secondary School	1982	II	Ben-Bella (Zanzibar)	-
English Lang. Level 11	1989	-	British Council	-

Experience

1984 to date

Working as laboratory technician at Water Quality Laboratory, Ministry of Water Resources.

Nature of work includes analysis of inorganic constituents in water using classical as well as automated methods.

Collection of water samples if and when specialized analyses or special treatment at site is required.

Analytical instruments operated.

UV/Vis spectrophotometer, automatic titration system, ion-selective analyzer and atomic absorption.

CURRICULUM VITAE

Name	Alice Jacob George..............
Husband's Name	Jacob George....................
Job Title	Secretary.......................
Date of birth	....
Marital status	Married.........................
Nationality	Indian..........................
Address	P.O.Box 5575, Ruwi,.............. Sultanate of Oman............... Tel 714054...................... ....

Educational Qualification

Degree	Year	Div/Grade	Institution	Subject
B.Sc	1977	II	Kerala University	Zoology Botany Chemistry

Experience

1984 to date

Working as secretary at Water Quality Laboratory, Ministry of Water Resources.

Nature of work includes

1. Typing of all laboratory related memos, worksheets, report write-up etc.

2. Sample reception, logging of samples, data entry into the computer, recording and despatching of completed analytical results.

3. Filing and despatching of in-coming and out-going mails.

Appendix E

REPRESENTATIVE MWR LABORATORY QA/QC INFORMATION

5.40 Job No from Code & Value

Type <4> CR while at the enquiries on window to proceed to this section.

The form for this option is displayed at the parameters screen (Fig 14). You are prompted for the constituent code and the value of the constituent. Enter the whatever values required. The computer then scans the entire results file for records having the constituent code and value entered and displays the job numbers of these records at the results window.

6.0 Quality Control Tests

Type <4> CR while at the main menu to proceed to this option.

A number of analytical determinations for a constituent are performed on a standard sample. The mean and standard deviation of the resulting constituent values are computed. Control limits are established from these statistics depending on the tightness of the control desired. In standard practice, control limits are placed at +/-2 standard deviations from the mean.

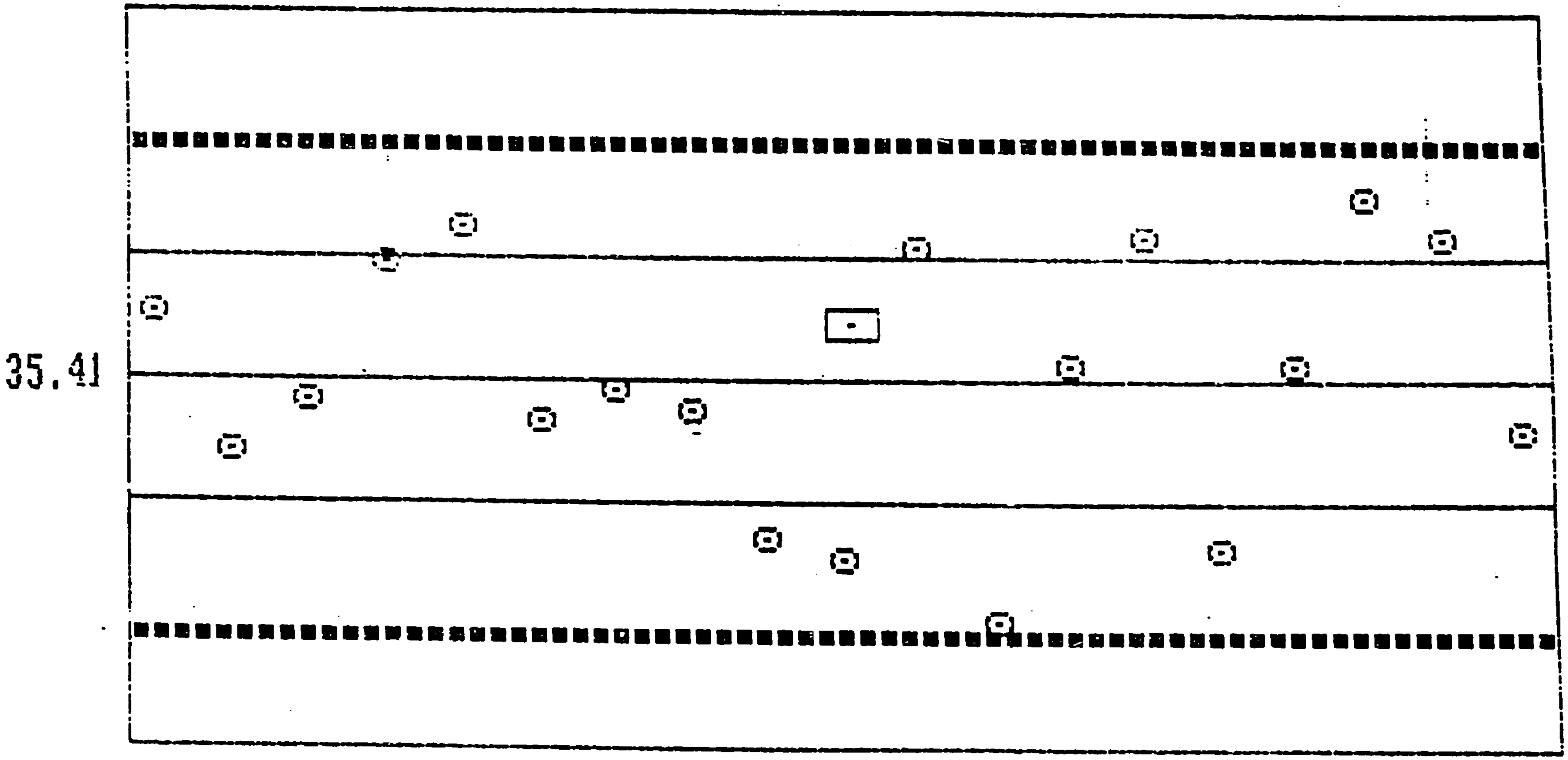
A control sample is included whenever a batch of samples is analyzed for the same constituent. The resulting constituent value is referred back to the previously established control limits and thereafter a decision is then made whether to accept or reject the analysis results.

The computer performs all the necessary computations and displays the results graphically (Fig 15). You can observe the position of the constituent value of the control sample relative to the position of the other previously determined values. You can likewise observe whether the constituent value is with-in the control limits.

During data entry, the quality control test form (Fig 16) is displayed. Enter the analysis name and the date. The file name of every determination is formed from the concatenation of the first 2 characters of the analysis name and the first 6 characters of the date.

You can then enter up to 90 constituent values. Hit ESC or go beyond the 90th prompt when there are no more entries to be made. A chart showing the quality control attributes (Fig 17) is displayed. The constituent value of the control sample is enclosed in a square while the other values are enclosed in circles. You may enter another constituent value and the position will likewise be indicated on the chart. If a hard copy is desired, prepare the printer and hit Shft PrtScr.

QUALITY CONTROL CHART FOR CHLORIDE DATE: 31/08/90



Analysis Spike Value: 35.2

Standard Deviations from the Mean: 0.56 Analysis is ACCEPTABLE.

SULTANATE OF OMAN

Ministry of Water Resources

Water Quality Laboratory

سلطنة عمان

ـنة العامة لموارد المياه

مختبر جودة المياه

ANALYTICAL WORK SHEET

No.	Date.	Lab. Job. No	Test.	A Reading	B Reading	Mean.	Spike. Reading	STD Reading	STD. Dev.	Perc Recov
1)	25/6/90	19032	Na	58	58	58	102	40	0.0	96%
			K	4.8	4.8	4.8	6.8	4	0.0	94%
2)	21/7/90	19057	Na	80	80	80	120	40	0.0	100
			K	2.0	2.0	2.0	6.1	4.0	0.0	101%
3)	22/7/90	19119	Na	137	137	137	180	40	0.0	98%
			K	3.6	3.65	3.625	7.8	4.0	.007	102%
4)	26/7/90	19123	Na	88	91	89.5	128.-	40	2.1	97%
			K	2.15	2.45	2.3	6.5	4.0	.21	97%
5)	11/9/90	19464	Na	101	101	101	144	40	0.0	102
			K	4.7	4.7	4.7	9.2	4.0	0.0	105
6)	17/9/90	19466	Na	170	169	169.5	191	20.0	0.7	101
			K	4.2	4.2	4.2	6.4	2.0	0.0	109
7)	19/9/90	19471	Na	73	68	70.5	77	40	4.9	103
			K	1.25	1.25	1.25	5.0	4.0	0.0	96.15
8)	22/9/90	19513	Na	22	22	22	60	40	0 0	103
			K	2.1	2.1	2.1	5.1	4.0	0.0	101
9)	26/10/90	19525	Na	18.67	18.67	18.67	86	66.67	0.0	100
			K	2.0	1.93	1.96	8.8	6.66	0.07	101
10)	29/10/90	19536	Na	42	42	42	100	60	0.0	98
			K	2.80	2.85	2.825	5.5	4.0	0.35	102
11)	1/10/90	19570	Na	152	152	152	197	40	0.0	102
			K	2.67	2.67	2.67	6.7	4.0	0.0	100

Analyst Name...... Jolly John..................

Appendix F

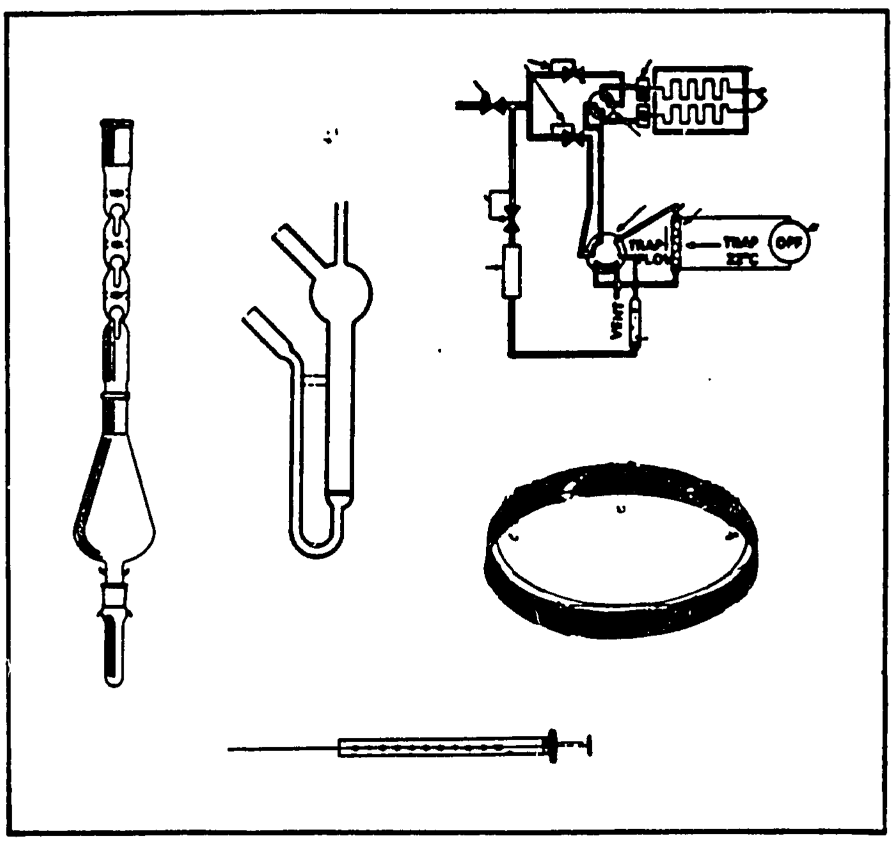
ORGANIC ANALYSES PARAMETER METHOD CROSS-REFERENCE

United States Environmental Protection Agency | Environmental Monitoring Systems Laboratory Cincinnati OH 45268 | EPA/600/4-88/039 December 1988

Research and Development

EPA

Methods for the Determination of Organic Compounds in Drinking Water



ACKNOWLEDGEMENT

This manual was prepared by the Chemistry Research Division, Environmental Monitoring Systems Laboratory - Cincinnati. Special thanks and appreciation are due to Patricia L. Hurr, Diane M. Schirmann, and Arleen M. Ciampone who provided outstanding secretarial and word processing support for the entire effort.

In addition, James J. Lichtenberg and James E. Longbottom, who managed the drinking water organic methods development program for a number of years, are recognized for their many important contributions. William Middleton, Jr. provided superb technical support during the development of all the mass spectrometric methods. Jean R. Wilson and Carol Brockhoff typed many of the earlier drafts of the methods. John P. Donnelly provided electronics engineering support during several of the methods development projects. Gerald D. McKee served as a manager during the development of several of the methods.

The staff of the Technical Support Division of the Office of Drinking Water, and particularly Richard Reding, provided extensive comments on the first draft of this manual, and on previous revisions of many of the analytical methods. Caroline A. Madding, working under the direction of Dr. Herbert Brass, tested and provided data for the cryogenic interface option in Method 524.2.

Finally, all the authors and contributors wish to thank the administrators and managers of the Environmental Protection Agency for their support during the development and preparation of this manual. Special appreciation is due to Robert L. Booth, former Director of the Environmental Monitoring and Support Laboratory - Cincinnati, Dr. Joseph Cotruvo, Director of the Criteria and Standards Division, Office of Drinking Water, and Thomas Clark, current Director of EMSL-Cincinnati.

EPA-600/4-88/039
December 1988

METHODS FOR THE DETERMINATION
OF ORGANIC COMPOUNDS
IN DRINKING WATER

Environmental Monitoring Systems Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

FOREWORD

Environmental measurements are required to determine the quality of ambient waters and the character of waste effluents. The Environmental Monitoring Systems Laboratory - Cincinnati (EMSL-Cincinnati) conducts research to:

- o Develop and evaluate analytical methods to identify and measure the concentration of chemical pollutants in drinking water, surface waters, groundwater, wastewater, sediments, sludge, and solid waste.
- o Investigate methods for the identification and measurement of viruses, bacteria and other microbiological organisms in aqueous samples and to determine the responses of aquatic organisms to water quality.
- o Develop and operate a quality assurance program to support the achievement of data quality objectives in measurements of pollutants in drinking water, surface water, groundwater, wastewater, sediment and solid waste.

This publication of the Environmental Monitoring Systems Laboratory - Cincinnati titled, "Determination of Organic Compounds in Drinking Water" was prepared to gather together under a single cover a set of 13 laboratory analytical methods for organic compounds in drinking water. We are pleased to provide this manual and believe that it will be of considerable value to many public and private laboratories that wish to determine organic compounds in drinking water for regulatory or other reasons.

Thomas Clark, Director
Environmental Monitoring Systems
Laboratory - Cincinnati

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INTRODUCTION

William L. Budde

Many of the nearly 200 organic analytes included in this manual may be identified and measured in drinking water using two or more of the documented analytical methods. For example, nearly 50 compounds are listed as analytes in four different methods. This approach of multiple methods for many analytes was selected to provide the maximum flexibility to method users from small and large laboratories. Some methods require relatively modest equipment, and others require sophisticated instrumentation. This flexible approach should meet the needs and requirements of nearly all laboratories.

GENERAL METHOD FEATURES

Each of the methods in the manual was written to stand-alone, that is, each method may be removed from the manual, photocopied, inserted into another binder, and used without loss of information. Revisions of these methods will be made available in a similar stand-alone format to facilitate the replacement of existing methods as new technical developments occur. This flexibility comes at the cost of some duplication of material, for example, the definitions of terms section of each method is nearly identical. The authors believe that the added bulk of the manual is a small price to pay for the flexibility of the format.

An important feature of the methods in this manual is the consistent use of terminology, and this feature is especially helpful in the quality control sections where standardized terminology is not yet available. The terms were carefully selected to be meaningful without extensive definition, and therefore should be easy to understand and use. The names of authors of the methods are provided to assist users in obtaining direct telephone support when required.

SAMPLE MATRICES

All methods were developed for relatively clean water matrices, that is, drinking water and some ground and surface waters. Some methods have been tested only in reagent water and/or drinking water. While some of these methods may provide reliable results with more complex water matrices, for example, industrial wastewaters and beverages, techniques for dealing with more complex matrices have not been included in the methods in order to keep them as simple and brief as possible. Therefore caution is needed when applying these methods to matrices other than relatively clean water.

Methods developed for drinking water include provisions for removal of free chlorine (dechlorination) which is assumed to be present in all samples. Dechlorination is necessary to stop the formation of trichloromethanes and other disinfection by-products, or to prevent the formation of method interferences and analytes generated from chlorination of impurities in reagents and solvents.

Similarly, pH adjustments are included in some of the methods for several reasons: (a) to retard growth in dechlorinated water of bacteria that can decompose some analytes; (b) to prevent acid or base catalyzed decomposition of analytes; and (c) to improve the extraction efficiency of certain analytes.

DETECTION LIMITS

Most methods include either a method detection limit (MDL) or an estimated detection limit (EDL) for each analyte. These limits are intended to provide an indication of the capability of the method, but they may not be of regulatory significance.

The MDL is calculated from the standard deviation of replicate measurements, and is defined as the minimum concentration of a substance that can be identified, measured, and reported with 99% confidence that the analyte concentration is greater than zero. The EDL is either the MDL, or a concentration of compound in a clean water matrix that gives a peak in the final extract with a signal-to-noise ratio of about 5.

If the replicate measurements needed to calculate an MDL are obtained under ideal conditions, for example, during a short period of time within a work shift, the resulting standard deviation may be small and give an unrealistically low MDL. The data acquired for measurement of an MDL should be obtained over a period of time (several days or more). Obtained in this way, the standard deviation includes normal day-to-day variations, and the MDL will be more realistic.

CALIBRATION STANDARDS AND QUALITY CONTROL SAMPLES

The methods contain separate calibration and quality control sections, and accurate calibration standards and quality control samples are needed to implement the methods. Calibration standards and quality control samples should be obtained from different sources so that the quality control sample can provide an independent check on the calibration and the other method variables.

Calibration standards and quality control samples may be available commercially, or may be available on a limited basis from the Quality Assurance Research Division, Environmental Monitoring Systems Laboratory-Cincinnati, 26 W. Martin Luther King Drive, Cincinnati, OH, 45268.

METHODS FOR VOLATILE ORGANIC COMPOUNDS (VOCS)

Six of the methods in the manual are for the determination of VOCs and certain disinfection by-products. These methods were cited in the Federal Register of July 8, 1987 under the National Primary Drinking Water Regulations. These are Methods 502.1, 502.2, 503.1, 504, 524.1 and 524.2.

The six VOC methods have been distributed in the form of photocopied documents by EMSL-Cincinnati to several hundred laboratories in the last two years. Five of these methods utilize the same basic purge-and-trap extraction technique, but, depending on the specific method selected, the user has a choice of a packed or capillary column gas chromatography (GC) separation and a mass spectrometer (MS) or conventional GC detector. The other method (Method 504) is a microextraction procedure for two compounds of special interest, ethylene dibromide (EDB) and 1,2-dibromo-3-chloropropane (DBCP).

Solicited and unsolicited written and telephoned comments have been received from some of the laboratories using the VOC methods, and some of these users suggested certain technical and editorial changes. In addition, the staff of the Chemistry Research Division recognized that some changes were needed to make the methods easier to understand and use, and bring them up-to-date. The revisions of the six VOC methods contained in the manual incorporate a few technical and many editorial changes which are summarized below.

Few technical changes were made to the six VOC methods. The use of ascorbic acid as a dechlorinating agent is described. Ascorbic acid has been extensively tested as a dechlorinating agent, and has been found to be as effective as sodium thiosulfate, but without the undesirable generation of sulfur dioxide at low pH.

The open split interface between the GC and the MS was incorporated into Method 524.2, but the interfaces previously mentioned were retained. Data is presented in the method to show that the open split interface can provide acceptable precision, accuracy, and detection limits. The previous revision of Method 524.2 allowed any interface that could meet the precision and accuracy requirements of the method. Many laboratories will find the open split interface to be the most economical for this method.

Changes were made in the recommended chromatographic conditions and internal standards in Method 502.2. These changes allow the measurement of all 60 VOCs in a single calibration solution.

Extensive editorial changes were made in all six VOC methods. These editorial changes were necessary to provide an organized, consistent, and much more complete presentation of the myriad details needed by laboratories to successfully implement the methods. The addition of these details, the consistent use of terminology, and the uniform organization of all the methods should substantially reduce the number of questions received and provide the user community with the information needed to obtain high quality results.

METHODS FOR SYNTHETIC ORGANIC COMPOUNDS (SOCS)

Four of the SOC methods were developed for a national pesticides survey conducted by EPA during 1987-1989, and these are designated Methods 507, 508, 515.1, and 531.1. One screening method (Method 508A) for polychlorinated biphenyls (PCBs) was developed as a result of a specific request from the Office of Drinking Water (ODW). Method 505, a relatively simple microextraction procedure patterned after Method 504, was developed to provide a rapid method for the determination of chlorinated hydrocarbon pesticides and commercial PCB mixtures (Aroclors) in drinking water. Method 525 is a broad spectrum GC/MS method for a variety of compounds under consideration for regulation, and it was developed specifically to utilize the new liquid-solid extraction technology and minimize use of the solvent methylene chloride.

Three of the methods used in the national pesticides survey utilize a liquid-liquid extraction of the SOCs from water followed by a high resolution capillary column GC separation and detection with an electron capture or other selective detector (Methods 507, 508, and 515.1). One of the methods (531.1) employs the direct analysis of a water sample with a high performance liquid chromatography (HPLC) separation and post-column derivatization to a compound detected with a fluorescence detector.

Method 508A was designed as a screening procedure for polychlorinated biphenyls (PCBs). The method uses the powerful chlorinating agent antimony pentachloride to convert all the PCB congeners in a sample extract to decachlorobiphenyl which is separated with either packed or capillary column gas chromatography, and detected with an electron capture detector.

Method 505 provides a rapid procedure for chlorinated hydrocarbon pesticides and commercial PCB mixtures (Aroclors). This method uses a high resolution capillary column GC separation and detection with an electron capture detector.

The new broad spectrum GC/MS method (Method 525) uses a liquid-solid extraction (LSE) procedure based on commercial LSE cartridges. These cartridges are small (about 0.5 in. x 3 in.) plastic or glass tubes packed with reverse phase liquid chromatography packing materials. Water samples are passed through the cartridges and some organic compounds are sorbed on the solid phase. After air drying, the organic compounds are eluted from the cartridges using a very small volume of an organic solvent. Cartridges from six suppliers were used in the methods research, and a quality control procedure was developed to permit selection of cartridges with acceptable performance characteristics.

The LSE procedure is attractive because it greatly reduces the use and worker exposure to methylene chloride and similar solvents. The compounds in the cartridge extract are separated, identified, and measured with a high resolution capillary column GC/MS procedure. This allows the simultaneous determination of 42 SOCs including chlorinated hydrocarbon pesticides, polycyclic aromatic hydrocarbons, phthalate and adipate esters, individual PCB congeners, several triazine pesticides, and pentachlorophenol. Laboratories will find this method attractive because of its potential economy of operation when a wide variety of analytes are to be determined.

Appendix G

PROPOSED QUALITY ASSURANCE PLAN FOR A TYPICAL WATER QUALITY LABORATORY

LIST OF FIGURES

Appendix H

MASTER LIST OF DATA MANAGEMENT SYSTEM VENDORS AND DESCRIPTION OF VG LIMS SOFTWARE

LABORATORY DATA MANAGEMENT SYSTEMS

Master Vendor List

ASC COMPUTER SYSTEMS, ST. CLAIR, MI 48081

BBN SOFTWARE PROD. CORP., CAMBRIDGE, MA 02138

BECKMAN INSTR., INC., ALLENDALE, NJ 07401

CHESAPEAKE SOFTWARE, INC., WILMINGTON, DE 19810

CL SYSTEMS, INC., SPRINGFIELD, NJ 07081

DYNAMIC SOLUTIONS, VENTURA, CA 93003

FEIN MARQUART ASSOC., INC., BALTIMORE, MD 21212

HEWLETT PACKARD, PALO ALTO, CA 94304

IBM CORPORATION, WHITE PLAINS, NY 10801

LABORATORY MICRO SYS., INC. TROY, NY 12180

NORTHWEST ANALYTICAL, INC., PORTLAND, OR 97208

PE NELSON, CUPERTINO, CA 95014

RADIAN COPORATION, AUSTIN, TX 78720

SOURCE FOR AUTOMATION INC., MILFORD, MA 01757

TELECATION ASSOCIATES, CONIFER, CO 80439

THE CHALLENGER GRP., INC., STAFFORD, TX 77477

TEXAS MICROSYSTEMS INC., HOUSTON, TX 77099

VG INSTRUMENTS, DANVERS, MA 01923

WATERS CHROMATOGRAPHY, MILFORD, MA 01757

PHILIPS ELECTRONICS INSTRUMENTS, MAHWAH, NJ.

LDS, INC. PITTSBURGH, PA, 412-826-3550

US ANALYTICAL INSTRUMENTS, SAN CARLOS, CA 94070, 1-800-437-9701

DELOITTE & TOUCHE, SALT LAKE CITY, UTAH 84144, 801-328-4706

CAELUS SYSTEMS, INC., AMHERST, NH 03031

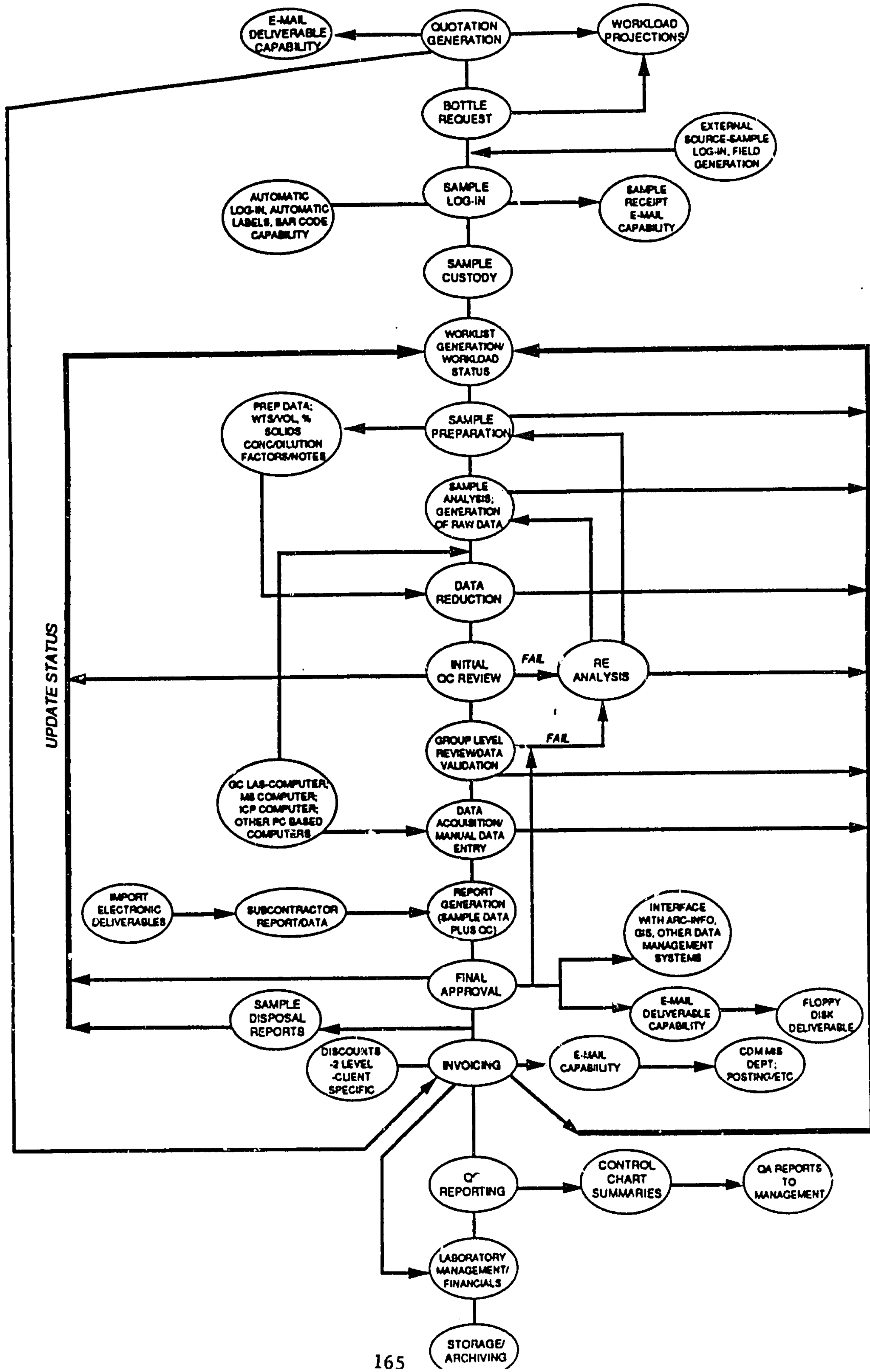
LIMS, INC., DANIA, FL 33004

CONCEPT DATA RESOURCES, NEW YORK, NY 10018

ANALYTICAL AUTOMATION SPECIALISTS, BATON ROUGE, LA 70809

AUTOMATED COMPLIANCE SYSTEMS, BRIDGEWATER, NJ 08807

LIMS FLOWCHART



VG LIMS

Introduction

VG LIMS is a full function Lab Information Management System (LIMS). These functions include sample tracking, sample receipts, sample location tracking, sample preparation documentation, hazard identification, status checking, test data and sample review and approval, and archiving of data. VG LIMS also includes a state-of-the-art AD HOC Report Writer and VGL, our 4th Generation Query Language. With VG LIMS even a novice can generate user-defined reports without training.

VG LIMS is available with a choice of database systems....RMS and ORACLE. The VG propriatary database is constructed with RMS indexed (keyed) files. The ORACLE RDBMS system features state-of-the-art Relational Data Base technology. The user interface for the two configurations is identical. The major differences are that ORACLE uses Standard Query Language (SQL) and that all the ORACLE options are available.

1.1 FEATURES

- Menu and function security by user
- Menu system with menu by-pass and command roll-back
- Hot-Key Menu System
- Browse - Dynamic Help/Lookup system
- On-line BUILD
- Sample dependent Log-in Screens
- Sample Log-in Screens with default values
- User Configured Sample Identification
- Sample Grouping by Analytical Request
- Automatic assignment of required tests
- Easy to use manual test assignment
- Automatic sample scheduling
- Bar coded Labels and Worklists
- AD HOC Retrievals and Reports
- Review/Approval by Test/Sample/Analytical Request
- Result Entry and calculations
- Product/Customer Specific Certificate of Analysis
- Configurable Audit Trail
- Archive and retrieval of all sample related data
- Link to Data Manager and Multichrom

1.1.1 Menu Security

The Security System is the user's first point of contact with the functions of the LIMS. The user must enter a user ID and password in order to gain entry to the system. VG LIMS then looks at the user's security level and checks for a user specific menu system. Each user of the system can have a completely different menu structure oriented to their function in the laboratory.

1.1.2 Menu Structure and Menu By-Pass

Once the security system is satisfied, the functions granted to the user appear on the screen. Each function and menu on the system has a unique two or three letter code. When a user knows the command fc. a function, that function can be entered directly and the Menu System is by-passed. The direct commands to the system are always shown in the menu to aide the user to learn them thereby speeding use of the system.

1.1.3 Hot-Key Menu System

From any place within the LIMS system, the user can freeze the current screen and enter a function into the HOT-KEY system. The Hot-Key Menu is invoked by entering Control-N and a user designed Hot-Key Window will appear. The user can put any frequently used functions in the window.

1.1.4 Browse

Within most laboratories the use of short codes for tests names, sample IDs, projects and customers is widespread. These codes are committed to memory or looked up each time they're used. This process frequently creates errors due to transcription, memory errors and errors of omission when the lab tech can't remember the code. VG LIMS has a 'browse' facility provided to solve these common problems. Using browse, the system searches the database to help the user the correct answer. When the Sample ID is 'Browsed', the user can configure the sample information shown in the browse window.

Browse is used in response to a prompt by LIMS for a code. To use browse, the user simply presses the FIND key. If there are any valid entries to the prompt, a one line window will open at the bottom of the screen, displaying the available codes in alphabetic order, together with their descriptions. This is known as 'basic' browse. To scan through additional codes, press the space bar until the desired code is displayed. The DO key or RETURN will enter the selected code as the response to the prompt.

Quite often the user knows the beginning of the code. In this case you can speed up the use of browse by typing the first few letters of the code before pressing the FIND key. The browse display will then start from that point in the list of available codes.

When the user wants to see a screen full of codes, 'extended' browse can be selected by pressing the FIND key twice. The extended browse displays a screen full of available codes. The user can select from among the displayed codes by using the up or down arrow keys to move the cursor to the desired code then press RETURN or DO as before. If the code you require is not on the current screen, you can press the NEXT SCREEN key to display more codes. From any point in browse if the desired code is not listed, the EXIT key will allow you to leave browse without making a selection. The BROWSE facility is available to the user throughout the system. Browse will assist the user at Sample Log-in, when maintaining codes within Laboratory Table functions, and even when using the AD HOC Report Writer.

1.1.5 On-Line Build

When a user is Logging-in Samples, a new customer, project code or charge code may need to be entered. In most LIMS, the user must exit the Log-in function to enter the new information via Data Base Table maintenance functions. With VG LIMS, the user can simply enter the new code into the field on the screen and type the 'INSERT' key, the LIMS then checks that user's security and if approved opens the appropriate table to add a new entry.

1.1.6 Sample Type Driven Log-in Screens

Many labs share the common problem of how to log-in the many different types of samples that the lab runs from day to day. In some labs each sample type gets a different log-in form, in others, separate log books are used. For these labs, the conversion to a LIMS means a compromise on the Log-in form used. For each type of sample the lab runs, VG LIMS lets the user design questions appropriate for that sample type. These different sample log-ins are stored as sample templates.

1.1.7 Sample Templates with Default Values

Sample templates are used within LIMS not only to select the proper questions for that sample (see 1.1.6), but also to aid the user in selecting the right response to the questions asked. The user who builds the sample template can supply default responses to the questions. This shows the user at log-in what tests to run, what report to generate, what sample prep to use, any hazards to be aware of, cost center, project number and other important facts.

1.1.8 User Configured Sample Identification

Built into the Sample Template system is the ability to have many, independent user configured sample identifier with automatic number generation. The system can be configured to run hundreds of autonumbering schemes concurrently. One type of sample can use a sequence such as BATCH_0001, while the next type uses a combination of date and time. The format of the ID is designed using a simple, high-level system.

1.1.9 Sample Grouping by Analytical Request

The VG LIMS includes the ability to manage the information from many samples as a group. If samples arrive at the lab to be run and reported together as a group, an analytical request or Job can monitor the progress of those samples as they move through the lab. Progress reports can be generated, summary reports can be written and estimated completion date determined. Once all the samples are completed, a single final report for the request can be written by the system. When samples arrive at the lab over many days, weeks or months and the samples need to treated as a group then the Project Management facility is used. Study Management is used to summarize and report sample and data that are part of a time based study such as Drug Stability Testing, Shelf-life Studies where a time based protocol is used.

1.1.10 Automatic Assignment of Required Tests

In most labs, standard groups of tests are assigned to specific types of samples. For totally automatic Log-in using the Sample Scheduler, automatic test assignment is a requirement. The VG LIMS has a built in Test Scheduler. The user simply enters a list of required tests and, if appropriate, a list of optional tests into a Test Schedule and gives it a name. Whenever an automatic or manual Log-in references a test schedule, the required tests are selected.

1.1.11 Manual Test Assignment

Manual test assignment can be handled primarily in two different ways within the VG LIMS system. Totally manual test assignment allows the user to chose tests by typing in the test codes and using browse to enter the tests from table of known tests. The second and more productive way to assign tests is with the aide of a test schedule (test group). During log-in, the test schedule will assign the required tests automatically and display a list of optional tests available for assignment. The user can also use browse to add other tests to the list.

1.1.12 Automatic Sample Scheduling and the Watch Dog Timer

The VG LIMS system comes with a Watch Dog Timer. The Watch Dog Timer is used to set-up automatic functions within the system. The Timer can be set by the user to automatically log-in routine samples or sets of samples, print out reports and many other time dependent functions. The timer simply uses a sample template to define the type of sample to be entered. The default responses entered at set-up time are used and other information can be added later by the user manually.

1.1.13 Bar Coded Labels and Worklists

Bar Code technology has proven itself to be an easy to use method of removing typing errors and increasing productivity in many industries. The VG LIMS brings this technology to the hands of the chemist. VG LIMS includes the ability to generate bar codes on a variety of devices and use many different bar code reading systems. The system can produce bar codes on the DEC LA series printers, DEC LN03+ Laser printers and also use Bar Code printers available from companies such as INTERMEC. The bar codes can be put on sample labels and also placed on worklists for lab personnel to take to an automated instrument.

1.1.14 AD HOC Retreivals and Reports

The main product of a lab is a report and a LIMS system is only a complete success when it can not only produce the reports the lab needs, but it must allow versatility to the user in how those reports are generated. The VG LIMS system includes a sophisticated report generator capable of producing reports in any format. However, the power of the system can only be realized when a user without special training can produce reports in a totally AD HOC fashion. The VG AD HOC Report Writer brings this power to the user.

The AD HOC Reporting system is simple to use. The user starts the report process by selecting the search fields using the browse facility. The user then enters the search criteria. The user shows the system what to put into the report and what report format to use. The report is then produced.

1.1.15 Review and Approval of Results by Test/Sample/Request

Review of results before reporting is a critical element in a LIMS system. The VG LIMS system allows the user to review the results as they are being produced, if the reviewer is satisfied with the data then approval is given to the test results. In many labs, once all the testing is completed on a sample or group of samples (request), it is reviewed as a whole. If the reviewer is satisfied, the sample is approved and a final report can be generated.

1.1.16 Result Entry and Calculations

A flexible method of entering data into the system is a critical item. Even the most automated lab systems still have some test methods which cannot be automated. For these test methods and for other test methods which do not justify automation, the VG LIMS system includes a configurable system to generate data entry screens. The system uses the same technology used within the report generator to make generic and test specific entry of data possible. When the screen is specific to a test then a calculation procedure can be added to the screen for maximum productivity. There is virtually no limit to the number of different screens and calculations that can be performed.

1.1.17 Product/Customer Specific Certificates of Analysis

Within the VG LIMS system, the user can specify the type of Certificate of Analysis (COA) that each type of sample will get. The COAs are designed using the report generator. When the sample is reported, the system automatically determines the correct COA form based on the sample information and uses it to build the Certificate of Analysis.

1.1.18 Configurable Audit Trail

The VG LIMS includes a complete audit trail facility to allow users to reconstruct the life of the sample as it moved through the laboratory. The audit trail is transparent to the user until it is needed to provide a record of changes to the sample. The Audit Trail can be configured to audit samples, results or any data base table. Both Silent and Prompt Auditing are supported. With Silent Auditing, the system will record the date and time of the change, who made the change, and both the original and modified data. With Prompt Auditing, the system also asks the user why the data was changed. The audit trail also audits its own configuration, when it was started or stopped and why.

1.1.19 Archive and Retrieval Of All Sample Related Data

The archive facility of VG LIMS is used to permanently store completed data and samples on inexpensive media such as magnetic tape. As samples are archived to tape, all the information associated with that sample is also archived. The information archived could include, the raw chromatographic data and any other raw or processed files referenced in the sample record. When samples are retreived from archive, the system brings back the entire record into the database for review and reporting.

1.1.20 Link to Data Manager and Multichrom

VG LIMS includes software to transfer data and electronic worksheets to Data Manager and Multichrom. These links allow data to flow freely between the packages. The facility to run these links over DECNET/ETHERNET communication lines between the DEC computers is included as standard.

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CONTROL CHARTS

Overview

A control chart is a graphical means of presenting how measured data vary with time. It is distinguished from a simple graph of data points by virtue of having statistically calculated limit or control values which can be used to indicate when the data are outside the range of values that could be attributed solely to random variation.

The most common form of control chart is one developed by W.A. Shewart in which data are divided into subgroups, each subgroup comprising a (usually fixed) number of data points. Properties of the subgroups, most often the mean (average value) and the range (highest value minus lowest value), are plotted against time.

The reason for using subgroups of data points rather than plotting the data values directly is that various useful statistical techniques may then be applied. For example, it is possible to obtain estimates of the "expected" values of the mean and range of the distribution from which the data were taken. These estimates can be used to calculate values for the limits which may then be plotted on the charts.

Specifically, division into subgroups makes use of a very powerful tool of mathematical statistics known as the Central LImit Theorem which states in simple terms that, irrespective of the shape of the distribution of a set of data values, the distribution of average values of subgroups of size n tends towards a normal distribution as n tends toward infinity. This means that values of the normal distribution may be used to evaluate probabilities related to the distributions of the means of subgroups, irrespective of the distribution of the population from with the subgroups were taken. In practice this relationship is valid even for quite small subgroups, say four or five data points, especially if the underlying distribution is anything like normal.

Control charts for means and ranges are usually referred to as X and R charts respectively. Each chart is drawn with time (or consecutive subgroup number) along the x-axis and the property being monitored up the y-axis. Also associated with each chart are horizontal lines drawn at positions representing the expected values (X and R), together with the upper and lower control limits (UCL and LCL). Because the limit values depend on subgroup size the positions of the limit lines will vary if this is not constant, smaller subgroups having wider limits. Obviously, the lower control limit for the range cannot be less than zero.

CONTROL CHARTS

A BRIEF SUMMARY

The new VG Control Charts package will be fully integrated into the VG LIMS software. It will allow the creation of the following types of chart:

1. Mean, Range and Standard Deviation Shewhart Charts.
2. Individual Measurement and Moving Range Shewhart Charts.
3. Percent recovery charts.
4. Quality control charts.

The package will contain the following features for all control charts.

1. Data can be taken directly from Sample Manager.
2. Graphical display of the chart.
3. Any type of Shewhart Chart may be created from the same data points.

Shewhart Charts will have the following features:

1. User defined trend definitions.
2. Data Limits may be calculated using the Actual Data, Target Values or Specification Limits.
3. In graphical display of the data, the user can decide whether one sigma and warning limits will be displayed in addition to the Control Limits.
4. Control limits may be calculated for segments of the chart.
5. The following charts can be displayed in pairs:
   a. Mean and Range Charts.
   b. Mean and Standard Deviation Charts.
   c. Individual Measurement and Moving Range Charts.

The positions of the limit lines are calculated from the population mean and standard deviation. These values may be obtained either from prior knowledge of the distribution or, more usually, estimated from the subgroup data. In the latter case the more data that is available the more accurate the estimate tends to be; at least 25 subgroups is recommended.

Once means and standard deviations have been obtained the control limits can be fixed at some multiple of the standard deviation each side of the mean. This multiple is usually 3 or 3.09. Sometimes warning limits are also set, usually at plus or minus 2 (or 1.96) standard deviations from the mean.

The statistical routines library included with the Control Charts option are designed to provide simpl statistical analysis and operate in conjunction with the graphical procedures and functions.

Statistical Capabilities:

1. Single Variable Operations

   a) Number of entries, Sum, Maximum and Minimum

   b) Sum, Average, Median and Sum of Squares

   c) Standard Deviation and Variance

   d) T-Test

2. Curve Fit Operations

   a) Curve Fitting using

      Upto 6th polynomial

      Cubic Spline

      Logarithmic

      Linear through zero

      All coefficients available

b) Curve interrogation

Calculate Y for given X

Calculate X for given Y

c) Display of curve fit

3. Data Passing

Data is passed in arrays with the ability to define the start and end points in the array for operations.

Appendix I

APPROXIMATE COST OF LABORATORY UPGRADING

PRELIMINARY MWR WATER LABORATORY PLANNING BUDGET
(ALL BUDGET FIGURES ARE APPROXIMATE)

No.	Item Description	Amount R.O.	Totals R.O.	Source of Funds
	<u>PLANNING & ENGINEERING PRELIMINARIES</u>			
A1	Preliminary design, technical assistance and aquisition managament	21,000		OAJC
A2	Architecture and engineering planning.	48,000		MWR
A3	Construction management 1 year	25,000		MWR
A4	Planning and obtain permits	4,000		MWR
	PRELIMINARY PLANNING & ENGINEERING COSTS.		98,000	
	<u>CONSTRUCTION & CONSTRUCTION RELATED ITEMS</u>			
B1	Site grading and preparation	5,000		MWR
B2	Site utilities.. (fire hydrants, water, water storage, etc)	40,000		"
B3	Hazardous waste handling facilities (if required)	5,000		"
B4	Paving, fine grading, drainage utilities	25,000		"
B5	Site landscaping	3,000		"
B6	Building construction, includes HVAC, plumbing, building sewers, restrooms, fire sprinklers, lighting, doors and glazing, cable chase, major walls, drop ceiling floor drains, explosion proof stores vault, delivery dock and detached stores building.			
	1300 - 1500 M^2 @ RO.400/M^2	560,000		"
B7	Uninterruptable power supply electrical power generator, enclosure, fuel storage, venting and switch gear 50 KVA.	80,000		"

PRELIMINARY MWR WATER LABORATORY PLANNING BUDGET

No.	Item Description	Amount R.O.	Totals R.O.	Source of Funds
B8	Final outfitting includes fume-boods, built-in cabinets, partitions, trim, electrical, connections, sinks	180,000		MWR
B9	Cold storage unit 6 x 16 meters racking for 2000 sample storage units	42,000		MWR
B10	Contingency funds	90,000		MWR
	PRELIMINARY CONSTRUCTION COSTS		1,030,000	
	LABORATORY EQUIPMENT & SUPPLIES *			
C1	Misc. minor testing machines and equipment	175,000		MWR/OAJC
C2	Misc. glassware, minor accessories	35,000		MWR
C3	Major analytic testing equipment	650,000		OAJC ?
C4	Chemical reagent stocks and other supplies	80,000		MWR
C5	Equipment spares and support tooling	40,000		MWR
C6	Support gases	40,000		MWR
C7	Equipment service contracts	40,000		
	APPROX. TOTAL PRELIMINARY EQUIPMENT COSTS		1,060,000	
	MISC. SUPPORT EQUIPMENT & SUPPLIES *			
D1	3000 water sampling kits with plastic racks and bottles @ RO.8/each	24,000		MWR
D2	2 each refrigerated vans for sample transportation with custom racking volume = 35 M^2	55,000		MWR

* Note: Near-field testing equipment and District Office support labs not considered. For purposes of this analysis these items were considered as incidental to the well inventory program.

PRELIMINARY MWR WATER LABORATORY PLANNING BUDGET

No.	Item Description	Amount R.O.	Totals R.O.	Source of Funds
D3	Furniture, carpets and supplies for laboratory	15,000		MWR
D4	Photocopy, telephones, printers and other hardware for laboratory	9,000		MWR
	TOTAL MISC. SUPPORT EQUIPMENT & SUPPLIES		103,000	
ANNUAL COSTS OF MWR STAFF PERSONNEL - PERMANENT STAFF				
E1	Laboratory Director, direct hire per year.	55,000		MWR
E2	Deputy Lab. Director/QA,QC Coordinator, direct hire.	45,000		"
E3	Specialist Water Chemists team leaders - 3 each @ 40,000 per year.	120,000		"
E4	Water Chemists/Advanced Technicians - 12 each @ 9,000/ per year (part Civil Service)	108,000		"
E5	Lab. Technicians (mostly Civil Service) 10 each @ 6,000 per year.	60,000		"
E6	Lab. labour, Drivers and other help - 4 each @ 8,000 per year.	32,000		"
	PERMANENT STAFF DIRECT ANNUAL COST		420,000	

PRELIMINARY MWR WATER LABORATORY PLANNING BUDGET

No.	Item Description	Amount R.O.	Totals R.O.	Source of Funds
	SECONDED OR CONTRACT SWING SHIFT + TRAINING PERSONNEL			
F1	Project Manager, lead chemist	48,000		MWR
F2	Water Chemists, 8 @ 12,000 RO.	96,000		"
F3	Water Lab. Technicians, 11 @ 10,000 RO.	110,000		"
	TOTAL SWING SHIFT ANNUAL COST		254,000	
	ANNUAL CONSUMABLES FOR LABORATORY			
G1	Reagents, chemicals, preservatives etc.	22,000*		"
G2	Major equipment service & spares	12,000		"
G3	Electricity, phones, office supplies.	10,000		"
	TOTAL ANNUAL COST OF CONSUMABLES		44,000	

* Figure may vary substantially

MWR WATER LABORATORY PLANNING BUDGET - ANNUAL CASH FLOWS
1990-1999

(ALL FIGURES IN RIALS OMANI)

					YEAR OF PAYMENT					
Cost Item	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
A. Planning & Engineering	15,000	55,000	28,000							
B. Constn. of Laboraory		600,000	400,000							
C. Lab. Equipment & Supplies		300,000	350,000	350,000						
D. Other support Equipment		64,000	40,000							
E. MWR Lab. staff	25,000	80,000	280,000	420,000	420,000	420,000	420,000	420,000	420,000	420,000
F. Contract Lab. Staff		100,000	120,000	254,000	254,000	254,000	80,000	20,000	...	...
G. Consumables for Lab.			44,000	44,000	44,000	40,000	35,000	30,000	30,000	30,000
TOTAL ANNUAL CASH-FLOW	40,000	1,199,000	1,262,000	1,068,000	718,000	714,000	535,000	470,000	450,000	450,000