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ENVIRONMENT AND WATER RESOURCES

WATER RESOURCES MANAGEMENT STUDIES IN THE TUBAN-ABYAN REGION

SECOND INTERIM DRAFT REPORT

VOLUME 1

Prepared for:

UNITED NATIONS PROCUREMENT DIVISION (RFPS-63)
NATIONAL WATER RESOURCES AUTHORITY, SANA'A, YEMEN
UNDP/NETHERLANDS WATER PROGRAMME: YEM/97/200

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SEPTEMBER, 2001

بسم الله الرحمن الرحيم

الجمهورية اليمنية
رئاسة مجلس الوزراء

الرقم: ...
التاريخ: ...
الموافق: ...

الأخ / لامون سكوبل-مدير مشروع المسح الجيولوجي للمياه في تبن أبين المحترم

بعد التحية:

إشارة الى رسالتكم بتاريخ 2001/7/27م للسيد سكوت كيبر خبير برنامج نزع الألغام في بلادنا ، بشأن طلب الإيضاح عن الأماكن المزروعة بالألغام من غيرها في مناطق العمل المحددة في الخرائط المرفقة.

علية نود إحاطتكم بأن الوحدة الفنية التنفيذية لنزع الألغام قد أفادت برسالتها رقم (285 /3400) وتاريخ 2001/7/31م أن المنطقة المحتمل وجود ألغام فيها هي وادي ملاح محافظة لحج. وذلك بناء على نتائج مسح المستوى الأول للألغام الذي نفذته هيئة التخطيط لتطهير الألغام وبإشراف الأمم المتحدة .

وشكـــــــــراً!!!

خالـــد عبدالوهـــاب الشريــــف

وزيـــر الدولـــة عضـــو مجلس الوزراء
رئيس اللجنة الوطنية للتعامل مع الألغام

نسخة مع التحية لـ:
الوحـــدة الفنيـــــــة

Fax to 02231167
Komex Aden

Date 06 Aug. 01.

To Ramon Scoble, Project Manager

Tuban - Abyan Area.

Mention to your letter dated 27 Jul. 01 to Mr. Sckot, CTA of deminings program in our Country and request to identify the area which has [illegible] minings from others in your working Locations according to your attached maps.

We like to inform you, that, the technical implemntation unit of deminings told us in their letter no. (395/3400) and dated 31 Jul. 01, the possible area where there are minings is Wadi AL-Melah, Lahj Governorate. This is regarding to the first [illegible] Level Survey for the mining which the planning Authority of minings [illegible] implemented and supervise by UN. Thanks

Khaled AL-Shareef
Minister of the State
chairman of National [illegible] of Minings.

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June 27, 2001

or to conducting field operations

with the programme of investigations around Aden under a UN DESA April and have a further segment of work which may take expatriate and es may pose a safety risk. We have also been made aware that unexploded in some areas under study.

assessment of geological outcrops along the mountain front between Um Riga' ns of Yemen. We anticipate commencing this work at the beginning of of maps indicating the area to be inspected and likely routes our staff will routes through the areas suggest that off-road driving will become necessary

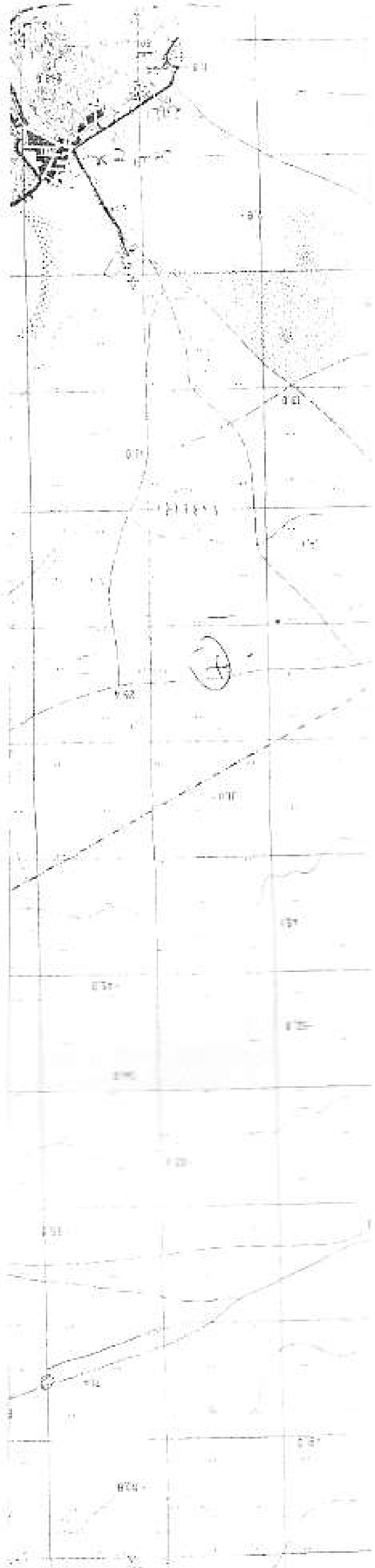
ing on the attached maps the presence or absence of mines in the areas here UXO presence is possible. If the maps could be returned to me at our 1 July 2001 I would be very appreciative.

told by local sources in Aden that additional mines or minefields have ed in the Bir Nasser area just north of Aden and adjacent to the Bir Nasser n Map and marked in). Could you confirm whether this is correct as this g work by our project.

June to 21 July 2001, further information regarding this request can be who can be contacted in our Aden office on (02) 231167 or by cell phone on

Pager 5431327

/92/102/103/113/114 with proposed investigation areas marked.



KOMEX Yemen Ltd.

ENVIRONMENT AND WATER RESOURCES

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FACSIMILE TRANSMISSION			
To:	United Nations Mine Action Program - Yemen		
Attention:	Jeffery S Pilkington		
Fax Number:	+967 (1) 302795	**Our File:**	5290
Subject	**MINE LOCATION INFORMATION**		
Number of Pages:	3	**Date:**	July 30, 2001

Dear Scott,

Thank you for meeting with me briefly on the morning of 22nd July at the United Nations Mine Action Program's (UN MAP) Sana'a office to discuss Komex's request of 27 June (copy attached) regarding obtaining mine locations before undertaking field investigations in the Tuban/Abyan areas of southern Yemen. The information was requested to enable Komex to ensure the safety of its own staff and employees of the National Water Resources Authority (NWRA) while undertaking field geophysical investigations. This fax is to confirm for Komex the substance and outcome of those discussions.

Mapped Areas
In our request we asked for indications of likely mined areas and possible unexploded ordnance (UXO) risk within an area along the mountain front/coastal plain margin from Um Riga in the west to Shuqrah in the east. We enclosed copies of maps with areas marked in red as those we wished to survey by vehicle and on foot. The areas were extensive and covered many hundreds of square kilometers.

You noted verbally that while we could view the maps in the office. I did so and noted that your staff had on at least one of these maps indicated the likely existence of a minefield by a pencilled circle. You stated that you did not consider it possible for the maps to be given to Komex and you hinted that the reason for this would be the potential liability if Komex staff or our associated Yemeni personnel were to encounter a mine in areas **not** marked as a risk by UN MAP staff.

From your comments we have understood that you would hold a similar position with respect to UXO. You have retained the copies of the maps which we sent to you.

Mines in Bir Nasser Wellfield Area
The second part of our request asked whether information given to Komex in late June regarding the discovery of additional mines in the Bir Nasser Wellfield area was correct. This is an area which was indicated as **not** having minefields by your staff on maps which we had submitted to your office earlier this year (Komex retains copies of those maps). Komex staff worked extensively

in the wellfield in April 2001. This matter was not discussed at our meeting and no other reply has been received from UN MAP.

Further investigation by Komex staff interviewing residents of the village adjacent to the wellfield has revealed that three (3) additional mines were located and removed from the wellfield in late June. The mines were discovered in the southernmost line of wells in the wellfield near to wells numbered 1 to 6 by the National Water and Sanitation Authority (NWSA). At that time a mine warning sign was present at the main road margin of the wellfield.

During their investigation there was no restriction on where within the entire wellfield Komex intended to operate. It was obviously possible that Komex staff or our associated Yemeni personnel (employees of NWRA and a NWSA pump removal team) could have been operating in close proximity to live mines in an area previously deemed safe by UN MAP.

Closure

While Komex thank you for the degree of assistance which UN MAP has provided to date with our project, all further Komex field investigations will be undertaken with extreme caution.

Yours sincerely,

Ramon Scoble

Project Manager, Tuban Abyan

Tel/Fax: (02)231167 Mobile: 71102054 Pager: 5831327

TABLE 1

PROJECT EXECUTION SUMMARY
TUBAN-ABYAN WATER RESOURCES MANAGEMENT PROJECT

5290

	WORK PACKAGE	SUB-TASKS	START	END	STAFF	PACKAGE LEADER	TECHNICAL DETAILS	COMMENTS	SCHEDULE COORDINATION	OBJECTIVES	OUTPUTS
1	Remote Sensing										
		data collection and acquisition	1.12.00	1.7.01	WM, RS	WM	purchase landsat imagery		ongoing	develop maps - topography, landuse, hydrology	1:50,000 maps - statics
		develop basemaps	15.1.01	1.7.01	WM, NWRA		topomaps DEM	1:250,000 and 1:50,000 maps	after UN notification to proceed	develop maps - geology/tectonics	1:100,000 maps - dynamics
		geology, vegetation, landuse maps	1.3.01	1.7.01	WM		static analysis	1:50,000 maps	field mapping after Haz... RS mission		
		mapping and ... maps	1.4.01	15.10.01	WM		dynamic analysis				
		field verification and ...	1.1.01	15.10.01	RS, NWRA, CC		GPS field verification - specific features		after dynamic analysis completed		technical report
		report and map generation	15.5.01	15.11.01	WM, CC						
2	Structural Geology										
		preparations	1.7.01	1.8.01	RS, KS	RS	review maps from RS task (Task 1)		after basemaps and geological RS work	verify remote sensing interpretations	1:250,000 maps - structural geology
		field mapping	1.8.01	1.9.01	RS, KS, NWRA		GPS waypoint mapping			support geophysical investigations	1:100,000 maps - tectonics
		map preparation	1.9.01	1.10.01	RS, KS		in concert with RS programme	1:250,000 structural, 1:100,000 tectonic		understand deep geology	technical report
		report	1.10.01	1.11.01	RS, KS						
3	Monitoring Network										
		preparations	10.1.01	1.3.01	AAL, MAF, RS	AAL			after UN notification to proceed	assess conditional suitability of current network	1:100,000 maps - monitoring network locations
		locate and design 3 wadi stations	1.4.01	1.6.01	AAL, MAF, NWRA		locations to be selected			select monitoring sites	monitoring station designs - 3 wadis
		locate and design 2 rain gauging station	1.4.01	1.6.01	AAL, MAF, NWRA		locations to be slected		after UN notification to proceed	assess flow characteristics of 3 wadis	equipment specifications for monitoring stations
		present designs to NWRA	1.6.01	1.7.01	AAL		NWRA review of designs			establish surface water data trends in 3 wadis	develop wadi hydrographs - 3 wadis,
		NWRA construct and instrument	1.7.01	1.8.01	NWRA		funds not yet secured by NWRA	option - southern governorates project stations		determine wadi bed infiltration	rating curves - 3 locations
		monitor	1.8.01	1.10.01	AAL, NWRA		monitor completed installations	could provide data for report	after facilities constructed and instrumented		technical report
		evaluate data	1.10.01	1.11.01	MAF		data available depending on construction				
		report	15.11.01	1.12.01	MAF, AAL						
		recommendations	15.11.01	1.12.01	MAF, AAL						
4	Geophysical Survey										
		preparations	1.3.01	1.4.01	RK, RS	RK		contract local logging equipment (if poss)	after UN notification to proceed	spatial distribution of quaternary deposits	1:100,000 maps - Tuban and Abyan deltas
		5 - 20km 2D ERT sections	1.4.01	15.05.01	RK, NWRA, RS		selected locations	ERT electrical resistance tomography	after UN notification to proceed	delineate deep geological formations	1:100,000 maps - geological boundaries
		8 - 2.5 km 2D ERT sections	1.4.01	15.05.01	RK, NWRA, RS		selected locations		after UN notification to proceed	identify geological boundaries	1:250,000 maps - geophysical survey results
		log up to 20 selected boreholes	1.4.01	15.05.01	RK, NWRA, RS		FC (openhole), UR (cased hole)	other tools as suitable - available	after UN notification to proceed	determine distribution of saline and brackish waters	technical report
		analysis of data	15.05.01	1.9.01	RK					identify major faults	
		report	1.9.01	1.11.01	RK, JD, PEH						
5	Hydrochemistry	preparations	1.3.01	5.4.01	GH Team, RS						
		identify wells to be sampled	1.4.01	15.5.01	GH Team, RS, JD	GH			after UN notification to proceed	spatial distribution of groundwater quality	raw data files
		collect up to 160 samples	1.6.01	1.8.01	GH Team, NWRA		GPS locate each well			evaluate origin of saline and brackish waters	1:250,000 map - sample locations
		laboratory analysis	1.6.01	1.8.01	Sana'a U Lab		main ions, field parameters	selected samples for organics and metals	ongoing during programme	identify possible pollution sources	1:100,000 maps - hydrochemistry
		analysis of data	1.8.01	1.10.01	GH Team, RS		main ions - Durov analyses	as required		assess aquifer vulnerability	1:100,000 maps - aquifer vulnerability and pollution
		report	1.9.01	1.11.01	GH Team, RS, JD						technical report
6	Recharge Study										
		preparations	1.3.01	1.5.01	RS	RS			after geophysics complete	develop understanding of recharge areas	1:100,000 maps - groundwater recharge zones
		data collection	1.6.01	15.7.01	RS, NWRA		coordinate with RS task 1		after RS basemap and static maps complete	estimate recharge quantity	technical report
		analysis	15.7.01	15.8.01	RS, JD		model-based approach		coordinate with modelling	define sustainable groundwater development	
		report	15.8.01	1.10.01	RS, JD						
7	Modelling										
		review previous models	1.6.01	1.7.01	JD	JD			after UN notification to proceed	improve water balance	model input and output files on CD ROM
		develop conceptual model	1.7.01	1.9.01	JD, PEH, LSL		use all data collected		after bulk of field data has been collected	examine water flow scenarios and trends	technical report
		develop updated model	1.9.01	1.10.01	JD		MODFLOW preferred code	previous model framework used if acceptable	after review of existing models	evaluate groundwater quality trends and scenarios	
		aquifer tests	1.7.01	1.8.01	RS, NWRA					evaluate aquifer parameters	
		report	1.10.01	1.11.01	JD, PEH, LSL			encompasses information from all project tasks			

STAFF QUALIFICATIONS SUMMARY

AA	Ahmed Aldemlish - PhD hydrogeologist, 10 years experience
AAL	Ali Alabadi - MSc hydrologist, 25 years experience
JD	Jane Dottridge, MSc Hydrogeologist, 25 years experience
LSL	Lucien Lyness, MSc Hydrogeologist, 25 years experience
KS	Karl Schmidt, Local Project Manager, MSc hydrogeologist, 15 years experience, geology background
PEH	Paul Hardisty, Project Director, MSc Engineering Hydrologist, 15 years experience
RK	Richard Kellett, PhD Geophysicist, 12 years experience
MAF	Murray Fitch, MSc hydrologist, 15 years experience
WM	Wes Macleod, MSc geomatics specialist, 10 years experience
RS	Raymond Scrimble, MSc, Local project manager - hydrogeologist, 10 years experience, geological background
GH	GhayB team led by Dr Ali Ghaleb, hydrogeologist

TUBAN-ABYAN 5290

TABLE 2: WORK PROGRESS COMPLETION CHART-September 2001

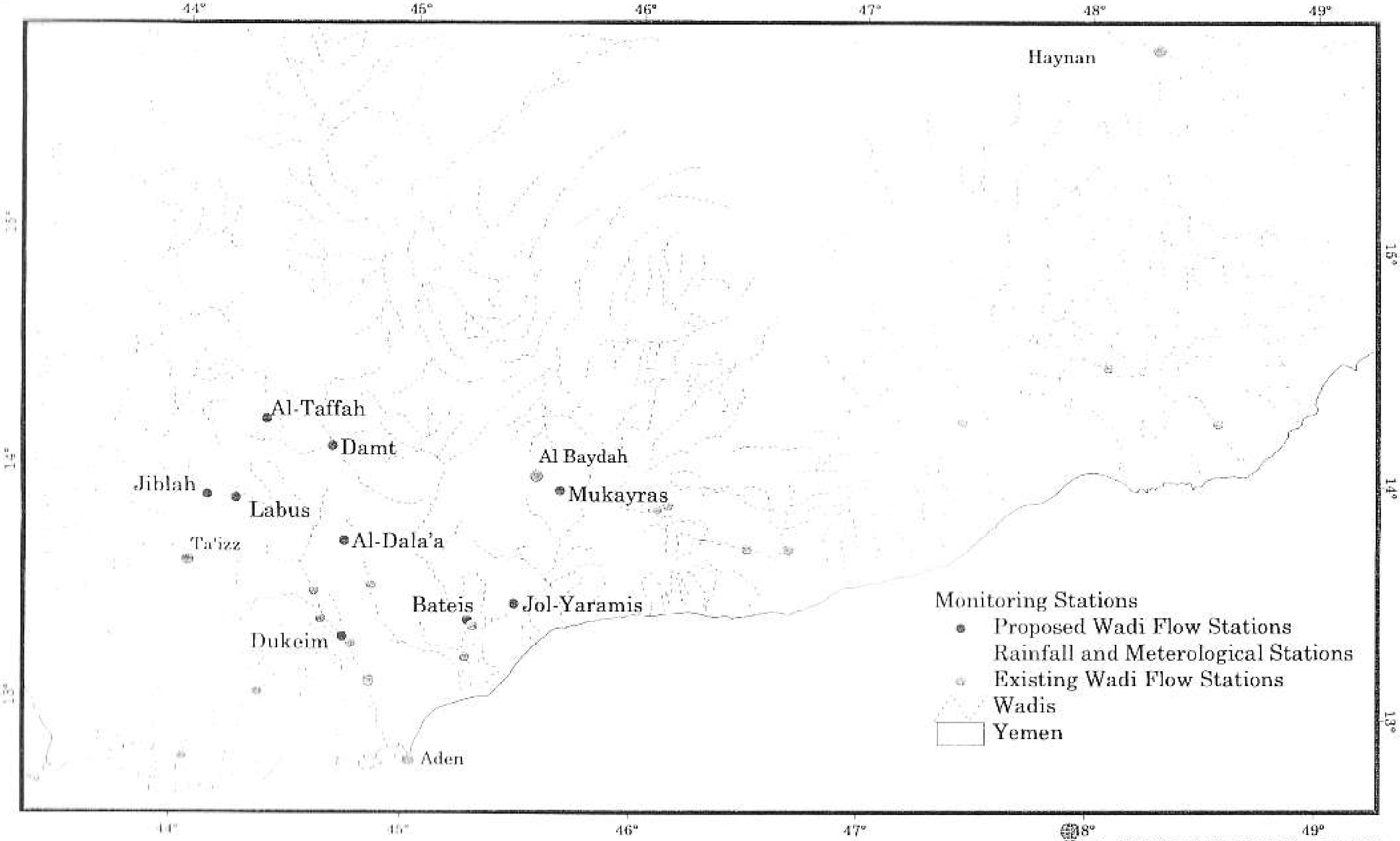
Percent Completion										
	10	20	30	40	50	60	70	80	90	100
Activity										
Mobilisation	■	■	■	■	■	■	■	■	■	■
Project planning	■	■	■	■	■	■	■	■	■	■
Review of data and databases	■	■	■	■	■	■	■	■	■	
Remote sensing study	■	■	■	■	■	■	■	■		
structural geology	■	■	■	■	■	■	■	■		
Monitoring network										
- field missions	■	■	■	■	■	■	■	■	■	■
- office work	■	■	■	■	■	■	■	■		
Geophysical survey										
- field missions	■	■	■	■	■	■	■	■	■	■
- office work	■	■	■	■	■	■	■	■		
Hydrochemistry - field (yemen subcontract)	■	■	■	■	■	■	■			
Recharge Study	■	■	■	■	■	■	■			
Modelling										
- office work	■	■								
- field work (aquifer tests)	■	■	■	■	■	■	■	■	■	■
Project management	■	■	■	■	■	■	■	■	■	
- in-country	■	■	■	■	■	■	■	■	■	
- overall	■	■	■	■	■	■	■	■	■	
Inception report	■	■	■	■	■	■	■	■	■	■
Interim reports	■	■	■	■	■	■	■	■	■	■
Final report										

TABLE 3: WORK PROGRAMME

Timescales (months)				
	2001 oct	nov	dec	jan
Activity				
Mobilisation				
Project planning				
Review of data and databases				
Remote sensing study				
- field missions				
- office work				
- NWRA				
Stuctural geology field survey				
- field missions				
- office work				
- NWRA				
Monitoring network				
- field missions				
- office work				
- NWRA				
Geophysical survey				
- field missions				
- office work				
- NWRA				
Hydrochemistry - field				
- NWRA				
Groundwater recharge Study				
- field missions				
- office work				
- NWRA				
Modelling				
- aquifer testing				
- modelling				
- office work				
- NWRA				
Project management				
- in country				
- overall				
Inception report				
Interim report - 1				
Interim report - 2				
Final report		DRAFT	review FINAL	

Total project duration 12 months from effective date (2 weeks after agreement of contract)

Tuban / Abyan Study Areas, Republic of Yemen



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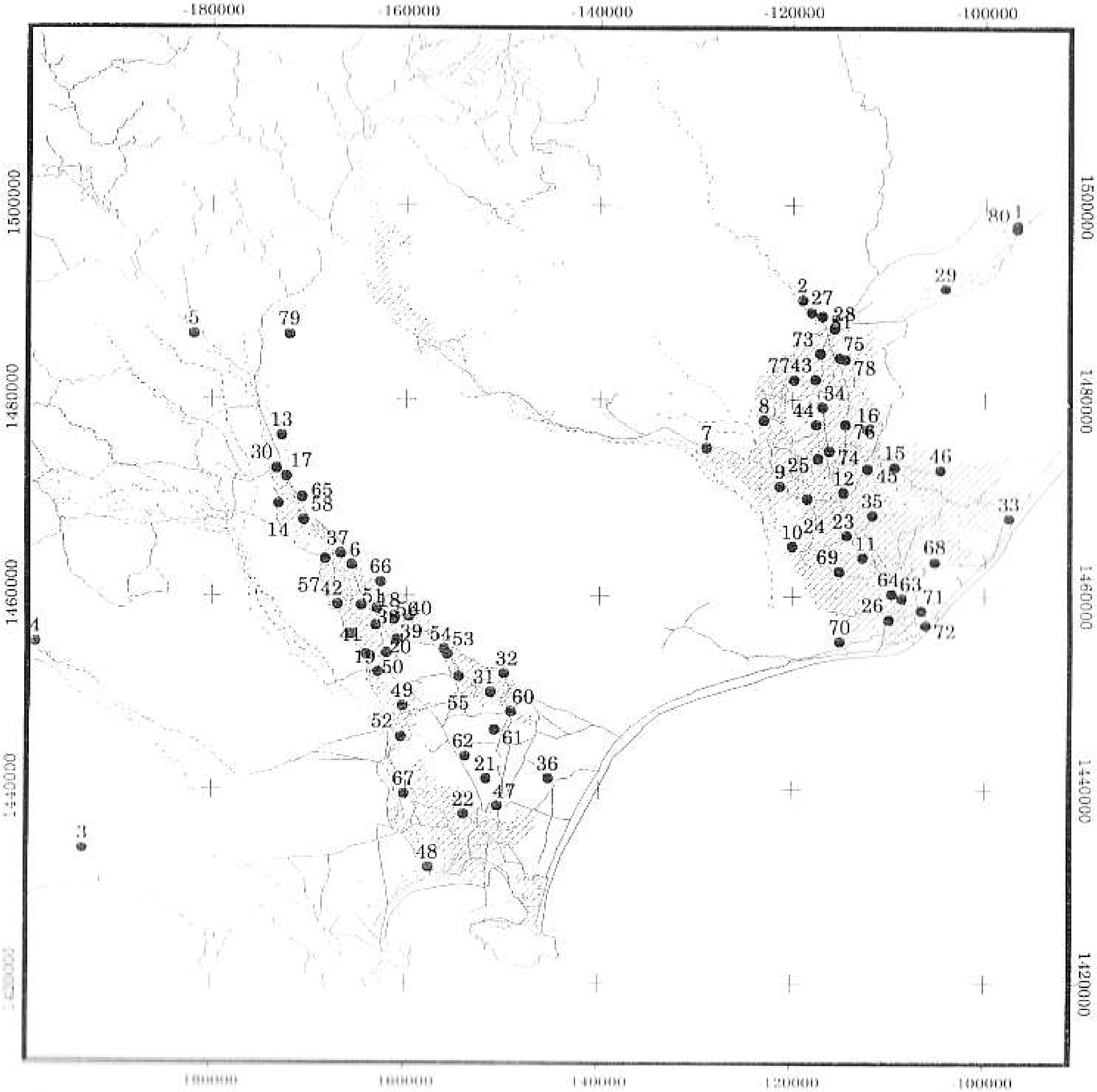
Scale 1:2,500,000

Figure 1

Tuban / Abyan Study Areas, Republic of Yemen



16 Well Location with Identifier

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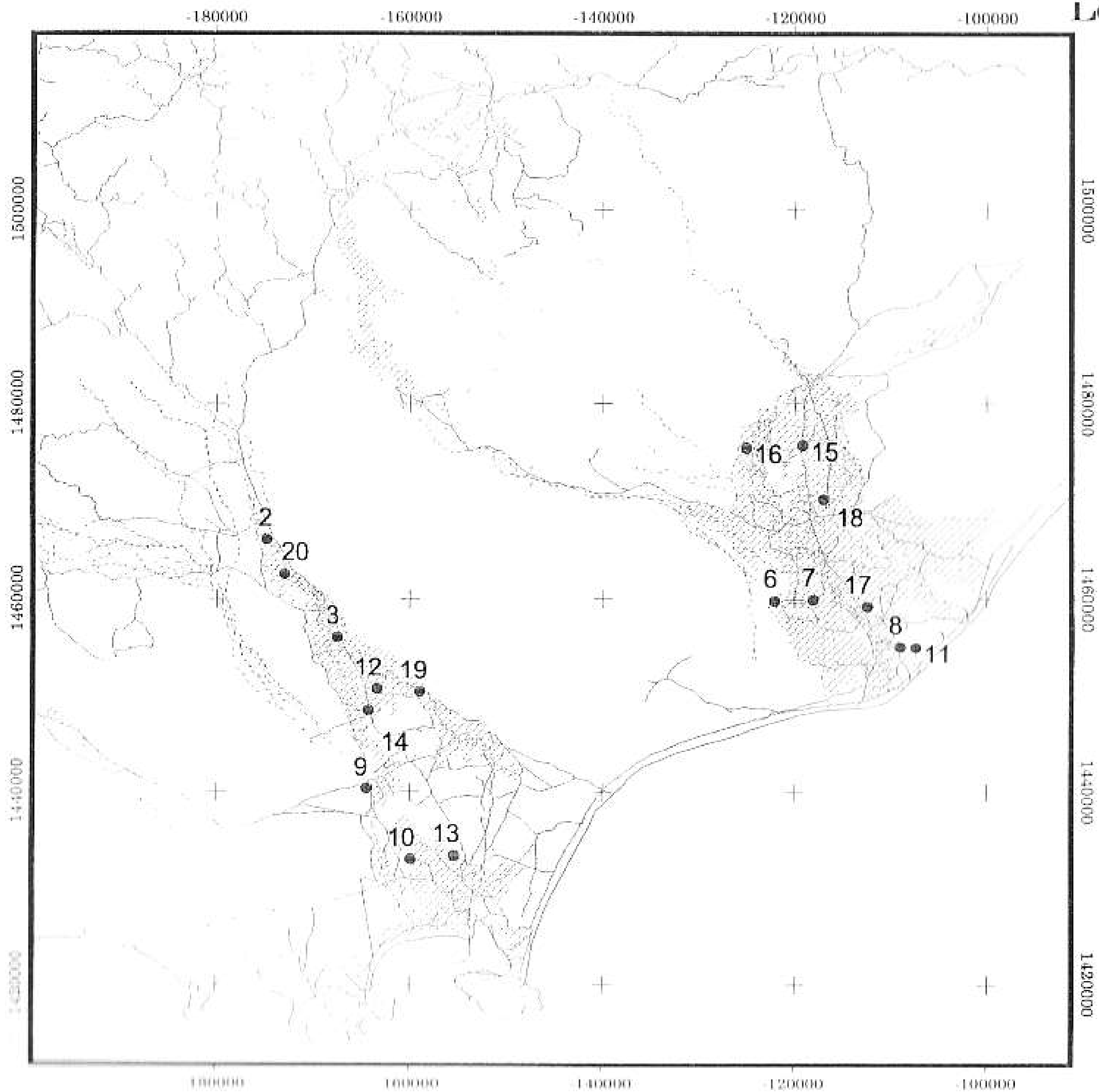
Scale 1:600,000

Figure 2

Locations of Pump Tests

Tuban / Abyan Study Areas,
Republic of Yemen



16 Pump Test Location with Identifier

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Scale 1:600,000

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1 INTRODUCTION

1.1 BACKGROUND

Komex is pleased to provide this second progress report for the Yemen Tuban-Abyan Water Resources study.

Komex responded to request for proposal RFPS-83 from the United Nations Procurement Division, and was awarded the contract to complete the work. An inception mission was conducted within three weeks of contract execution, as specified in the contract. The mission took place between 6 and 24 November 2000, in Yemen, and the results of the mission and subsequent analysis and discussions were presented in Komex's approved inception report (Komex, Dec 2000).

As per the requirements of the contract, this progress report describes the activities undertaken up to September 1, 2001.

The draft of this progress report was completed and delivered to NWRA and the UN as per the revised schedule of project milestones, provided in Komex's letter of 13 March 2001 (attached in Appendix VII).

This progress report contains the following:

- A description, progress and details of project activities to September 1, 2001, following on from the first interim report ;
- A chronology of main project activities undertaken during that period;
- Draft presentations of data collected during the period, in each of the active work packages;
- Preliminary discussions and analysis of the data and information collected.

As set out in the approved project inception report, Komex has designed this progress report as per standard Komex reporting formats. The report is broken down in way that provides a technical synopsis of progress in each of the main work package areas, as set out in the RFP, the Komex proposal and contract.

As set out in the approved Project Inception Report, this progress report is intended as an overview synopsis of work in progress, and the information, analysis and data contained herein is preliminary in nature, and has not, in some cases, been fully scrutinized or reviewed. Information is included only to give the UN and NWRA a picture of project progress, and a preliminary impression of the technical findings and data being collected. Complete data analysis and interpretation will be provided in the final report.

1.2 PROJECT INFORMATION

The objectives and technical scope of work of the project are provided in detail in Komex's proposal KP-476 dated June 2000 to the UN. The reader is referred to this document for information on project scope of work, technical requirements, and approach. The official terms of reference are provided in the UN's RFPS-63. Contract details, terms of payment and conditions of engagement are set out in the contract No. PD/C0247/00 between the United Nations and Komex International Ltd. The final agreed implementation basis for the project is set out in Komex's Project Inception Report KI-5290 (Komex, Dec 2000).

1.3 ACKNOWLEDGEMENTS

Komex would like to thank all of the members of NWRA for their kind support during the course of the project so far. In particular, we are grateful to the following:

- Chairman Jamal Abdo
- Salem Bashauib
- Ahmed Al Shami
- Mohamed Danekh
- Viktor Rybakov
- Mansoor Jafer Ali Ahmed.

Komex also thanks the directors and staff of the other organisations working in the study area for their continuing collaboration and assistance.

2 PROJECT MANAGEMENT

2.1 DATA COLLECTION

Since no formal data collection task was included in the work-scope for the Tuban-Abyan project, this important issue is discussed within the project management section of this report.

Collection and review of existing data and reports forms an important part of the project, and continued throughout this reporting period. To date, the information search has included the NWRA library in Sana'a, NWRA offices in Aden, Ministry of Oil and Minerals (Geological Survey Department and Yemen Petroleum Company), Southern Governorates Rural Development Project, Ministry of Agriculture (AL-Kod Research Centre, Irrigation Department and Department of Drilling), Yemen Survey Authority, Canadian Nexen, and the Komex archives. Further details of the information requested are provided in the meeting notes in Appendix V. At present we estimate that we have now collected over 90% of the relevant reports and data which are available for the project study area.

It should be noted that, despite persistence by Komex staff and the goodwill of the relevant Yemeni government ministries and agencies, relevant information has been slow to appear and difficult to obtain. As stated in the contract, the UN and the Government of Yemen have undertaken to provide all available basic documentation at no cost to the consultant.

2.2 PROJECT ADMINISTRATION

The in-country project manager, Mr. Ramon Scoble has been active in Yemen since the start of the project. Mr. Scoble has undertaken the following activities during the reporting period:

- Organization of all project logistics, including organization of accommodation and project offices in Aden, provision of communication sand computing equipment, and transport;
- Set up of local financial mechanisms for payment of NWRA field per diems, local sub-contractors, and local logistics, through Komex Yemen;
- Interface with NWRA personnel on a daily basis, including organization of NWRA project staff, and informal progress reporting to NWRA on a regular basis;
- Coordination with UN security personnel in providing official travel clearances for all project staff movements and activities;
- Continuation of data collection activities which were begun during the inception mission; review, cataloging and transfer of collected data and reports;
- Interface with remote sensing work team on data collection;
- Preparation for and initiation of monitoring network review work package, including field preparations, logistical support, meeting coordination, data provision, and organization of site surveying;
- Preparation for and initiation of geophysical survey work package, including preparations for team arrival, equipment customs clearance preparation, logistical set-up, vehicle provision, and active field participation;

- Preparation for and initiation of well survey and hydrochemical work package activities, including provision and customs clearance of field equipment, coordination of NWRA personnel assignments, and field quality control.
- Coordination and full-time supervision of aquifer testing program (modelling package);
- Detailed field geological mapping and verification, in all accessible areas of the project area, in support of remote sensing and geological mapping work packages;

Komex Yemen Ltd., a registered Yemen corporation, with head office in Sana'a, has provided its office in Sana'a as the base for project administrative services, which include:

- Financial and banking services for the project, including payment of local subcontractors, NWRA staff per diem and travel allowances, and local logistical costs;
- Communications services, including telephone, fax, and internet access points;
- Accommodation in Sana'a for project staff, usually in transit from outside Yemen to Aden;
- Provision of customs clearance support for project equipment shipped to Yemen;
- Support for supplementary security arrangements in Yemen, through Griffin's security connections.

2.3 CONTRACT ISSUES

The contract terms are being fulfilled, and in general the project is proceeding relatively smoothly.

2.3.1 Interim Report Copy Delivery

The current contract calls for Komex to provide 6 draft copies of each interim report to UNDESA in New York. In recent correspondence and discussions with some of the members of the NWRA team in Yemen, it appears that NWRA may consider that at least 3 copies of the report should be sent directly to NWRA in Yemen. We would ask that UNDESA and NWRA discuss the issue, and if necessary, issue in writing a revised specification for report copy deliveries, which would amend the current contract terms. Also, if these terms are to be altered, please specify to which NWRA office the reports should be sent, how many copies are required, when they are required, and to whom they should be addressed. Komex supports the idea of sending 3 of the six copies directly to NWRA, as a way of speeding up the review progress.

2.3.2 Review of Komex Work Product

Please find attached in Appendix VII, a detailed summary of the results of meeting held the first week of September 2001, in Yemen, between the Komex project director and key NWRA project staff. These meetings revealed that to date, NWRA staff responsible for reviewing the interim reports and interfacing with Komex field staff, have not had access to all of the required documents, with which to carry out appropriate review. This was caused largely due to incomplete communications between NWRA in Sana'a and in Aden branches. This matter is only now being solved, and Komex anticipates much improved working communications for the rest of the project.

2.4 PROJECT TASKS AND COMPLETION

Table 1 provides a detailed summary of the sub-tasks included in each work package, along with information on assigned staff, anticipated start and completion dates, and outputs. This table was provided in the inception report, and is updated herein. It represents a more detailed work plan, based on the findings of the inception mission, discussions with team and NWRA staff, analysis of logistical information gleaned over the first few months of the project.

Table 2 provides a chart of each of the main project tasks, with APPROXIMATE (+/- 10%) percent completion, broken down by category.

2.5 PROJECT RESOURCE INPUTS

A table providing the provisional estimated resource inputs for each task, up to September 1, 2001, will be provided to UNDESA shortly as a separate letter. It should be noted that Komex has already brought significant additional resources to bear to the project, and in many cases has extended its work beyond that required in the ToR and inception report. A summary of extras provided by Komex to date was provided to NWRA and UNDESA in a letter dated September 4, 2001, which is also provided in Appendix VII.

2.6 SCHEDULE

2.6.1 Background

As per our letter of March 13, 2001 to the UN, and based on discussions between the Komex in-country project manager and the UN CTA in Sana'a, and as laid out in our approved Inception Report (Komex, 2000), a revised project schedule and milestone dates for payment have been set. At this stage in the project, Komex anticipates that the project will be completed in the calendar year 2001, as required.

2.6.2 Project Milestones

The project milestones are (as per our letter of March 13, 2001):

- May 15, 2001: Tuban-Abyan Interim Draft Report 1 - COMPLETED
- September 15, 2001: Tuban-Abyan Interim Draft Report 2 - COMPLETED
- November 15, 2001: Tuban-Abyan Draft Final Report
- December 15, 2001: Tuban-Abyan Final Report (subject to obtaining review comments within 2 weeks as set out in contract)

An updated project schedule is shown in Table 3. No major changes to schedule have occurred since the last interim report.

2.7 PROJECT TEAM AND STAFFING

The key project team members remain as specified in the project proposal and the approved Inception Report (Dec, 2000). The work leaders and main project management team consist of:

Dr Paul Hardisty	PROJECT DIRECTOR
Mrs. Jane Dottridge	PROJECT MANAGER
Mr. Ramon Scoble	LOCAL PROJECT MANAGER (LPM)
Ghrayth Ltd.	SUBCONTRACTOR – HYDROCHEMISTRY
Mr. Ali Alabadi	SUBCONTRACTOR – MONITORING NETWORK
KOMEX Staff (Ex-Pat)	TECHNICAL SERVICES
NWRA staff	FIELD AND OFFICE SUPPORT
Griffin/Komex Yemen	ADMIN AND LOGISTICS

As per contract requirements, a total of 5 NWRA staff have worked on the project in different technical capacities and for different periods of time, during the reporting period. A list of NWRA staff who were active on the project during the reporting period, and their roles, is provided in Appendix VII.

2.8 SAFETY

2.8.1 General

Recent events in Yemen, including the attack on the USS Cole in Aden, have created a heightened awareness of security issues. As discussed in the approved Inception Report, Komex's partner in Yemen employs a specialist security advisor who continues to work with our team during the project. This allows Komex to operate all over Yemen with an acceptable degree of security. At times during the work to date, vehicle travel was made with armed escort.

All project movements have been pre-cleared and approved, as required, with the UN security officers, and a good working relationship has been established with that group. Komex's UN security briefing for the area explicitly states that we should confined our activities to "well traveled roads only".

As mentioned in the Inception Report, while Komex is familiar with Yemen, and our partners have strong links to the Yemen security forces and local tribes, there is always the possibility that the security situation could deteriorate further. Komex reserves the right to halt work in Yemen, should the security situation, in our opinion, warrant such action. We would of course discuss any such decision with the UN and NWRA prior to taking action.

2.8.2 Mine Safety – Initial Developments

Having been alerted to the potential risk from mines in Yemen, Komex contacted the United Nations Development Program's Mine Action Program. An initial meeting with the Chief

Technical Advisor of the program advised Komex that mines could be present in the study areas and that all minefields in Yemen have been located. Yemen has the distinction of having all of the sown minefields dating back to the 1970's identified on location maps, many hand-drawn, which clearly delineate their locality and general extent with reference to local landmarks. However these maps detailing minefield locations in the study area could not be provided to Komex by the Mine Action Program, as this was said to have potential military security issues.

The CTA indicated that the process Komex should follow in planning field activities was to identify potential investigation areas and submit maps showing these. Once the proposed area had been considered Komex would be advised of localities (villages, named areas etc) which may have mines near them and should be avoided. *It was made clear to Komex that the mine risk in Tuban and Abyan is very real and that attempting fieldwork in areas not previously cleared with Mine Action would pose a serious and unnecessary risk to personnel.* At the same time it was not possible for Komex to receive copies of locality maps of all mined areas so as to avoid them, therefore requiring cooperation from Mine Action Program.

Following initial field reconnaissance maps indicating 8 proposed geophysical investigation areas in Abyan and 13 proposed investigation areas in Tuban were taken to the Mine Action Program on 6 April following a meeting for which no Mine Action personnel were able to attend on 5 April. The maps were considered and one proposed area in Abyan (two minefields present) and five proposed areas in Tuban (7 minefields present) were considered as high risk to be entered only in the presence of Mine Action personnel with location maps. The maps indicated presence of minefields by the marking of 1 to 4 km square areas where minefields were known to exist, but more specific location maps could not be obtained.

A verbal request made during the meeting for Mine Action personnel assistance and the response was that this would require a written request countersigned by the agency under which we were operating (UN DESA for this project). A faxed request was sent on 7 April 2001 by Komex, and a countersigned copy of the fax was forwarded to the Mine Action Program by Dr John Skoda the same day. *No response was received from this fax.* A follow-up fax was sent on 16 April indicating that there was some urgency to the matter with the incipient arrival of the geophysical investigation team. No response was received to this fax or to telephone calls made on 19 April immediately prior to the geophysical investigations commencing.

Accordingly the high-risk areas were treated with caution. The mined area in Abyan with two minefields present in the area surrounding the villages of Al Kod and Gawla (Sheet D-38-103 Zinjubar) was completely avoided. Two proposed areas in Tuban with three minefields present in the area surrounding the villages of Al-Habil and Al-Mansura in Upper Tuban and the locality of AL-Amaad in Lower Tuban (Sheet D38-115 Aden) were completely avoided.

One of the mined areas in Tuban, adjacent to the NWSA Bir Ahmed well-field, was investigated after field reconnaissance indicated that the Mine Action Program was operating in the area and had delineated minefield areas. No Mine Action staff were present at the site during survey. To achieve sufficient length for the investigation in this area required commencing the geophysical survey within 25 metres of the active minefield area. Other items of ordnance (possibly unexploded) indicated that this area was one of heavy fighting during the recent conflicts and staff were accordingly warned not to stray from the indicated corridor.

Another area adjacent to the NWSA Bir Nasser well-field was indicated by the NWSA Field Operations Manager Khaled Al-Hureiby to have been the scene of heavy conflict during the 1994 war and that unexploded ordnance could still be present within the well-field. Access roads traverse the well-field and made the survey possible to complete in this location.

While the geophysical field program was able to be undertaken without mine-related injury *the level of cooperation shown by the Mine Action Program in assisting safe field practice was less than satisfactory*. This has resulted in an inability to work in many key areas in which Komex would have liked to conduct field activities. An email identifying our concerns regarding mines was sent to UNDESA by the Project Director, Dr Paul Hardisty of Komex on May 2, 2001.

2.8.3 Mine Safety – Recent Developments

The correspondence and drawings discussed in this section are reproduced in Appendix I.

As noted in the first interim report there is a risk of the presence of mines (anti-personnel and anti-tank) in the study area. Komex has followed the procedure outlined in that report of contact with the United Nations Mine Action Program (UN MAP) in attempting to ensure safety to its own staff and NWRA trainees within the project activities. Freedom of travel and access was required for a number of the project components to enable ready investigation yet such freedom was not possible in either planning or executing the activities.

For the geophysical program initial field reconnaissance maps indicated proposed geophysical investigation areas in Tuban and Abyan. Maps of these areas were considered by UN MAP and areas were identified as high risk to be entered only in the presence of Mine Action personnel with location maps. The maps provided to Komex at that time (March 2001) indicated presence of minefields by the marking of 1 to 4 km square areas where minefields were known to exist, but more specific location maps could not be obtained. An example of these maps (Appendix I) annotated by UN MAP shows from Map Sheet D-38-114 the location of a mined area near Bir Ahmed (named black hatching) which Komex planned to work close to (lower red hatching). Komex relocated to an area to the west of this site where UN MAP were actively de-mining and staff were cleared by Komex for working on a road section (light blue marking).

Komex also undertook geophysical sampling in the vicinity of the Bir Nasser wellfield indicated in the upper right of the figure (red hatching). It can be noted that no areas of mine risk have been identified by UN MAP in this area on the map. After the geophysical program had been completed a Mine Hazard sign was noted on the main road at Bir Nasser and a verbal report came through NWRA staff that mines had been located and removed in the well-field area.

Confirmation was asked of local personnel and *it was verified verbally that 3 mines had been located and removed from the well-field within which Komex had been cleared to operate freely, and had operated freely.* Due to this identified uncertainty, and the plain inability of MAP to provide an appropriate level of assurance of personnel safety, both the hydrochemical investigations and additional recharge study investigations were restricted by Komex from operating in areas unknown to NWRA staff.

A response to the issue of the earlier clearance and subsequent location of mines at Bir Nasser was requested from UN MAP along with clearance for work on the structural geological-geomorphological study which requires unrestricted access along the mountain front north of the Tuban-Abyan area. Maps and an accompanying letter in English stating this were hand delivered shortly after 27 June 2001 to UN MAP for them to indicate of where mine risk existed.

A visit was made by the Komex Local Project Manager to UN MAP in Sana'a on 22 July 2001 to retrieve the maps. At this meeting, Komex was told verbally by the Director of the Mine Action Program that the maps could not be returned due to a potential liability to UN MAP. A follow up fax was sent on 30 July, 2001, to confirm the discussions, but was not responded to. Komex therefore has had to restrict all activities to marked roads. A letter, in Arabic, was received on 6 August 2001 from the Minister of the State - Chairman of the National Committee of Minings, which after being translated described that risk existed in Wadi Al-Milah, but did not indicate where.

While the field investigations have been undertaken without mine related injury, the level of cooperation shown by the Mine Action Program in assisting safe field practice has been less than satisfactory. Any subsequent field activities not along marked and used roads subsequent to this report will request similar vetting from the Program.

The presence of mines has been a difficult factor in execution of this project to date. However, at this stage, Komex is of the opinion that only the geophysical program has suffered to a degree that affects our ability to deliver all the requirements of the ToR. Geological mapping, recharge studies, hydrochemical sampling and aquifer testing programs have all been conducted within the constraints created by mines, but without adverse impacts. The geophysics program, by its very nature, however, was severely restricted and slowed down by the significant and real concerns over mines. The geophysical field crew leader, while working in the project area, made a direct representation to the Project Director of Komex that they were very concerned about mines and mine safety, and despite having completed a significant amount of the required field work, could not in good conscience continue, feeling that his crew was in significant danger. On this basis, as required by the Komex health and safety policy, and based in part on the lack of satisfactory assurances provided by MAP, the project director agreed to end the program at that point. The geophysical program described herein shows all data collected up to that point. The project resources use chart will also show that the geophysics team expended MORE than the allocated budget in time and resources on this task, showing clearly that the restrictions and uncertainty put on them due to the presence of mines and unexploded ordnance slowed their work considerably.

3 TECHNICAL REPORT

3.1 REMOTE SENSING

3.1.1 Imagery

The primary objectives during this phase of the program were to update the preliminary maps created and presented in the first interim report, and to compile the information for additional maps required as outputs by the Inception report and ToR.

The maps produced during this period are entitled:

- Base-data of the Tuban/Abyan Study Area, Republic of Yemen
- Topographic Map of the Tuban/Abyan Study Area, Republic of Yemen
- Geological Map of the Tuban/Abyan Study Area, Republic of Yemen
- Geomorphology Map of the Tuban/Abyan Study Area, Republic of Yemen
- Regional Base-data of the Tuban/Abyan Area, Republic of Yemen

Maps themes included:

- Landsat imagery;
- Topography;
- Geology ;
- Geomorphology (Surficial geology);
- Landuse and Vegetation;
- Wadis and surface water features;
- Transportation networks; and
- Populated areas.

Maps were also prepared as part of the surface water and well investigations including proposed rain gauge and wadi flow gauge locations.

All interim draft maps are provided in Appendix II

3.1.2 Map Specifications

The maps are divided into three areas:

1. The Tuban Delta at 1:100,000 scale
2. The Abyan Delta at 1:100,000 scale
3. A regional map that includes the two detailed study areas at 1:250,000 scale

In the technical proposal the regional study area was identified as the area bounded by 330000E, 1390000N and 580000E, 1480000N. The base data available to the project including topographic, landuse and geological mapping sources covered from 440000E to 550000E and these extents were adopted for the regional study area. If it is determined that there are important features that lie outside of these horizontal extents, additional interpretation can be conducted using the satellite imagery.

In addition, the technical proposal stated that maps of the detailed study areas would be produced at 1:50,000 scale. Since the majority of the source data was available at 1:100,000 scale it would not be appropriate to view this data at a larger scale.

All of the maps prepared for the Tuban/Abyan area are presented in UTM Zone 38 north, WGS84 projection. For convenience, the UTM and latitude/longitude grids are shown on each map.

All maps were prepared using ESRI's ArcView software. The shape files created by ArcView can be read directly by most spatial database software programs including ILWIS.

3.1.3 Project Personnel

Primarily, the Komex staff working on the remote sensing component of this study have been:

- Wes Macleod – senior remote sensing scientist
- Christine Cadman – remote sensing project coordinator; and
- Lynette Lawlor, cartographer and GIS specialist.

These are the same key personnel indicated in the proposal and inception report.

3.1.4 Topography

Two primary sources of data for the topography were identified. The first was the GTOPO30 data provided by the United States Geological Survey, EROS Data Centre. This data is collected and provided at 1:1 million scale and has global coverage. This data was used only at the beginning of the project as a reconnaissance and planning tool.

The second topographic data source was the 1:100,000 scale paper topographic maps published in Arabic and made available through the Komex Yemen offices. These maps were used to create a digital elevation model for the study area by digitizing the contour lines and incorporating them into a three dimensional model. The scale of these maps is appropriate for producing 30-40 m contours for the entire regional study area. Topographic map numbers used as sources are D-38-114, 115, D-38-102, 103 and D-38-90, 91.

The elevation model covering the two study areas and the surrounding area has been completed and undergone a preliminary review but may still require some edits.

3.1.5 Geology and Geomorphology

The geology and geomorphology themes were interpreted using the 1:100,000 scale maps prepared by the CSSR Geological team and the Department of G.M.E., based on the field work done by these teams in 1983-1987 and published by the Ministry of Energy and Minerals, Department of Geology and Mineral Exploration, Aden. Geology map numbers available were D-38-101, 102, 103, D-38-113, 114, 115 and D-38-91. Note that map number D-38-90, which cover part of the study areas was not available for interpretation. Detailed field verification of the geological information has been carried out by the Komex LPM throughout the project area.

The interpretation and digitizing of these maps has been supervised by a senior Komex geologist/geophysicist familiar with the region. Currently, the geology maps presented in this report are awaiting review and edits and are not considered to be final.

The primary geology of the area is divided up into the following units:

1. Cainozoic – including Tertiary and Quaternary;
2. Mesozoic – including Jurassic and Cretaceous;
3. Paleozoic – including Cambrian to Ordovican; and
4. Proterozoic – including lower and upper designations.

These units have been further subdivided and are shown in detail in the legend accompanying the geology maps.

In addition fault and structure lines were collected based on interpretation of these 1:100,000 source maps and are included on the geology map.

The geomorphology of the study areas is presented on separate maps at this time. This information was interpreted from the 1:100,000 source maps and reviewed by Komex senior geologists. Again, field verification for this interpretation was conducted by the Komex LPM. The primary units presented include the following:

1. Quaternary Sediments;
2. Volcanic Rocks;
3. Mesozoic Sediments;
4. Precambiran Rocks; and
5. Intrusive Rocks and Dykes.

These designations are further divided into categories including dunes, basalts, cherts, limestones and other groups as detailed on the legend accompanying the geomorphology maps.

The interpretation of the geology and geomorphology was completed at a 1:100,000 scale as dictated by the source map scale.

3.1.6 Populated Areas, Transportation and Surface Water

These themes were interpreted primarily from the Landsat imagery and the 1:100,000 scale Yemen topographic basemaps.

The populated areas were identifiable on both the topographic maps and on the Landsat imagery. The Landsat imagery was used to review the populated areas and to update these areas based on new developments apparent on the imagery.

Transportation networks were digitized from both sources, first from the topographic basemaps and then confirmed and updated using the Landsat imagery. The major roads or tracks primarily follow the alignment of the deltas with some connecting roads running through the scantly populated areas.

The wadi channels were digitized primarily from the 1:100,000 scale topographic maps as their visibility on the Landsat imagery was limited. In most cases, the primary wadi channel was digitized, even though some smaller or braided channels may exist. The wadis show up on the Landsat imagery as wash patterns in the ground surface.

In addition, wadi and transportation layers compiled by NWRA for some areas were used in these datasets.

3.1.7 Ground Truthing

Prior to the first progress report, some ground truthing was conducted by Mr. Wes Macleod in the Hadramawt region. During the week of July 23 and July 30, 2001 a supplementary ground truthing session was carried out by Mr. Macleod to verify some of the classifications. In addition, significant ground truthing of geology and geomorphology was carried out by the Komex LPM and the geophysics field crews. Based on accessibility, a number of expected types of land use were identified on the imagery including:

1. Vegetated / non-vegetated;
2. Populated / non-populated;
3. Wadi channel characteristics and features;
4. Individual geology types; and
5. Roads .

The information gathered through the ground truthing session included:

- Location (UTM – GPS coordinates);
- Photos;
- Geological description;
- Population description;
- Vegetation description; and

- Terrain description.

It is anticipated that additional ground-truthing will be conducted to confirm cropping patterns/types and to further classify the populated and/or agricultural areas in this region during the first half of October, 2001.

A complete summary of the field verification, including photos, will be provided with the next report.

3.1.8 Maps and Figures

Draft copies of all maps discussed herein are provided in Appendix II of this report. It is important to note that these maps are preliminary only, and should be considered as works in progress and not as final products. Final versions of these maps and all other deliverables will be provided in the final draft report for the project. The information provided in the interim reports is intended only to provide an indication of progress and project status. Komex fully intends to deliver all map outputs specified as deliverables in the Inception Report.

3.2 STRUCTURAL GEOLOGY SURVEY

Preliminary in-country field reconnaissance has been undertaken by Komex and NWRA staff along all accessible roads along the mountain front north of the Tuban-Abyan plain. These activities were restricted to accessible and traveled roads, as specified in our UN security conditions, and as required based on the presence of mines (see above).

The intention of this work was to both identify access routes to the areas of interest and provide confirmation of existing information. This reconnaissance involved comparison of available geological information with observable exposures. Current information includes that from previous reports on the study area and geological maps at 1:100,000 scale. No observable discrepancies or errors in the available information were noted during field visits. There is a restriction on access to the west of Wadi Tuban in the Al-Anad area due to a large military installation. Some access is possible into this area from further west in the vicinity of Wadi Um Riga' which is still to be investigated. Additional access to areas outside of traveled roads could provide additional geological information. Komex has sent a letter to NWRA and copied to the UN requesting the necessary clearances to allow this work to occur (See Appendix VII). However, the work already completed is sufficient to provide the detail necessary for production of the required output.

Based on the available data and field mapping and verification, a geological structure map has been prepared, and is presented in Appendix IV of this report. In addition, a detailed geological interpretation has been provided in Appendix IV, based on the geophysical surveys and review of available data. In the final reporting period, this information will be used to complete a revised structural interpretation of the project area, linked in with the findings of the other work packages and the modelling results.

3.3 MONITORING NETWORK REHABILITATION

3.3.1 Introduction

The overall Project focuses on strengthening NWRA's capabilities in developing and managing the water resources within the region. The primary objective of this aspect of the project is to enhance and re-develop NWRA's monitoring system in the Tuban-Abyan region, to produce a comprehensive database of the water resources in the region. The aim is to provide essential data for ensuring optimal use of water for resources in the region.

The area encompasses the catchment area of Tuban-Abayan region in its entirety, between the latitude UTM 1390 to 1480 N and Longitude UTM 330 to 580 E. The study area is of a varied subtropical climate. (e.g. minimum temperature of 24°C taken at Jaar meteorological station). The area has three major basins: Wadi Tuban, Wadi Bana and Wadi Hassan, and two small basins: Wadi Suhaibiyah and Wadi Mahriyan. The study area comprises of a plain sloping from the high mountains in the north, towards the Gulf of Aden in the south. Wadi Tuban in the west has its own delta, and is crossed by four wadis, namely Wadi Bana (catchment area of 7260km^2), wadi Suhaibiyah (catchment area 1420 km^2) and wadi Marariah (catchment Area 260Km^2) and Wadi Hassan (catchment area 300 km^2). The upper catchment of these wadis are in the mountains between Taiz and Al-Bayda and in the extension of high ground running parallel to the coast to the north of the coastal plain to the east of Aden. These wadis drain south towards the Gulf of Aden and are important to the agricultural areas of these wadis and delta areas. The continued pressure on groundwater resources demonstrates the increased importance of wadi flow records as they are related to potential recharge changes in the coastal delta.

The primary activities of this phase of the work were as follows:

1. An assessment of the, suitability, consistency and compatibility of the existing hydro-meteorological monitoring network for the collection of relevant data.
2. Compilation of historic data into a GIS-based data management system (ArcView);
3. An appraisal of the selected Wadiflow gauging stations- conducted by Komex and NWRA, together with their design, cost estimates, and equipment requirements for installation for further network enhancement.
4. A commitment to standardizing procedures for sampling and monitoring so that the output data format for all monitoring programs in the region, carried out by all organizations, are consistent with the NWRA information systems: and,
5. Development of specifications for the installation new wadi flow and precipitation monitoring and recording stations, in order to obtain a comprehensive operational monitoring network for the collection of hydrological, climatological and groundwater data according to the well-established standards.
6. Preliminary review of the existing groundwater monitoring program being conducted by NWRA, and preliminary conceptualisation of future requirements for groundwater monitoring.

3.3.2 Data Collection and Compilation

The second stage consisted of mapping and field reconnaissance of the selected catchments in the project areas in order to select positions and identify the necessary equipment requirements for the proposed wadi flow and rainfall gauging stations. Komex and a team of NWRA personnel carried out selection of the gauging sites. (This was done by extensive site reconnaissance of old Wadi flow gauging stations, many of which were washed away during flooding in 1989). It was recognized that site location should be chosen so as to draw upon work carried out by other organizations and past studies, rather than repeating or duplicating the work. Selection of the sites was made from an analysis of field survey information, with the co-operation between interested parties, and by review of secondary information from previous projects. The stages of this review are identified below:

1. An assessment of the secondary information focusing in particular on the period of record, the quality assurance practices used for the collection of data, and their value to the project.
2. A review of the proposed water monitoring plans for the region.
3. An assessment of the quantity of surface waters.
4. An assessment of surface water monitoring and sampling.
5. An assessment of portable and in-situ monitoring methods.
6. An assessment of the general water balance for each of the main catchment basins.
7. An assessment of the quality of the surface water in terms of its potential use for drinking, agriculture and industry.
8. An evaluation of statistical trends in the groundwater levels and groundwater quality.
9. Development of a table showing geographical co-ordinates of all newly proposed monitoring stations (Rainfall and Wadiflow) with at least 50m field accuracy.

Onsite survey work on each gauging station included:

1. The determination of each newly proposed monitoring station co-ordinates, a site plan and five x-stations across a reach of 200-300m long and the longitudinal profile connecting the lowest points of the five x-stations.
2. Development of technical concepts for design of gauging stations.
3. Calculation of the Roughness Coefficient from Manning's formula coefficient.
4. Calculation of catchment characteristics: Area (km^2), elevations of highest and lowest points (m).

3.3.3 Secondary Data Analysis

All available historic hydrometeorological information has now been entered from the available reports into spreadsheets, and is currently in the process of being converted to GIS-based data files. At the time of writing (August, 2001), a CD of data from NWRA containing data from the on-going monitoring network had just been received, but has not yet been reviewed. It is anticipated that the data contained in this database will be merged with information entered from reports to create a master database of water-related information for the Tuban-Abyan Region.

3.3.4 Wadi Flow Gauging and Precipitation Stations

The following sections present a brief summary of the flow and precipitation gauging stations. The proposed network is presented in Figure 1.

3.3.4.1 Wadi flow

Discontinued Flow Monitoring Stations

There are a number of non-operational flow stations that currently exist within the basin. This is mainly as a due to the fact many stations were washed away during flooding in 1989. On inspection of the old Wadi stations it was decided to repair the Dukeim Wadi flow Station, (Wadi Tuban). All other sites are to be newly constructed, (see Table B).

Existing Flow Monitoring Stations

Existing flow monitoring stations are presented in Table A and Table B.

Table A: Existing Wadiflow Station Sites – Abyan Project Implementation Unit

(Equipment provided by the Land and Water Conservation Project (LWCP)

Station name	Wadi	Lat.	Long.	Type		
				Automatic	Staff gage*	Cable way
Fouad Dam**	Wadi Ahwar	13' 42"	46' 41"	1		
Ahwar	Wadi Ahwar	13' 42"	46' 30"	1		
Am Fara'ah	Wadi Wajr	13' 53"	46' 09"	1		
Al-Halawah	Wadi Maran	13' 52"	46' 06"	1		
Al-Diou dam***	Wadi Bana	13' 13"	45' 16"		1	
Al-Rowdah	Wadi Hassan	13' 29"	44' 36"		1	
Mayfa'ah	Wadi Mayfa'ah	13' 17"	47' 31"	1		
Hajr	Wadi Hajr	14' 16"	48' 34"	1		
Al-Sadarah	Wadi Al Sadarah	14' 30"	48' 05"	1		
Baties Dam***	Wadi Bana	13' 21"	45' 18"		1	
Hayrat/Uruq	Wadi Bana			1		1
Sub Total				8	3	1

Equipment provided by the Land and Water Conservation Project (LWCP)

* One staff gauge = 3.3 meters

** Fouad dam : Three staff gauges i.e. One with water level recorder and two at the gates

*** Diou dam : Two staff gauges at the diversion gates

**** Baties dam : Four staff gauges i.e. One with the existing water level chart recorder, two on the main Wadi and one on the main canal

Table B: Existing Wadiflow Station Sites – LahIj Project Implementation Unit

(Equipment provided by the Land and Water Conservation Project (LWCP)

STATION NAME	Wadi	Lat.	Long.	Type		
				Automatic	Staff gage*	Cable way
Aqqan	Wadi Aqqan	13° 22′	44° 38′	1		
Sabaa dam**	Wadi Rabwa	13° 31′	44° 51′	1		
Howareb	Wadi Timnan	12° 46′	44° 03′	1		
Al Khatabia	Wadi Maaden	13° 03′	44° 22′	1		
Faleg Dam	Wadi Al Kebir	13° 06′	44° 51′		1	
Baysag dam***	Wadi Al Seghir	13° 07′	44° 51′	1		
Dukeim	Wadi Tuban	13° 16′	44° 46′			1
Total				5	1	1

* One staff gauge: 3.3 meters

** Sabaa dam: 5 staff gauges are needed i.e. One with automatic water –level recorder and four staff gauges at the distribution gates of the dam.

*** Baysag Dam: four staff gauges are needed i.e. One with automatic water level recorder U/S the dam and three at the dam

Figure 1: Proposed New Flow and Precipitation Monitoring Network.

Figure 1 can be found under the figure tab following the main report text.

3.3.4.2 Proposed hydrometeorological network flow monitoring stations

In addition to the analysis of secondary data it has been proposed that three gauging stations are replaced/rebuilt (as shown in Table C: Proposed Hydrometeorological Network Stations (NWRA- Komex 2001)

1. Reconstruction of the station at Dukeim, in Wadi Tuban,
2. Replacement of the existing station at Bateis, in Wadi Bana, and;
3. Replacement of a station at Jol-Yaramis, in Wadi Hassan

The gauges were located to maximize the measured catchment area. Previously established wadi flow gauging stations on these three Wadis have significant gaps in the period of records and like the rest of the region there is no continuous record. Wadi sediment data also does not exist which is necessary to provide information on the amount of suspended and/or bed load sediments. A good number of rain gauges are currently operating in the delta area, however, there are few in the sparsely populated areas of the upper reaches of the Wadi. These stations supplement the existing gauging network, and to provide rainfall information in the upper part of the catchment. The proposed rain gauge instrument is the SIAP 8150, a tipping-bucket type gauge with a chart-recorder[1]. This gauge is already in use by NWRA in a number of locations.

[1] for details, see the SIAP web site, http://www.admaiora.uni.it/SIAP/eng/str_prec.htm).

Table C: **Proposed Hydrometeorological Network Stations (NWRA- Komex 2001)**

WADI NAME	LOCATION	COORDINATES				STATION TYPE	ALTITUDE (m)
		UTM-N	UTM-E	LAT-N	LONG-E		
Wadi Tuban	Dukeim	1469314	470665	13° 17' 27"	44° 43' 45"	Wadi flow Gauging*	400 – 3119
	Al-Dala'a	1515057	470644	13° 42' 16"	44° 43' 42"	Recording Rain gauge	
	Jiblah	1534997	405457	13° 53' 00"	44° 07' 30"	Recording Rain gauge	
Wadi Bana	Bateis	1478469	529987	13° 22' 25"	45° 16' 37"	Wadi flow Gauging*	180 - 3180
	Damt	1558965	464109	14° 06' 05"	44° 40' 03"	Recording Rain gauge	
	Labus	1533722	525010	13° 52' 20"	44° 15' 00"	Recording Rain gauge	
	Al-Taffah	1571165	534749	14° 12' 40"	44° 22' 30"	Recording Rain gauge	
Wadi Hassan	Jol-Yaramis	1486644	552018	13° 26' 50"	45° 28' 50"	Wadi flow Gauging*	360 – 2250
	Mukayras	1540639	572316	13° 56' 06"	45° 40' 10"	Recording Rain gauge	

*Note: all flow monitoring stations to consist of water level recorder, cross sectional staff and crest gauges

Komex, NWRA, and WHADP staff used the following criteria to select the site locations and equipment:

(i) Purpose (ii) Control characteristics, (iii) Measuring conditions, (iv) Structures, (v) Accessibility, and (vi) Economics. More information on these criteria is presented in Appendix II, including le a detailed discussion of selection criteria for each of the sites.

In an attempt to generalize and standardize the equipment between installations, the gauges are to be constructed with the following specifications:

- Stilling well of metal pipe (18" diameter) with adequate cleanout/inspection door, steel box to house/ shelter the water level recorder and intake pipes of galvanized steel;

Type A, Model 71, Water level recorder (see specification in Appendix II)

- Natural control;
- Primary and auxiliary staff gauges and steel supports;
- Crest gauges; and,
- Concrete footings, and anchors;

It is suggested that a mobile ladder be taken from the office to the field every time the station is visited. An aluminum or steel ladder of sufficient height to reach the water – level recorder

Specifications and design drawings for the gauges are presented in Drawings 1-27. Lists of materials, construction requirements, and costs are presented in Appendix III.

3.3.5 Precipitation

3.3.5.1 Historic gauges

Data provided from past projects and historic gauges was collected in the early stages of the project, and is currently being incorporated into the ArcView GIS. The aim is to produce a comprehensive picture for the region.

3.3.5.2 Existing precipitation gauges

There are fourteen operational recording rain gauges in the Tuban-Abyan Region, (sixteen in total) all of which are the responsibility of the NWRA's hydrological department. This includes a meteorological station in Saber / Lahij, and Ja'ar that are operated and maintained by CAMA. In addition there are eleven meteorological station sites in Abyan provided and operated by LWCP, these stations are shown in Table C. Most of the locations are concentrated around the southern parts of the region, where annual precipitation is low. Few exist in the upper part of the side Wadis, where much of the runoff is generated. Data from these stations is shared with the NWRA hydrological department. Figure 2 identifies the type of station and its coordinates.

Table D: Existing Tuban – Abyan Regional Study Rainfall Monitoring Network (2001)

Station Name	COORDINATES				Altitude (m)	Date Installed	Type of Station & Remarks
	UTM N	UTM E	LAT N	LONG N			
Lahj-Saber	1437848	490586	13° 23' 14"	44° 54' 48"			Meteorological including Automatic Recording Tipping Bucket Rain Gauge, Max. & Min Wind Speed, Wind direction, Solar Radiation, Humidity Recorder, Max. & Min Temp. There is no evaporation pan
Jaar	1463210	534480	13° 14' 8"	45° 19' 06"	76	Mar-97	As above
Al-Husun	1471500	532000	13° 20' 16"	45° 17' 44"	125	Mar-97	Manual / Daily Rain Gauge, Abyan Delta
Rusud	1502131	531528	13° 35' 15"	45° 17' 29"	1000	May-97	Manual / Daily Rain Gauge, Wadi Hassan
Moqcifia'a	1519674	572036	13° 44' 44"	45° 39' 59"	745		Manual / Daily Rain Gauge, wadi Hassan
Jol-Yaramis	1483824	550756	13° 25' 18"	45° 28' 08"		May-97	Manual / Daily Rain Gauge, wadi Hassan
Al-Habeelain	1495958	483661	13° 31' 55"	44° 50' 56"		Jul-98	Automatic Tipping Bucket Recording Rain Gauge, Wadi Suhaibiah / Wadi Tuban
Harad	1473901	444270	13° 19' 55"	44° 29' 08"		Jul-98	Automatic Tipping Bucket Rain Gauge, Wadi Tuban
Al-Dala'a	1515057	470644	13° 42' 16"	44° 43' 43"		Jul-98	Automatic Recording Tipping Bucket Rain Gauge, Not Operational, wadi Suhaibia / Wadi Tuban
Oresima	1494985	438255	13° 31' 21"	44° 25' 46"		Jul-98	Automatic Recording Tipping Bucket Rain Gauge, Wadi Tuban
Well No.256	1452177	536671	13° 08' 09"	45° 20' 18"	34	May-97	Automatic Recording Tipping Bucket Rain Gauge, Not Operational, Abyan Delta
NWSA 530 NL	1472537	534342	13° 19' 12"	45° 19' 02"	138	Mar-97	Automatic Recording Tipping Bucket Rain Gauge, Abyan Delta
Well No. 188	1467413	535606	13° 16' 25"	45° 19' 44"	100	Mar-97	Automatic Recording Tipping Backet Rain Gauge, Abyan Dalta
Well No. WRAY – 10	1456587	537324	13° 10' 35"	45° 20' 40"	30	May-97	Automatic Recording Tipping Backet Rain Gauge, Abyan Dalta
Warazan	1483321	417618	13° 24' 59"	44° 14' 21"		Jul-98	Automatic Recording Tipping Backet Rain Gauge, wadi Tuban
Bulan	1484000	398099	13° 25' 19"	44° 03' 32"		Jul-98	Automatic Recording Tipping Backet Rain Gauge, wadi Tuban
Bateis	1477088	531282	13° 21' 40"	45° 17' 20"			Waditlow Gauging Station wadi Bana
Dukeim	1470150	471150	13° 17' 54"	44° 44' 01"			Wadiflow Gauging Station, wadi Tuban
Jol-Yaramis	1486429	551821	13° 26' 43"	45° 28' 44"	274	May-97	Wadiflow Gauging Station, Not Operational, wadi Hassan

Table E: Existing Meteorological station sites- Abyan Project Implementation Unit.

Equipment provided by the Land and Water Conservation Project (LWCP)

Station name	Lat.	Long.	Type of Raingauge		
			Automatic	Manual	Meteo
Ahwar	13° 31'	46° 43'	1		
Al-Kawd (AREA)	13° 05'	45° 22'			1
Mawdiya	13° 56'	46° 05'		1	
Lawdar	13° 53'	45° 52'		1	
Moqayras	14° 01'	45° 40'	1		
Al –Khobar	14° 09'	47° 04'			1
Juban	14° 01'	44° 53'			1
Al –Saddah	14° 07'	44° 25'	1		
Al –Mahfad	14° 04'	46° 55'		1	
Al –Mahjalah	13° 58'	46° 27'		1	
Al –Khabr	13° 26'	46° 10'			
Total			3	4	3

3.3.6 Groundwater Monitoring Review

Based on the final results of the hydrochemical sampling program, discussed below, and a detailed review of the current NWRA groundwater monitoring program (Now underway), a detailed review of groundwater monitoring requirements in the project areas will be completed. This work has started in the beginning of September, and will be presented in the final report.

The project to date has revealed that the shallow aquifers presently being used in the project areas are vulnerable to groundwater contamination. Indeed, our work has shown that it is extremely likely that significant pollution of the shallow alluvial aquifers has occurred and is occurring at present. Anecdotal evidence indicates that waste management practices harmful to groundwater are widespread in the area, including:

- Disposal of sewage into holes dug in alluvium to the water table,
- Widespread use of old water wells in the alluvium as disposal points for sewage;
- Disposal of car-wash liquids and wastewater into old water wells and pits dug to the groundwater surface,
- Unrestricted dumping of waste oils and fuels;
- Unrestricted and unprotected landfill and rubbish tipping operations atop vulnerable aquifers;
- Operation of many petrol service stations throughout the are, which are not properly maintained, tanks not inspected. American Petroleum Institute data would suggest that under these conditions, it is statistically likely that as many as 75% of existing service stations are leaking fuel to the groundwater;

It is our view that the issue of groundwater contamination will emerge as one of the most important water resource issues in the project area. To date, the situation has been masked because of:

- Lack of proper monitoring for parameters indicative of groundwater pollution, particularly common bacteriological and organic contaminants.
- Lack of basic understanding within the regulatory and monitoring communities of the importance of these issues;
- Lack of reporting mechanisms for well owners and farmers to report water contamination to NWRA;
- Lack of understanding of the issues within the user community;
- Lack of knowledge of the long term health effect of exposure to common groundwater contaminants likely to be present in the shallow aquifers in the area;

On this basis, groundwater pollution monitoring will form a key part of the final recommended groundwater monitoring program for the project area, and will include:

- Analysis for routine parameters indicative of groundwater pollution;
- Focused efforts to monitor well close to and down-hydraulic-gradient of suspected or potential sources of groundwater pollution;
- Increased training of NWRA staff on groundwater pollution behaviour and monitoring;
- Development of a laboratory capability in Yemen for analysis of selected organic contaminants such as aromatic hydrocarbons, and other GC-MS parameters.
- Monitoring for thickness of light non-aqueous phase liquids (LNAPL) as part of standard monitoring procedures;
- Development of institutional mechanisms which will allow NWRA to respond to the appearance in monitoring data of evidence of groundwater contamination.

3.3.7 Future Work

Future work on the monitoring network will focus on the compilation and analysis of historic data, and incorporation of these data into a GIS-based hydrologic modelling package, and the construction and monitoring of the Hydrometeorological stations (NWRA responsibility, not within the scope of the Komex contract).

3.3.8 List of Documentation Collected to Date

1. **WS Atkins and Partners** (1984) Feasibility Study for Wadi Bana and Abyan Delta Development Project, Volumes 1 (Main Report), 2 (Hydrology and Water Resources), 3 (Engineering) and 4 (Soils, Agriculture, Agricultural Economics and Project Evaluation)

2. **General Department of Hydrology** and TNO (1990-95) Water Resources Assessment Yemen, Abyan Delta, Volumes 34 (Main report), 34.1 (Well Inventory), 34.2 (Geophysical Investigations and Exploratory Drilling), 34.3 (Pumping Tests), 34.4 (Surface Water), 35

3. AM Kheir (1996) **Baseline survey for Water Resources Management** in Abyan Delta, NWRA Aden

4. AM Kheir (1997) **Analysis of Monitoring Network Data**, Groundwater quality, Abyan Delta, NWRA Aden

5. AM Kheir (1998) **Analysis of Monitoring Network Data, Rainfall, Surface** water, and **Groundwater levels, Abyan Delta, NWRA Aden**

6. NWRA Aden (1997) **Analysis of Well Inventory Data, Abyan Delta**

7. VH Mudallal (1999) **Review of the previous Hydrogeological Studies and Reports**, Abyan **Delta Area**

8. WS Binnie and Partners **Ltd (1987) Wadi Hadramawt Agricultural Development Project Phase III, Feasibility Study for Long Term Wadi Rehabilitation – Draft Final Report** Vol IV: **Wadi Hassan and Mudia Region**

9. F Salmin and M Jaafar **(1998) Analysis of Monitoring Network Data: Abyan Delta and Wadi Tuban Basin, NWRA Aden**

10. VH Mudallal (2000) **Aden/Abyan Regional Water Resources Management Plan (Aden, Abyan and Lahj Governorates)**

11. VS Rybbakov (2000) **Hydrogeological Evaluation for the Preparation of a Water Resources Management Plan in the Tuban-Abyan Region, Final Draft, Mission Report**

12. F Salmin and M Jaafar **(under preparation) Analysis of Monitoring Network Data: Abyan Delta and Wadi Tuban Basin, NWRA Aden**

13. TNO-Delft (1989) **Water Resources Assessment Yemen, Hydrogeological Networks, Automatic Meteorological Stations, Volume 14.4 (Manual)**

14. TNO – delft (1995) **the Water Resources of Yemen – A summary and digest of Available Information, Report WRAY – 35, Ministry of Oil and Mineral Resources, Yemen**

15. Italconsult (1974) **Soil and Water Utilization and Conservation in the Wadi Tuban Watershed Area, Volume 1 (Conservation of the Irrigation Systems), Volume 2 (Hydrological Report including Well Inventory and Observation and Monitoring Wells)**

16. Groundwater Development **Consultants (1981) Wadi Tuban Water Management Study, Operation Manual, Final Report**

17. NWRA Aden (1997) **Rehabilitation of Well No. 20 in the Upper Tuban Delta (in Arabic)**

18. TL Kinski (1983) **Yemen Surface Water, Final Report Part II**

19. Hunting Geology and Geophysics **Ltd (1983) Proposal for Satellite mapping and Airborne Geophysical Surveys, Yemen Joint Project for Natural Resources**

20. Robertson Group Plc **(1992) The Natural Resources Project – Satellite Mapping**

21. Geological Consulting Company (1992) Explanatory Note to the Potential Exploitational Groundwater Resources Map 1:500,000, International Academy of Sciences, Russia, and Geological Survey Authority and Ministry of Oil and Mineral Resources, Yemen

22. Geological Consulting Company (1995) Groundwater Resources Available for Development Map 1:500,000, International Academy of Sciences, Russia, and Geological Survey Authority and Ministry of Oil and Mineral Resources, Yemen

23. Explanatory Note to the Hydrogeological Map of the Southern Part of the Republic of Yemen 1:500,000, Hydrogeological Map and Groundwater Points Catalogue (1992).

24. G Ainsworth (1992) Groundwater Resources of the Southern Governorates, UNDP/NU DESD Project Yem/88/001, Hydrological Services International

25. A Shihap and A Ahmed (2000) **Agro and Hydro-meteorological Network, Land and Water Conservation Project, UTF/Yem/024, MAI**

26. M Tayaa (1999) Yemen **Hydrometeorological Network – Selection of Hydrometeorological Stations Sites, FAO, UTF/Yem/024, MAI**

27. Sir Mott MacDonald and Partners **Ltd (1986) Greater Aden Water Supply, Final Report,** Volume 1

28. SM Mirza (1983) **Wadi Tuban Agricultural Development Project, Annual Progress Report, FAO, UTFN/PDY/005**

29. Technical Secretariat of the High **Water Council (1994) Water Resources Management – Analysis in the Abyan Delta, A Methodological Framework, UNDP UN DDMS Yem/92/056**

30. Ministry of Agriculture **and Agrarian Reform (1988) Scheme of Irrigation Development at Bateis and Hajja Command, Volume 1 (Natural Conditions), Book 1 (Explanatory Report)**

31. Chilton PJ (1980) Hydrogeology **of the Mountain Plains, Yemen Arab Republic, ODA**

32. VS Rybakov et al (1995) Groundwater Resources Available for Development, International Academy of Sciences, Russia, and Geological Survey Authority and Ministry of Oil and Mineral Resources, Yemen

3.4 GEOPHYSICAL SURVEY PROGRAMME

This interim report provides information on the progress up to September 1, 2001, in the geophysical program. A detailed description of all activities, methods, staff utilisation, and outputs is provided in Appendix IV. However, please note that all information and data presented here are PRELIMINARY, and are still subject to on-going detailed evaluation and processing over the coming weeks.

3.4.1 Objectives

The aim of the preliminary phase of the geophysical program was as follows:

- Gather existing geophysical and geological data for the Tuban/Abyan region
- Build on existing models for the hydrogeology of the region
- Design field program to gather new data and improve understanding of the hydrogeology of the region.
- Investigate saltwater intrusion from the coast

3.4.2 Data Gathering From Existing Studies

All available sources of existing data are being investigated. These include data sources from Yemen, and the Europe. The primary sources of information have been previous groundwater investigations in the two regions including:

1. Water Resources Assessment Yemen (WRAY) report 1995, General Department of Hydrogeology (Yemen), TNO Institute of Applied Geoscience, (Netherlands). Over 150 1D resistivity soundings were made in the Abyan Delta.
2. Abyan Delta Project 1972, Ministry of Agriculture and Agrarian Reform, The Peoples Democratic Republic of Yemen.
3. Wadi Tuban Water Management Study 1981, Groundwater Development Consultants International Ltd., U.K.
4. Greater Aden Water Supply Project 1986, John Taylor and Sons Consulting Civil Engineers. Upper Abyan Delta Drilling and Wellfield Design.
5. Geological Map of the Republic of Yemen 1996, BGR, Germany.

The Landsat 7 TM scene acquired as part of the project is currently being used to build a bedrock and structural geological map of the upper reaches of each wadi and delta. The Landsat image is also useful in mapping recent sediments within the delta.

Seismic Data

Seismic lines were shot in the project study area, based on information obtained during the data review. However, Komex has not been able to access this data. A detailed discussion of attempts made to secure these data is provided in Appendix VII. In recent meetings, NWRA have pledged to assist Komex in obtaining these data, which could provide significant additional data for the project. However, it should be noted that the seismic is likely very old, and even if obtained, the tapes may not still be readable. In Appendix IV, please find correspondence from Komex to NWRA indicating that if these tapes could be accessed, Komex would do its utmost to read and recover these data for incorporation into the report.

Literature Review

An extensive literature review was undertaken by Andrew Hinnell. This review included visits to the libraries at NWRA, NWSA, Yemen Geological Survey, and Southern Governance Agriculture Authority.

The following is a list of references located. They have either been copied or copies have been requested. Most of these reports do no include the actual geophysical data, but refer to data collected during the preparation of the report. There are significant numbers of geophysical logs in these reports.

- Report: GHD and TNO, Water Resources Abyan Delta, Main Report (34 - 1995), Well Inventory (34.1 - 1994), Geophysical Investigation and Exploratory Drilling (34.2 - 1990), Pumping Tests (34.3 - 1994) and Surface Water (34.4 - 1994).

- Report: Italconsult, Soil and Water Utilisation and Conservation in the Wadi Tuban Watershed Area, Volume 1 and Appendices

The following reports of geophysical significance have been requested from various sources, but have not yet been obtained:

- 1:5,000,000 Structural geology map including the Tuban Abyan area
- 1:100,000 Russian geological maps – Sheets D38-91, D38-101, D38-102, D38-103, D38-113, D38-114, and D38-115
- Complete report "Natural Resources Project – Fixed Wing High Sensitivity Aeromagnetic Survey, Technical Report" including 1:250,000 scale maps
- 1:100,000 scale Aeromagnetic survey maps for sheets 12G, 12H, 13G and 13H
- Report: Sir Mott Macdonald and Partners Ltd, Greater Aden Water Supply, Groundwater Volume 1, November 1986
- Report: Sir Mott Macdonald and Partners Ltd, Greater Aden Water Supply, Final Report Volume 1 Report, November 1986
- Report: Sir Mott Macdonald and Partners Ltd, Greater Aden Water Supply, Draft Final Report Volume 2 Appendices, April 1986
- Report: John Taylor and Sons, Greater Aden Water Supply Project, First Stage: Final Report on the Upper Abyan Delta Drilling and Upper Abyan Wellfield Design, Volume 1 - Report and Volume 2 - Appendices.

3.4.3 Field Program

During the 2001 geophysics field program in the Tuban/Abyan Deltas, two different types of data were gathered: Natural Gamma Logging and Electrical Resistivity Tomography (ERT) data. ERT data was collected on 11 different lines for a total of 11.4 km in the Abyan Delta, and 22.8 km in the Tuban Delta. Natural gamma logging was completed at 11 different wells in the Tuban Delta area. Table 1, Appendix IV summarizes the ERT data that was collected, and Table 2 summarizes the logging data that was collected. Completed Field Notes from the field program are detailed in Appendix IV.

The Komex field crew was composed of three Canadian Geophysicists, one Canadian Geophysical Technician, three Yemeni laborers and twelve NWRA Geoscientists. The Yemeni field crew quickly acquired competence in 2-D ERT, both from a practical aspect in the field, and from a theoretical aspect through evening lectures on the subject. This greatly aided the success of the project. Completed ERT cross-sections can be found in Appendix IV.

Additional logging data was collected from two other sources. The 1986 report by John Taylor and Sons, Consulting Civil Engineers, contains lithology, resistivity, spontaneous potential, and natural gamma information on the Upper Abyan Wellfield. The 1990/1991 work reports by the China State Construction Engineering Corporation contains self-potential, long-normal and short-normal resistivity, and lithology information on the Bir Ahmed Wellfield (wells numbered 15 - 22) and the Upper Tuban Wellfield. Table 2, Appendix IV summarizes the additional logging data that was compiled by the Komex field crew. Complete geophysical borehole logs with lithology can be found in Appendix IV.

Lastly, 1-D soundings were acquired in both digital and hard copy from the 1995 WRAY report. A total of 145 soundings were collected (Figure 3, Appendix IV).

It may be noted that Komex was unable to collect the required amount of data in both areas. It is a policy of Komex not to put any of its field crew into harmful or inherently unsafe situations. In addition, Komex will not deploy field crews if corporate liability is deemed unnecessarily high. With these criteria, it considered the threat of land mines in the Tuban/Abyan Deltas as an unacceptable working environment. As a result, Komex did all available ERT lines in areas that were cleared of land mines and that were suitable for large cable ERT. The delays and uncertainties with the presence of mines, and the elongated travel times and restrictions on laying of cables severely restricted operations, and made operations last significantly longer than expected. This is discussed in more detail above, in the section on Mine Safety.

3.4.4 Geophysical Results – Abyan Delta

Geoelectric cross-sections are compiled for the Abyan Delta from two different sources: WRAY 1-D resistivity soundings (1995) and 2-D ERT Cross-Sections (Komex, 2001). Analysis of these data indicate a geological model with three layers. These layers are the quaternary alluvium, sandstone, and bedrock.

The quaternary alluvium is composed of sand and silt. It is present over the entire delta, thickening slightly towards the coast. This layer is potential aquifer material.

Beneath the quaternary alluvium, a layer of sandstone is present in much of the delta. This sandstone layer is most likely Arkosic sandstone in the upper part, and Tawilah (Mukalla) sandstone in the lower part. The Arkosic sandstone was first identified in the WRAY report (1995) by drilling two exploratory drill holes. The first drill hole reached a hard and resistant formation after 26 m. Initially, it was thought to be bedrock, but after careful analysis it was found to be Arkosic sandstone. A second exploratory drill hole hit Arkosic sandstone 108 m below ground surface. Drilling continued to a depth of 250 m below ground surface, not having reached the base of the Arkosic sandstone. The boundary between the Arkosic sandstone and the Mukalla sandstone could not be identified. This layer is also potential aquifer material.

Finally, a third layer of basement rock is present in the northern parts of the delta. This layer is composed of crystalline basement rocks or younger, highly consolidated formations, and is present in the northern part of the delta.

From the resistivity values, the distribution of saline or brackish groundwater can be derived. Low resistivity values were found in the lower part of the delta, in the south, east and west. This corresponds to saline or brackish groundwater, which is present up to 15 km from the coast.

Various composite geoelectric cross-sections (draft) are provided in Appendix IV.

3.4.5 Results – Tuban Delta

Interpreted cross-sections are compiled in the Tuban Delta from three different sources: well logs from the China State Construction Engineering Corporation (1991), Gamma Logs (Komex, 2001) and 2-D ERT Cross-Sections (Komex, 2001). Analyses of these data indicate a geological model with three layers, namely the quaternary alluvium, alluvial deposits, and bedrock.

Quaternary alluvium is present throughout the delta and is composed of silt and sand, with clay and gravel present in some areas. In the central part of the delta, silt with sand and gravel lenses is present. These sand lenses are possible paleo-wadi channels, as well as potential aquifer material.

Next, a layer of alluvial deposits is present. These are composed of cemented silts and clays with gravel and sand. Geophysical investigations for this project could not follow the base of the alluvia in the central and southern part of the delta, because of the great depths involved (in excess of 400 m).

The Italconsult Report (1975) stated that an exploratory drill hole was drilled by B.P. Oil to a depth of 755 m without basement rock being reached. In addition, the alluvial cover exceeding 500 m in thickness appears to be quite uniform laterally (west-east), and has good-water bearing characteristics, even at a considerable distance from the present wadi alignments. Pursuant to this, Komex discovered two targets west of the study area in the central zone of the delta. These targets (specifically, the most western one) have high resistivities, making it highly unprobable that they contain saline or brackish ground water, but rather, fresh water. These targets are potential aquifer material.

From the resistivity values, the distribution of saline or brackish groundwater can be derived. Low resistivity values were found in the lower part of the delta, specifically in the south. In addition, brackish groundwater was detected at depth (300 m to 400 m below ground surface) in the central part of the delta.

Various geophysical cross sections (Draft) are provided in Appendix IV, along with detailed interpretation.

3.4.6 Preliminary Conclusions

The conclusions of the geophysical work cover several different topics including geology, geochemistry, hydrogeology, and data visualization. Each of these subjects will be covered in turn as the results of the geophysical data gathering are synthesized into a cohesive interpretation of the subsurface of the Tuban and Abyan Deltas. Conclusions are discussed in greater detail in Appendix IV.

Geology

From the work done in the Tuban and Abyan Deltas, the subsurface geology is interpreted to a depth of 400 m.

In the Abyan Delta, the geophysical program mapped three different geological strata. These strata are the quaternary alluvium, sandstone, and the bedrock. In general, the quaternary alluvium thickens towards the coast, and is mainly composed of sands and silts. The sandstone appeared throughout the Abyan Delta. It is most likely the Arkosic sandstone in the upper part, and Tawilah sandstone in the deeper strata. The boundary between the Mukallah sandstone and the Arkosic sandstone could not be visualized due to the similarities in resistivity of the two materials. The bedrock appeared in the north of both the Abyan Delta and the Tuban Delta.

In the Tuban Delta, the geophysical program mapped three different geological strata. These layers are the quaternary alluvium, alluvial deposits, and bedrock. The quaternary alluvium overlies cemented alluvial deposits, and is excellent aquifer material. The cemented alluvial deposits are silt and clay. The bedrock is only visible in the northern part of the delta, and underlies the alluvial deposits.

Geochemistry

From a geochemical point of view, the geophysical program in the Tuban/Abyan Deltas is successful in mapping the relative changes in the salinity of the groundwater.

In the Lower Abyan Delta, brackish to saline groundwater is found encroaching from the south, east and west, up to a distance of 15 km from the coast. In the Tuban Delta, saline groundwater is present up to 5 km from the coast and brackish groundwater up to 20 km.

Hydrogeology

From a hydrogeological point of view, the geophysical program in the Tuban/Abyan Deltas is successful in delineating possible aquifers. Potential aquifer materials are interpreted in many of the cross-sections. The material includes sandstones, sand and silt deposits, and gravel and sand deposits. The sand, gravel and silt deposits generally occurred at a depth of between 50 - 200 m below ground surface. The sandstone is present in the northern Abyan Delta between 50 and 300 m below ground level. In addition, two potential aquifer targets were discovered outside the study area at the western end of the central zone in the Tuban Delta.

Data Visualization

By combining the geophysical data gathered in the Tuban/Abyan Deltas with remote sensing data, a 3D data management visualization system is created. The system is created using a software package called Arcview. The system allows the graphical integration of the geophysical data sets with the geological, remote sensing, cultural and infrastructure data. As the hydrogeological and hydrogeochemical data becomes available, it will be integrated with the system as well. This system will be included in the final report.

3.5 HYDROCHEMICAL STUDY

3.5.1 Data Collection

The major data collection activities for this work component have been undertaken during this reporting period. In addition to field data acquisition, Komex and NWRA staff have been collecting historic hydrochemical studies and data for the study area, accessing NWRA hydrochemistry records, and parameter levels from municipal supply well-fields for the previous 10 years have been obtained from the National Water Supply Authority (NWSA).

3.5.2 Well Sampling

Hydrochemical sampling as proposed in the Technical Proposal stated that Komex would seek wells with known construction and installed pumps for sampling. With NWRA having data from 3 consecutive years of sampling some 30 wells in the study area, and additional data from one year for at least another 35 wells, re-sampling from at least some of these wells was imperative. When the uncertain nature of the mine risk was identified, Komex chose to sample all of these wells for this study as access safety could be guaranteed. Maps of the sampling locations are presented in Figure 1 and 2. All data available to date in the program is presented in Appendix V.

Field data collection has been undertaken by Komex's subcontractor, Ghayth Aquatech, as identified in the approved Inception Report. Pre-testing analytical work was required to prove that Ghayth's laboratory quality assurance and quality control program would be successful in identifying sample parameters with the required accuracy and precision.

3.5.3 Training and Quality Control

A detailed QA-QC program was developed by Komex for Ghayth to follow, under the funding provided by CIDA-INC as a supplement to this project. These funds have been used to provide additional training and capacity development to NWRA and the private sector in Yemen, in support of this project. This additional contribution by CIDA-INC comes with a requirement of matching funds from Komex, and is described in Komex's correspondence to NWRA and

UNDESA of September 4, 2001, included in Appendix V.

Data from bottle washing and accuracy/precision testing is included in Appendix V. A description of the significance of these results was not available in time for this report, but will be included in the draft final report.

3.5.4 Field Program

Full details of the actual field practice will be included in the draft final report. Sample collection methods and sample holding times were required to comply with United States Environmental Protection Authority protocols or those of the analytical instrument manufacturer. Field parameters were collected at the time and location of sampling, and data was collected about the well where possible. Some analysis of field measured parameters was calibrated in the field to ensure reliable data collection. Field data sheets including calibration data are presented in Appendix IV.

Analytical techniques used by Ghayth comply with either the requirements of APHA Standard Methods (17^{th} Edition) or those of the analytical instrument manufacturer. Summary laboratory analytical results are presented in Appendix V as a table.

3.5.5 Additional Sampling

Additional samples are still to be taken for a small subset of sites and a range of parameters unable to currently be analysed within Yemen: hydrocarbons and trace elements. In addition some bacteriological analyses will also be conducted in Yemen.

Following analysis of the existing hydrochemical data, the data collected by this field program and consideration of known and suspected sources of contamination; sites will be selected for additional sampling. Once collected according to the appropriate methods the samples will be flown to an out-of-country laboratory for analysis within the required holding times. These samples ill be collected in the final reporting period and will be shipped to an accredited lab in the UK for analysis.

3.5.6 Pollution and Aquifer Vulnerability

This section of the report is directly linked to the discussion of groundwater pollution provided in the Section above (Monitoring Network). As discussed, groundwater pollution will emerge from this study as one of the most important water resources issues to be faced within the project area. In fact, it may be surmised that groundwater quality issues will overtake water quantity issues as the most pressing issue in this area of Yemen. This is a result of the following factors:

- Highly vulnerable aquifers (shallow water tables, permeable materials, general lack of surficial low permeability protective layers);

- Very poor to non-existent waste management practices (disposal of all manner of water directly into the shallow aquifers, including sewage and oils);
- Concentration of potentially harmful activities atop the most vulnerable aquifers;
- Lack of understanding of the issue of groundwater pollution within the general public and with NWRA;

The final report will contain maps of aquifer vulnerability, identifying located potential sources of contamination. This will also be used in development of the recommended groundwater monitoring program, discussed above.

3.6 GROUNDWATER MODELLING STUDY

3.6.1 Aquifer Pumping Tests

The field data collection of the pumping test sub-component of this study has been completed within this reporting period. Data analysis is now underway and will be presented in the final draft report. A map of the locations tested and the data collected is presented in Appendix V.

A total of 20 pumping and recovery tests were conducted on shallow wells in the Tuban-Abyan area. The wells were selected based on criteria such as accessibility and availability, cooperation of the owner and adjacent owners and costs. At none of the wells selected was an appropriate observation well available for use.

As well test information and resulting aquifer parameters were available for deeper wells and aquifer sections, Komex proposed to undertake the majority of tests for this project in shallow wells. This will also assist in clarifying aquifer parameters for the recharge segment of the project. Subsequent to all of the tests being completed, part of a report produced in 1975 by Italconsult was made available which detailed the testing of 20 shallow wells in the Tuban area. Had this report been available in the planning stage Komex would have been able to focus shallow aquifer information collection in the Abyan area.

The Technical Proposal stated that wells would be tested at a constant rate for 72 hours and recovery monitored for 24 hours. In many of the wells tested, and as anticipated due to their depth and construction, draw-down stability began to be exhibited well within this time period. In a number of wells this could be corroborated by testing of conductivity and pH during pumping. While the wells could in theory have been pumped for 72 hours Komex staff supervising the tests concluded that only minimal additional information would have been obtained by doing so once near stability had been reached. In meetings held on September 4, 2001 in Aden, between Komex and NWRA staff, it was agreed that NWRA would review the raw aquifer test data, and determine if any of the tests actually may have required the full 72 hour testing. These data were provided to NWRA shortly thereafter.

Komex issued a detailed letter outlining our technical aquifer test protocol to NWRA in August 2001. Detailed technical justification for ending aquifer tests and ability to find and use monitoring wells for tests are discussed therein. This letter is included in Appendix VI.

All data collected will be analysed using at least two methods for both the pumping and recovery phases to determine aquifer parameters. The data obtained will be compared in the Tuban area with those determined in the Italconsult report. All analysis will be conducted in the next reporting period and NWRA staff will be involved in analysis and interpretation of data.

3.6.2 Modelling

Groundwater modelling is the final element of an integrated water resource appraisal, since it requires all of the collected and spatially adjusted data from all of the other study components. As such, modelling activities have only just begun in the beginning of September.

3.6.2.1 Data Requirements

Modelling of the study area requires a full set of data, with every measurement related to location and elevations, and dates of measurement recorded for time variant parameters. Much of the required data has now been processed or partially processed to give the spatial coverage needed for rapid input into a groundwater model.

The data required comprise:

1. Project Area
   The digital maps will form the basis, with identification of key features which need detailed representation;

2. Boundary conditions
   Location of boundaries will be based on a compromise between extending the modelled areas to clear hydrogeological features and availability of data. Piezometric maps are essential for definition of flow lines, groundwater divides etc.

3. Aquifer geometry
   Topography
   Tops and bases of all layers, both aquitards and aquifers from borehole data, geophysical survey and geological mapping
   Zones of faulting or other structural importance requiring more complex or detailed representation.

4. Hydraulic properties

   Transmissivity/hydraulic conductivity for all aquifers from pumping tests and specific capacity data;

   Vertical hydraulic conductivity of all aquifers and aquitards - if no data exist, then values will be estimated from lithologies and literature values;

   Specific yield/confined storage coefficients for all aquifers - if no data exist, then values will be estimated from litholgies and literature values;

5. Recharge

   On both areas, direct infiltration of local rainfall, outside of the irrigated areas, is likely to be negligible.

   To define recharge rates, information is needed on the distribution and changes with time of:

   Wadi flows - location, duration, frequency, transmission losses;

   Irrigation - location, crop types, distribution system (lined/unlined), source of water (spate/groundwater), irrigation rates, losses from fields and from distribution system;

   Urban losses - from water distribution, piped sewerage and septic tanks.

6. Abstraction and pumped discharge

   Location, rates and changes with time in abstraction for:

   Domestic supply

   Industrial use

   Irrigated agriculture

7. Natural discharge - now and historically, with location and approximate dates for:

   areas of natural vegetation,

   any areas of groundwater/saline discharge,

   baseflow in wadis.

8. Calibration data:

   Piezometry - to produce maps at different times and hydrographs

   Spring flows if any

   Salinity and water quality - to produce maps at different times and hydrographs

3.6.2.2 Approach

The groundwater model will use the MODFLOW code, with Groundwater Vistas as the pre- and post-processor. If possible, the standard Windows version of MODFLOW will be used. If problems arise, the version MODFLOW-SURFACT will be selected to provide a stable solution for layers which dry out.

The initial models will be developed separately for the Tuban and Abyan areas. There is insufficient data coverage to allow simulation of the intervening and outlying sparsely populated areas (SPA). All model input will be based on a consistent set of coordinates (UTM coordinates in m) and related to a common datum of mean sea level. This provides an option to combine the two data sets at some future date, should sufficient information become available in the SPAs.

3.6.2.3 Tuban Area

The Tuban area model will cover the main area of the delta from Dukeim to the coast. The anticipated boundaries are:

- Mountain front in the north, modelled as a no flow boundary;
- Coast in the south, with fixed head;
- Eastern and western boundaries, approximately parallel to flow lines and selected to coincide with the limits of data availability.

The model grid will be designed to give the most detailed coverage in the key areas, such as:

- The channels of wadis Tuban, Al Kabir and As Saghrir;
- Bir Nasir, Bir Ahmed and Upper Tuban wellfields;
- The main zone of intensive irrigation.

It is envisaged that the model will comprise several layers:

- Superficial silt, which acts as a (semi-) confining layer in the coastal zone;
- Main unconsolidated alluvial aquifer, using approximately three layers to represent changes in lithology and hydraulic properties with depth. This also has the advantage of allowing abstraction to be allocated to different layers, depending on well depths;
- If required, the underlying cemented alluvium.

The base of the model will therefore be defined either by the top of the cemented alluvium or by the top of the bedrock. Hydraulic properties will be taken from the recently completed pumping tests and previous reports and data-sets.

Recharge will be simulated from:

- Transmission losses in the wadi channels, particularly the reach of Wadi Tuban between the mountain front at Dukeim and Al Arais Weir. This will follow the approach described in the recharge study (Appendix VI) of dividing the channel into reaches according to flood frequency and transmission losses;
- Return from irrigated agriculture, for both spate and groundwater irrigated areas. This will include an estimate of both channel and field losses;
- Urban recharge from leakage of the pressurised water distribution system and disposal of un-sewered waste water.

Direct infiltration of local rainfall within the delta is considered to be insignificant and will not be modelled.

Abstraction will be simulated from:

- The Bir Nasir, Bir Ahmed and Upper Tuban wellfields, operated by NWSA;
- Wells used for irrigation and domestic supply to small towns and villages. This will be apportioned on an area basis, using typical abstraction rates and considering irrigated area and population.

The abstraction will be allocated to the appropriate layer within the alluvium depending on the type of well and their typical depths. This allows a distinction to be made between shallow dug wells and deeper boreholes, providing that relevant data are available.

3.6.2.4 Abyan area

The Abyan area model will cover the main area of the delta from Bateis and Al Kathib to the coast. The anticipated boundaries are:

- Mountain fronts in the north and north-east, modelled as no flow boundaries;
- Coast in the south, with fixed head;
- Eastern and western boundaries, approximately parallel to flow lines and selected to coincide with the limits of data availability.

The model grid will be designed to give the most detailed coverage in the key areas, such as:

- The channels of wadis Bana and Hassan, also wadis Suhaybia and Mahariah if data coverage in these areas is adequate;
- Upper Abyan wellfield;
- The main zone of intensive irrigation;
- The basement outcrops and areas with rapid changes in alluvial thickness.

It is envisaged that the model will comprise several layers:

- Main unconsolidated alluvial aquifer, using two to four layers to represent changes in lithology and hydraulic properties with depth, and to allow for the significant changes in alluvial thickness, particularly the zone of thin alluvium in the central area;
- If data are available, the underlying Tawilah sandstone.

The base of the model will therefore be defined either by the top of the consolidated bedrock or by the top of the Amran limestone. Hydraulic properties will be taken from the recently completed pumping tests and previous reports and data-sets.

Recharge will be simulated from:

- Transmission losses in the wadi channels, particularly the northern reach of Wadi Bana between Bateis and Al Husn. This will follow the approach described in the recharge study (Appendix VI) of dividing the channel into reaches according to flood frequency and transmission losses;
- Return from irrigated agriculture, for both spate and groundwater irrigated areas. This will include an estimate of both channel and field losses;

- Urban recharge from leakage of the pressurised water distribution system and disposal of un-sewered waste water.

Direct infiltration of local rainfall within the delta is considered to be insignificant and will not be modelled.

Abstraction will be simulated from:

- The Upper Abyan wellfield, operated by NWSA;
- Wells used for irrigation and domestic supply to small towns and villages. This will be apportioned on an area basis, using typical abstraction rates and considering irrigated area and population.

3.7 RECHARGE STUDY

3.7.1 Introduction

The important mechanisms and sources of groundwater recharge in the Tuban and Abyan deltas are:

- Infiltration of spate flows in the wadi channels, which is the main mechanism of recharge, thus providing the source of water for the coastal area;
- Return flows from irrigation, especially when supplied by surface flows;
- Leakage and losses from the distribution system in urban areas, particularly Aden where 95% of the population are connected to mains supplies and per capita consumption is high (185 l/d in 1991);
- Infiltration of waste water from sewage and cess pits in the urban areas, which act as a source of groundwater contamination;
- Direct recharge by infiltration of local rainfall on the coastal plain, which is expected to be very small or negligible due to the combination of low rainfall and high temperatures.

Initially, the recharge study focused on recharge in the Tuban catchment, due to transmission losses occurring during wadi flow events, which are generated as high energy, short duration events in the higher rainfall, upland areas. Rainfall-runoff was modelled using a distributed implementation of the *USDA SCS* Curve Number (CN) method. Transmission losses were related to upstream flow volumes according to work by Jordan (1977). The recharge model comprised an integration of a similar transmission loss model for distributing losses on the delta, and a one dimensional, analytical groundwater flow model.

3.7.2 Recharge Modelling

Two models were used to quantify groundwater recharge to the aquifer underlying the Tuban Delta:

- A rainfall runoff model, which simulates runoff generation in the upper catchment;
- The recharge model, which calculates the distribution of losses, using the transmission loss sub-model, and the infiltration of flows from wadi beds, using a one dimensional groundwater flow sub-model.

3.7.3 Rainfall-runoff Model

3.7.3.1 Concepts

Rainfall in the upper catchment of Wadi Tuban is converted to runoff from steep jebels and gravel hills giving rise to high energy short duration flows, which are rapidly channelled downstream. These flows eventually reach Dukeim at the mountain front. This model deals with quantifying these flow volumes.

The upper catchment was discretized into smaller units by identifying all significant wadis and their associated sub-catchments.

The "sub-catchment elements" were conceptualised as runoff generating elements with rainfall as the primary input. "Wadi elements" were conceptualised as elements facilitating the channelling of runoff downstream with flow volumes being the primary input. These conceptual ideas led to the formulation of a distributed rainfall-runoff model comprising "sub-catchment elements" and "wadi elements".

3.7.3.2 *US SCS* Curve Number method

The mathematical rainfall-runoff model that has been adopted for this study, was developed by the USDA SCS (United States Department of Agriculture, Soil Conservation Service) in 1954. This simple model has been applied and tested internationally and has extensively shown its strengths in the arid and semi-arid environment.

The SCS Curve Number method is used for estimating direct runoff from storm rainfall, where direct runoff describes both surface runoff and subsurface flows, therefore excluding base flow from the definition. This property of the model fits the hydrological characteristics of arid and semi regions, where base-flow is generally negligible during most of the year. The proportion of surface runoff and subsurface flow are evaluated by means of the runoff Curve Number (CN), which is an indicator of the probability of the flow type, i.e. the larger the CN, the more likely that the flow type is surface runoff.

The CN-method is based on the assumption that a linear relationship exists between accumulated runoff and accumulated rainfall for a catchment area. This linear relationship is strictly applicable only after "T" minutes since the start of the storm, since there is an "initial abstraction" of rainfall (the value of "T" may vary). Runoff Q is uniquely related to precipitation depth P and a given initial loss I_a. An empirical relationship between S (a transformation of the Curve Number) and the initial loss I_a was developed by the USDA based on rainfall and runoff data obtained from experimental small watersheds.

The empirical relationship is:

$$I_a = 0.2S$$

The relationship between runoff and precipitation is:

$$Q = \frac{(P - 0.2S)}{2(P + 0.8S)}$$

The parameter S is a transformation of the CN and is related to the CN as follows:

$$CN = \frac{1000}{(S+10)} \quad \text{or} \quad S = \frac{1000}{(CN-10)}.$$

A soil-cover complex is defined as a combination of a hydrological soil group, a land use and a treatment class. The USDA SCS has assigned individual CNs to a large variety of different soil-cover complexes. Thus, knowing the soil group and the soil-cover (land use, treatment or practice and hydrological condition), it is possible to obtain an estimate of a CN for the area or sub-area of interest. High Curve Numbers are associated with high runoff potential and vice versa.

As stated in the technical proposal and inception report, Komex will shortly also collect some typical samples of these soil-cover material for laboratory analysis in Canada, to further refine the model results and provide an added level of accuracy.

Previous studies in arid and semi arid regions have shown that Curve Numbers tend generally to be high for these regions. This is generally due to limited vegetation cover, steep slopes and low-permeability soils that may comprise large areas of bare rock. Typical values that have been used varied from 77 to 95 depending on the geology and topography of the area. It is worthwhile noting that if initial losses are taken as 20% of the transformed CN (S), these Curve Numbers correspond to initial losses varying from 2.7 to 15.2 mm.

3.7.3.3 Transmission losses in wadi channels, upper catchment

Transmission losses in ephemeral streambeds occur during periods of surface flow. As these losses can be high, they were included in the modelling of surface runoff in the upper Tuban catchment. A simple transmission loss model was therefore adopted and was eventually integrated with the SCS CN method for runoff generation.

It was decided to adopt a reasonably widely accepted loss function for characterizing the wadi bed losses in this study. The method used in this study was originally developed by Jordan (1977). He showed that by plotting field observations of "transmission losses" versus "flow volume at upper station" on a double log scale, a linear trend could be fitted to the data.

This trend implied that the rate of loss at any given point between two gauging stations is proportional to the flow at that point.

$$\frac{dV_x}{dx} = -kV_x$$

where

x:	Distance downstream of the origin	[km]
V_x:	Flow volume at location x	[m^3]
k:	Constant of proportionality	[m^{-1}]

This differential equation can be expressed as follows (Wheater et al, 1997):

$$V_D = V_U(1-\alpha)^L$$

where

V_U:	Upstream flow volume
V_D:	Downstream flow volume
α:	Loss coefficient
L:	Reach length

The loss coefficient α represents the proportion of flow lost per unit distance for a given channel element.

The rainfall-runoff and transmission loss models could be linked, since both were defined in terms of flow volumes. Transmission losses were calculated for each "wadi element" using a systematic bookkeeping of runoff volumes. Runoff was generated for individual sub-catchments using the SCS CN-method as described above. These flow volumes were then "distributed" according to individual loss coefficients for each wadi.

3.7.3.4 Data and parameter requirements for the model

The data requirements for the rainfall-runoff model are described below.

Catchments

1) The surface area corresponding to uniform Curve Number sub-areas within each sub-catchment [km^2]. The model allows 4 different uniform CN sub-areas within each sub-catchment. The CN values for each of the 4 uniform areas should be the same for the entire catchment.
2) The mean annual precipitation (MAP) for each of the sub-catchments [mm/year].
3) The coordinates of the centroid of each sub-catchment according to the local UTM grid, UTM Zone 39 north, WGS84 projection. This was used to interpolate rainfall for each sub-catchment.
4) Catchment name.

Wadis:

1) The length of the wadi element [km].
2) The transmission loss coefficient ⌷⌷[non-dim]
3) Wadi name.

Rainfall stations:

1) The coordinates of rainfall stations according to the local UTM grid [m].
2) A sequence of daily rainfall depths for a period of 365 days [mm/day].
3) Rainfall station name.

3.7.3.5 Interpolation of daily rainfall

Due to the lack of sufficient spatial coverage of daily rainfall for the upper Tuban catchment, rainfall was allocated to each sub-catchment by interpolating or extrapolating from rainfall gauges, using a simple weighting function.

The interpolation and extrapolation scheme for daily rainfall involved the assignment of daily rainfall depths to each sub-catchment by weighting rainfall according to the inverse of the distance from each rainfall station. Since rainstorms in the upper catchment are predominantly convective in nature, sub-catchments closer to the location of the rain event typically receive more rain than those further away do. Rain producing cells typically also move during the storm event and add complexity to the distribution of rain depths, both in time and space, however this was not simulated in this study.

Following the allocation of daily rainfall by weighting, rainfall depths were scaled according to estimates of the mean annual precipitation (MAP) for each of the sub-catchments.

3.7.4 Recharge model

3.7.4.1 Concepts

Once wadi floods reach the delta, flow velocities reduce and transmission losses to wadi beds occur as these flows propagate downstream. These transmission losses give rise to rising water tables in wadi beds and eventually a lateral movement of groundwater towards the aquifer underlying the coastal delta. Surface flows are diverted from these wadis for the spate irrigation of crops on the delta. Losses from these irrigated areas are generally believed to have a lower contribution to groundwater recharge and a slower response time. In contrast, the observed groundwater levels at wells on the major wadi banks in the upper Tuban delta show a fast and substantial recharge response, due to lateral flow of groundwater following wadi infiltration.

The upper Tuban delta area was discretized in order to model the distributed nature of wadi flows. Transmission losses were modelled using the same function than the one that was used in the rainfall runoff model, based on Jordan's (1977) work. This relates transmission losses to both upstream flow volume and wadi lengths. The lateral movement of groundwater was subsequently modelled by taking these transmission loss values as inflow fluxes to the aquifer, which was divided into strips allocated to wadi reached. By comparing the simulated recharge response with measured groundwater level fluctuations at observation wells contained within these "strips", it was possible to calibrate the transmission loss parameters for individual "wadi elements" and eventually the recharge rates.

3.7.4.2 Distributing wadi flows

The distribution of surface flows on the delta is governed by a number of diversion weirs situated along the main wadis. Flows are either diverted to irrigation channels servicing plots on the wadi banks or is merely directed downstream to other diversion structures where flow is again diverted for irrigation.

There is no clear operating rule regarding the diversion of flows at these structures. In addition to this, these structures are generally in poor condition, and sometimes temporary structures are used to maximize the diversion of flows for irrigational purposes. The estimation of diverted volumes was limited to information on flow volumes and the frequency of flooding supplied by local farmers. Diversion estimates based on the capacity of diversion structures GDC (1981) are highly uncertain given the current condition of these structures.

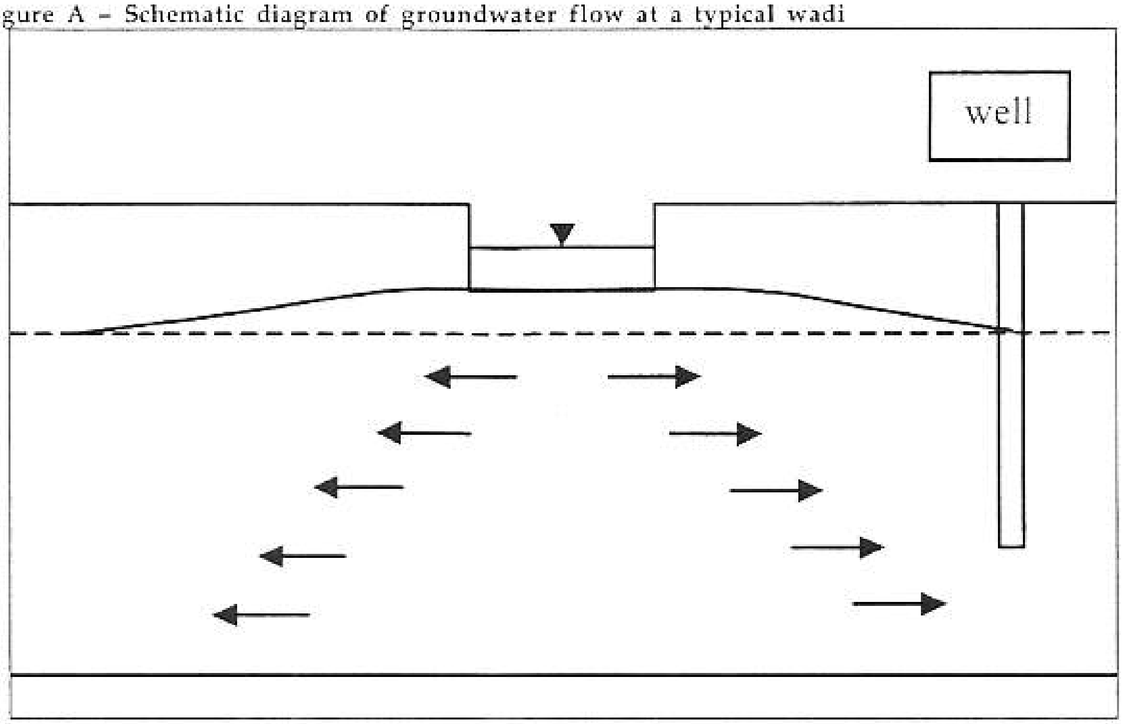
3.7.4.3 Modelling lateral groundwater flow from wadi beds

Given the limited availability of groundwater data, a simple solution was devised to describe the groundwater recharge response. This focused on the "fast" groundwater response for which groundwater data of short duration was available.

Transmission losses to a wadi streambed are believed to cause a rapid rise in the water table beneath the wadi. This phenomenon is linked to wadi losses saturating the bed material above the water table as water moves downwards through the relatively coarse material generally found in these beds.

Figure A shows schematically a cross section of a wadi with underlying aquifer. An idealized watertable response at the wadi as a result of transmission losses recharging the bed locally is shown. This response propagates sideways as groundwater flow, recharging the aquifer.

Figure A – Schematic diagram of groundwater flow at a typical wadi



The lateral movement of groundwater results in a recharge response at the well shown in the figure above. The water table (head) response at the well is a function of the distance from the wadi, aquifer parameters such as hydraulic conductivity and specific yield and also the recharge flux. Describing the head mathematically as a function of the aquifer parameters and the recharge flux was a fundamental step in the formulation of the lateral groundwater flow model.

A simple analytical solution for a semi-infinite strip of aquifer was adopted. The groundwater recharge process was modelled for an idealized aquifer bounded at one end by a constant flux boundary (wadi bed) and at the other end by a constant head boundary at an infinite distance away from the wadi. The idealized aquifer was assumed to be uniform within each element. The distance between the wadi and the well was taken as the shortest distance between the well and the nearest bank of the wadi. The width of the wadi channel corresponding to each well was measured in the field. These widths were regarded as important parameters for linking calibrated losses to the potential area of infiltration. Other parameters that were related to the geometry of the problem were aquifer thickness and the saturated thickness.

The recharge flux was defined as a simple function in time. A constant flux was assigned for a time $t < T$ and a zero flux for time $t > T$. This simple time function was adopted since detailed information on the recharge phenomenon in time was not known, i.e. information on the temporal distribution of infiltration was not available to support the use of a more complex function. Knowing that flood events generally lasted approximately one day, the value of T was equated to one. Transmission losses were subsequently translated to a constant recharge flux of one day.

This simple model involves saturated groundwater flow only. Data limitations rendered the use of complex unsaturated flow models unsuitable. It was further assumed that the saturated aquifer was of constant thickness. As the water level changes were generally small compared to the thickness of the aquifer, the assumption of confined flow was made, which allowed superposition to be used to construct a *net* groundwater response as a result of daily impulses. Further, the recharge flux was taken as a constant value in time, because the lack of information on the temporal distribution of bed losses prompted the use of a simple function. The aquifer was assumed to be of a homogeneous, isotropic and non-leaky nature. The observation borehole/well was assumed to fully penetrate the aquifer (i.e. measuring an integrated head over the full aquifer thickness). These assumptions are regarded acceptable giving the general uncertainty of aquifer extent and aquifer parameter values. Limitations of this model are associated mainly with the fact that groundwater flow is assumed only to occur in one direction, this being perpendicular to the wadi. Groundwater flow parallel to the wadi is therefore not described and the recharge response of such flows is not accounted for.

Discretization was done by using 1:100 000 topographic maps of the Tuban delta as well as a schematic layout of the main diversion structures as summarized by GDC (1981). The schematic layout proved to be of great help especially where details on the topographic maps were unclear. The discretization of the wadi network covered the Northern Zone and upper Central Zone, as these were the focus areas for the recharge study. Wadi Al Kabir was discretized to include the Mugahed Weir and Wadi Al Saghrir to include the Bustan Weir. The farmland downstream of these weirs is mainly irrigated by groundwater and wadi floods do not often reach this far downstream. In the rare case of flows reaching these weirs, it is believed that all flow is diverted unless the event is exceptional (1:50 years or more).

3.7.5 Stage-discharge relationship for Dukeim Gauge

3.7.5.1 Introduction

A preliminary stage discharge relationship for Wadi Tuban at Dukeim was needed in order to translate a record of measured stage values to theoretical discharge rates. Detailed open channel flow calculations were not possible given the fact that stage was only measured at one location. However, a uniform open channel flow assumption proved to give reasonable results given the uncertainties that existed in bed levels and flow depths.

Knowing the stage discharge relationship, it was possible to calculate a discharge time series from the stage time series. By eventually integrating the discharge time series with respect to time, a time series of daily flow volumes was obtained and used for comparison with the output of the rainfall-runoff model.

3.7.5.2 Methodology

It was evident from previous work on surface flows that the stage discharge relationship at Dukeim varies with time, due to the dynamic nature of the riverbed at this gauging site. Stage discharge curves were established in the late 1970's and early 1980's (GDC, 1981). At the time of the 1981 study, it was noted that problems existed with the recording gauge, only stage above 1.0 m was registered at Dukeim. Given the possibility of substantial changes to the bed over the past 20 years and changes to the reference level of the gauge, which was changed to an automatic gauge in 1998 (Salmeen et al., 1998), these stage discharge curves may no longer apply.

During a visit to the gauging site at Dukeim (July/August 2001), it was noted that the point of zero stage (or reference point) for the flow gauge is situated approximately 0.75 m above the lowest bed level across the gauging section. This corresponded to an average value of approximately 0.50 m assuming a horizontal bed. The lowest point of the bed was present on the left bank where stage is recorded. The channel at Dukeim cuts into hard basement rock forming a quite uniform rectangular channel for a considerable length, both upstream and downstream of the gauging point. The bed slope is quite uniform upstream as well as downstream of the gauging point.

Given the constraints of time and resources, it was assumed that uniform flow occurs within the channel at the gauging site at all discharges. The assumption of uniform flow made it possible to determine flow velocities in terms of bed roughness, wetted perimeter and average bed slope. Thus, by using Manning's equation as applicable to steady uniform open channel flow under hydraulic rough conditions (Reynolds number > 2000), a pragmatic method for relating stage to discharge was possible.

$$v = \frac{1}{n} R^{\frac{2}{3}} S_0^{\frac{1}{2}}$$

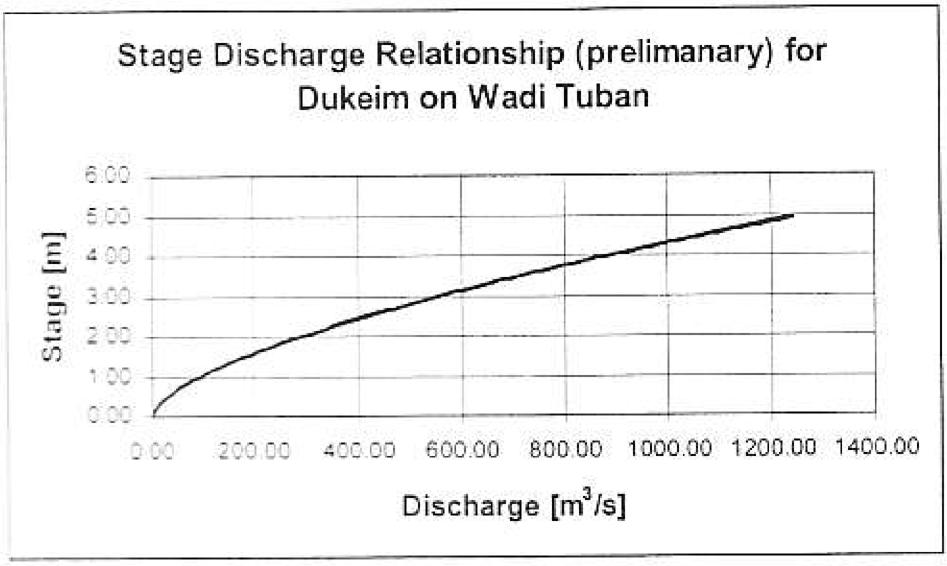
Definitions

v:	Average flow velocity	[m/s]
n:	Manning's roughness coefficient	[$m^{1/3}s^{-1}$]
R:	Hydraulic radius	[m]
S_o:	Average bed slope	[m/m]

The hydraulic bed roughness was taken as n = 0.032 $m^{1/3}s^{-1}$. This complies with typical roughness values for gravel bed streams over a typical large range of hydraulic radii (R ≈ 1 to 20 m) (Rooseboom et al, 1997). The average bed slope S_o was taken from longitudinal sectional data that was established from surveying in April 2001. The hydraulic radius R, defined as the flow area divided by the wetted perimeter, was calculated from the relationship between flow width W and flow area A. The average flow width for the adopted rectangular flow profile at Dukeim, was taken as 40 m.

Figure B shows the preliminary stage discharge relationship that has been established for Dukeim using the uniform flow approach as described above.

Figure B – Stage Discharge Relationship for Dukeim on Wadi Tuban



The following analytical approximation to this curve was derived from a regression analysis, giving stage h as a function of discharge Q.

$h = 0.0608Q^{0.6164}$ or $Q = 93.951h^{1.622}$

where

h:	Stage [m]
Q:	Discharge [m³/s]

3.7.5.3 Assumptions

The Manning's equation applied in this study assumes the following:

1) Flow is uniform for all discharge rates
2) Channel roughness is constant with time and with discharge
3) Flow depth is uniform with width
4) Velocity of flow is uniform with width

These assumptions are regarded reasonable given the general uncertainty of hydraulic parameters and their dynamic nature in the arid and semi-arid environment.

3.7.6 Calibration

3.7.6.1 Rainfall runoff model

Calibration involves a process where the modelled response is compared with an observed response followed by the adjustment of model parameters in such a way that the modelled behaviour fits the observed behaviour.

When dealing with a large catchment, the calibration procedure generally involves starting at the upper most tributary and working systematically in a downstream direction. A network of gauged flows within the catchment is therefore essential to characterize the spatial distribution. Since flow has only been measured at Dukeim on Wadi Tuban, a rigorous calibration of the rainfall-runoff model was not possible.

A practical solution was however adopted to cope with the limitations posed by the one flow gauge at Dukeim, based on the results of a previous study conducted in a similar area in Oman by Wheater et al. (1995). This study showed that the transmission loss parameter generally increased in a downstream direction, because the wadis were wider downstream. The pattern of increasing losses also coincided with the order of the streams, i.e. higher order streams (being further downstream) showed higher loss coefficients. Since no information on stream widths in the upper Tuban catchment were available, the distribution of loss coefficients was related to stream order, using similar numerical values to those used in the Oman study.

The upper catchment dominantly comprises gravel hills (estimated to be 40% of area) and steep rocky jebels, estimated to cover 60% of the area from a topographic map. Adopting similar Curve Numbers as those used in Oman and previous studies in Yemen, i.e. 85 for alluvial gravel hills and 95 for the steep jebel areas, an areal average CN of 91 was adopted for the upper Tuban catchment. This value was used for the rainfall-runoff model.

The model was calibrated using a 4 month period from June to October 1998, when daily data for rainfall and flow, and well hydrographs were all available. model. It should be stressed that this short record was surely not ideal for the calibration of the rainfall-runoff model, but by making optimal use of the available data, the model performance could be evaluated.

Although the detail of the simulated flows matched the observed record poorly, the total runoff (98.6 Mm^3) compared reasonably well with the observed total (109.9 Mm^3).

Sensitivity analysis showed that the results were most influenced by rainfall data, due to the localised and intermittent nature of the rainfall. The uncertainty is reduced by increasing the number of rainfall stations and by increasing the duration of the time period considered.

3.7.6.2 Recharge model

The calibration of the recharge model entailed a systematic procedure of solving transmission loss parameter values for discretized wadi reaches, followed by comparison of the results of the one-dimensional groundwater flow model with the closest observation well hydrograph. than the observed, the vice versa procedure was followed.

The observed flow record for June to October 1998 was used to calibrate the transmission loss parameters. During calibration, the overall water balance was checked, allowing surface flow to reach Mugahed Weir on Wadi Al Kabir and at Bustan Weir on Wadi Saghrir. This definition of a boundary was consistent with the general observation that groundwater recharge from channel losses is mainly restricted to the Northern Zone and upper parts of the Central Zone. In addition, groundwater irrigation predominates to the south of these weirs suggesting that spate flows rarely reach this locations. It was therefore assumed that all flow that did reach these weirs was diverted and not conveyed downstream.

Since no information regarding the allocation of flow volumes for irrigation were available, estimates from hydraulic properties of weirs and diversion structures were made for calibration of the transmission losses for the recharge model. .

As an introduction to the calibration results of the recharge model, those parameter values that were used in the lateral groundwater flow sub-model are summarized. These parameters were fixed since this sub-model, which was integrated with the transmission loss model, was meant to link wadi losses to groundwater response at the wells via an aquifer of "known" properties in order for these losses to be calibrated.

Input to the analytical groundwater model used the following values of aquifer properties, based on recent pumping tests and those conducted in previous studies (GDC, 1981):

- Saturated thickness, from 30 m in the north, increasing to 165 m in the south;
- Hydraulic conductivity, decreasing from 20 m/d in the north to 3 m/d in the south;
- Specific yield, 0.2.

The average saturated thickness of the aquifer was determined from total aquifer thickness estimates and water-table depths measured during this study.

Table 5 summarizes the recharge results.

Table 5 - Summary of recharge estimates

Wadi reach	Transmission loss as % of upstream flow volume [%]	Recharge flux [m³/km/day]	Approximate length [km]
N. Dukeim - Al Arais, Wadi Tuban	0.44	≈ 50 000	7.5
Wadi Tuban	0.95	≈ 1400	5.9
To Ras Al Wadi	0.97	≈ 1025	3.9
Wadi Kabir	0.98	≈ 675	2.1
	0.98	≈ 525	2.2
	0.93	≈ 850	3.6
	0.78	≈ 875	8.2
	0.93	≈ 750	6.8
Wadi Saghrir	0.81	≈ 2500	3.5
	0.93	≈ 1000	2.3
S	0.94	≈ 950	3.2

The calibrated recharge flux for the northernmost reach, from Dukeim to Al Arais, is more than an order of magnitude larger than the average recharge flux for other reaches. This is related to flood frequency. According to the GDC (1981) report, 50 floods on average are measured at the gauging station at Dukeim, mostly between July to October . According to a farmer who farms along Wadi Tuban downstream of Al Arais, the average number of floods per year at his farm varies from 5 to 10. Thus, according to this observation 80-90% of the floods on average hardly reach a point further downstream than the Al Arais Weir. This supports the high transmission loss and also justifies a high volumetric percentage of flow diversion at Al Arias Weir. A large percentage of the floods are apparently small enough to be either lost in the northernmost reach or diverted at Al Arais.

The recharge fluxes for the remaining reaches of Wadi Tuban are larger than the fluxes downstream. This was expected since Wadi Tuban, being in excess of 200 m, is almost twice as wide as Wadi Al Kabir and Wadi Al Saghrir. Smaller widths imply smaller areas for potential infiltration per unit length. Recharge fluxes for reaches on both Wadi Al Kabir and Wadi Al Saghrir tend to increase in general in a downstream direction. This phenomenon is ascribed to the fact that floods are less frequent and water tables lower. The recharge fluxes for Wadi Al Saghrir and Wadi Al Kabir are generally similar - this is expected since the diversion structure at Ras Al Wadi ensures that both wadis receive equal amounts of flow. These wadis also have similar widths (≈ 120 m).

Sensitivity analysis showed that simulated groundwater hydrographs were highly sensitive to transmission losses as well as aquifer parameters such as hydraulic conductivity, specific yield and saturated thickness. In the northern part of the area, where recharge is highest, the results were strongly influenced by saturated thickness.

3.7.7 Conclusions

Recharge rates varied from approximately 500 m^3/km/day to 50 000 m^3/km/day. The recharge rate north of Al Arais weir is more than an order of magnitude higher than those downstream of this location. A general observation of approximately 50 floods per year at Dukeim and only 5 to 10 downstream of Al Arais supports a general high transmission loss for this reach. However, there is some uncertainty since no groundwater response was available to calibrate the losses for the reach immediately upstream of Al Arais, and there are no measurements of the volume diverted at Al Arais or at smaller temporary diversion structures north of Al Arais. A range of recharge rates will therefore be used for a large scale groundwater model, distributed according to the results of this study.

Recharge estimates for Wadi Al Kabir were typical smaller than for Wadi Tuban. This is ascribed to less frequent substantial flows, as well as smaller flow widths, thus a smaller potential infiltration. Flow diverted to Al Kabir is substantially reduced at Ras Al Wadi weir where approximately half the flow is diverted to Wadi Al Saghrir.

The calibrated recharge values are based on the period from July to October 1998. The runoff for these months totaled approximately 109.9 Mm^3. Since 52.5 Mm^3 was calculated to be wadi infiltration, recharge is approximately 48 % of the surface influx to the delta. This value compares well with a value of 45% noted by Salmeen et al. (1998) taken from a study by Italconsult in 1975. Note that inflow volumes to the delta are uncertain, due to the lack of a long-term stage-discharge relationship for Dukeim and that recharge estimates are based on only a 3b month data record. In addition to this, transmission losses (and recharge rates) are affected by flow volumes diverted at weirs along the wadis. These diversions are highly variable, given the complexity of temporary gravel structures and the general low functionality of gates at diversion weirs.

Recharge to the aquifer as a result of deep percolation from irrigated fields was estimated at around 20% of the total volume diverted to irrigated fields GDC (1981). By adopting this value, an estimated 58% of surface water entering the delta area is recharging the aquifer.

In general, it is believed that recharge estimates for all wadis south of Al Arais are generally underestimated. This is due to the fact that transmission loss parameters, and thus recharge, were calibrated according to groundwater hydrographs that have potentially been influenced by groundwater abstractions, because pumping is not recorded at observation wells. Thus, it is believed that the groundwater response under "no pumping" conditions would have been more substantial and losses correspondingly higher. Quantifying the degree of underestimation is not possible given current information on monitoring wells and abstraction rates.

3.7.8 References

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3.8 PROJECT MANAGEMENT

Project management activities continued throughout the reporting period. A chronology of events and list of key project management meetings is provided in Appendix VII.

3.9 TRAINING

Training activities conducted as part of this program are described within each work package chapter, above. A summary of training undertaken so far, and planned for the coming weeks, is provided below:

Remote Sensing:
Formal seminar with selected NWRA personnel, to be conducted in the first week of October, 2001 in Sana'a, by Christine Cadman of Komex. The focus will be on interpretation and verification of project data.

Geological Study:
The field review and mapping of geological structure and lithology conducted in the field was done by Koemx staff and NWRA counterparts. The NWRA staff received training in field identification on geological features.

Monitoring Network:
During the data review and collection period, selection of wadi gauging sites and rainfall stations. Ali Alabadia of Komex conducted training on-the-job with NWRA staff. Formal training in interpretation of gauging and rainfall data to be provided to NWRA in Sana'a in October 2001, by Ali Alabadi of Komex.

Geophysics:
As detailed above, significant geophysical training was provided both in terms of field operation of the ERT and logging equipment, and detailed training in data interpretation and processing, which was done in the field and in the evening after data collection. No further training in geophysics is envisaged.

Hydrochemical Study:
Sampling and data manipulation was conducted by Wrayth staff in conjunction with NWRA staff. Sean Kelly of Komex (under the auspices of the CIDA-INC supplementary contract to this study) provided detailed lab and sampling QA-QC training for NWRA staff. Dr Paul Hardisty of Komex conducted a full day seminar and data interpretation exercise focusing on groundwater pollution in Tuban-Abyan, with NWRA Aden staff on September 3, 2001. Dr Hardisty will conduct a further training seminar in data interpretation in Sana'a, for selected NWRA staff in October.

Modelling and Aquifer Testing:
The full aquifer testing field program was conducted by NWRA staff directed by Koemx expat staff. NWRA staff were trained in all aspects of running a test and collecting and recording data. NWRA staff will be involved in data interpretation over the coming weeks.
Ms Jane Dottridge of Komex will conduct a modelling seminar for selected NWRA staff in Sana'a in October 2001. In addition, Komex has provided NWRA with a proposal for training of two NWRA staff in modelling in the UK.

Recharge Study:
NWRA staff were involved in the field aspects of the brief recharge field study which was conducted. Ms Jane Dottridge will cover recharge estimation through modelling in her modelling course in Sana'a in October.

3.10 CLOSURE

Komex has now made significant headway in all aspects of the project, including data collection, field activities and training. NWRA staff are fully involved in all aspects of the project. Fulfilling the contract requirement, this second progress report provides details of all activities for the period from the start of the project until September 1, 2001.

In summary:

- The presence of many areas of mines, and the difficulty in obtaining satisfactory written clearance of these areas is the only major hindrance to project execution at this time. Work has proceeded as possible within these constraints;
- NWRA personnel have been fully integrated into the project, and all members of the team are working together on a co-operative basis;
- Remote sensing data has been acquired, and detailed output is presented herein;
- Monitoring network program field activities and designs of gauging stations have been completed, with which NWRA can scope, contract and construct the necessary monitoring stations;
- Geophysics field work has been completed, and significant data collected, and presented in draft form herein. Final product is still in development and will be presented in the final report.
- Hydrochemical sampling has almost been completed, and data evaluation is now underway;
- modeling has begun;
- and substantial work has been completed on recharge studies;
- Project management is ongoing;
- Safety remains a concern, but Komex is able to work in Yemen under current conditions.

Komex anticipates that the final report, which will provide synthesised interpretation of all of the data, will present some new and interesting conclusions and findings regarding the water resources of the project area.

If we can provide any additional information, please feel free to contact the undersigned at any time.

Report submitted by:
KOMEX INTERNATIONAL LTD.

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APPENDIX I

SAFETY

APPENDIX II

REMOTE SENSING